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The Ravenala Attitude Hotel
Balaclava
Mauritius

Conference Chair:
Prof. Sunjiv Soyjaudah

Editors:
Dr. Sameerchand Pudaruth
Prof. Pius Owolawi

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ICONIC 2022

Table of Contents

General Chair

Professor (Dr) Krishnaraj Madhavjee Sunjiv Soyjaudah, Senior Member of IEEE was the General Chair and the TPC Chair of AFRICON 2013. He received his BSc (Hons) degree in Physics from Queen Mary College, University of London in 1982 as a recipient of the UK commonwealth scholarship, MSc degree in Digital Electronics from King's college, University of London in 1991 again as a recipient of the UK Commonwealth Scholarship, PhD degree and Gold Medal for pure research from University of Mauritius in 1998. He then pursued legal studies and obtained a LLB (Hons) from University of London in 2007, Post Graduate Diploma in legal studies at the Bar from Manchester law school in 2015 as a recipient of the Vice Chancellor's Scholarship and called to the degree of the Utter Bar of the Honourable Society of Middle Temple Inn in November 2015.

As a Professor of Communication Engineering, he has served as Dean of the Faculty of Engineering at the University of Mauritius. Professor Soyjaudah has also held senior management positions in regulatory authorities namely as Executive Director of the Tertiary Education Commission and Executive Director of the Information and Communications Technologies Authority. As an academic researcher, Professor Soyjaudah has published over 240 refereed International Journal and Conference Research papers and has successfully supervised two post-doctoral fellows and 18 PhDs.

His expertise is also solicited by foreign universities and he examined several PhDs from South African and Indian Universities. Professor Soyjaudah was the Chairman of the Mauritius Qualifications Authority from 2002 to 2005, Board Director of the Multicarrier Mauritius Limited (MCML) from 2001 to 2016 and chaired MCML's staff and finance and procurement committees. He served as Board Member, in the capacity of a technical expert, in the Energy Efficient Management Office from 2011 to 2015.

Message from the General Chair

The 3rd edition of the 2022 International Conference on Intelligent and Innovative Computing Applications (ICONIC) was held on the 8th and 9th of December 2022 at the Ravenala Attitude Hotel, in the paradise island of Mauritius. This conference is being organised by the Society of Information Technologists and Engineers in order to provide an opportunity to academic researchers, industry professional, government delegates and students to interact and share their experiences and knowledge on cutting-edge developments in the fields of Cloud Computing, Internet-of-Things, Networked Systems, Data Communications, Computer Security, Computer Vision, Intelligent Computing, Robotics, Machine Vision, Signal Processing and ICT4D. Our main objective is to promote scientific and educational activities towards the advancement of knowledge by improving the theory and practice of various disciplines and areas of ICT and Engineering.

Papers were invited for Mauricon ICONIC 2022 on topics lying within the scope of the conference. All the presented papers were of high quality, original, and have not been previously published elsewhere. All the papers were reviewed by at least three (3) members of the International Programme Committee (IPC) by following a double–blind review process. Depending on their degree of innovativeness and quality of presentation, papers were selected for oral presentation and publication in the conference proceedings. The papers from this conference are published in a conference proceedings with an ISBN number.

We hope you enjoyed your stay in Mauritius.

Professor Sunjiv Soyjaudah
General Chair, ICONIC 2022
Mauritius

Keynote Speakers

Prof. Pius Adewale Owolawi is a dynamic young man who received a B. Tech. Degree (Hons) in Applied Physics/Electronics from the Federal University of Technology (FUTA), Nigeria. He started his career with the Central Bank of Nigeria as a Resident Network Engineer under Safole Nigeria Limited. Afterwards, he proceeded to postgraduate studies in engineering. He obtained Master's and PhD degrees in Electronic Engineering from the University of KwaZulu-Natal in 2006 and 2010, respectively.

In 2016, he received an advanced diploma in Remote Engineering, Mechatronics and Robotics from the Engineering Institute of Technology, Australia (EIT). In June 2020 and February 2021, he completed a Postgraduate Program in Artificial Intelligence and Machine Learning and Data Science and Business Analytics, respectively, both from the University of Texas, Austin, United States of America. Prof Owolawi further strengthened himself in emerging technologies when receiving an additional postgraduate diploma in Cloud Computing from the Great Lakes Institute of Management, India. He obtained a certificate in Management Development Programme (MDP) within the management space through the University of Stellenbosch Business School.

In his quest for knowledge, he further registered with the University of South Africa to study Bachelor of Law (LLB) and Great Lakes Institute of Management, India, to study Postgraduate Program in Digital Marketing.

Besides conventional qualifications, Prof Owolawi has several industry certifications in information technologies, such as Cisco Certified Network Administrator (CCNA) and Cisco Certified Network Professional (CCNP). Others are Certified Wireless Administrator (CWNA) and Professional (CWSP) and Microsoft Certified System Engineer (MCSE) from well-established proprietaries. In terms of Radio engineering and Optic link design, he obtained Certifications in Radio Planning and Optimization of 2G to 4G from Tele-Resources engineering Ltd in Australia and Certified Fiber-Optic Technician (CFOA) and Fiber-Optic Systems Design (CFOS/D) through Triple Play Fiber Solution, South Africa.

He is a member of several professional bodies, both in South Africa and internationally, such as the Engineering Council of South Africa (ECSA), the Institute of Electrical Electronics (IEEE), South African Institute of Electrical and Electronics Engineer (SAIEE), South African Radio Amateur League (SARL), South African Amateur Radio Satellite Association (SA AMSAT) etc.

He has worked with several organizations/companies on engineering projects such as Eskom (Energy, Demand Side Management (DSM), Transnet (Embedded Remote Wireless Weight Gauge), GIZ (German development cooperation), and several research-based products. Prof Owolawi has worked with institutions such as the University of KwaZulu-Natal, University of South Africa, Durban University of Technology, and the Mangosuthu University of Technology, where he was a former Head of Department in the Electrical Engineering Department. He has developed accredited programmes in Engineering at both undergraduate and postgraduate levels in two universities in South Africa. He has been a reviewer for CHE (Council of Higher Education) academic programmes (Undergraduate and postgraduate programmes) in South Africa for the past few years, 4IR research Chair and Trade and Occupation programme developer with MICTA SETA. His research interest and the focus of postgraduate students under his supervision are Energy hybridization (combined solar, wind and other energy sources, Energy computation and modelling, higher frequency radio spectrum (millimetre and microwave bands), free-space optical wireless communication, fibre-optic communication, Green Energy for mobile Telecommunication, satellite and wireless communication and Image Processing (Activity recognition, facial biometric, medical image, event detection and Robotic vision), Artificial intelligence and machine learning, Computer Vision and Computational electromagnetic. He is currently involved in several projects, such as Agriculture 5.0 and LMS system development, National AI Institute, AI in financial and medical applications and Industrial Internet of Things (IIOT).

Prof Owolawi ranks among the top 500 researchers in Africa, based on his contribution to the body of knowledge and scholarly output between 2015 and 2020.

He has published several scientific papers (over 180 scientific articles) with over 900 citations, served as a technical member and reviewer of several journals and conferences, external examiner for many universities locally and internationally, and reviewer of professorship portfolios for an international university and member of interview panels for the appointment of professors and authored of a book titled "Rain at SHF and EHF for Radio Links in South Africa" Published by a German publisher LAP LAMBERT academic publisher.

Title of Speech: **Law-abiding Artificial Intelligence Machines: Law, Ethics, Legality, and Privacy**

Dr Sheeba Armoogum is a Senior Lecturer in the Faculty of Information, Communication & Digital Technologies (FoICDT) at the University of Mauritius (UoM). She has a PhD in Cybersecurity and is a recipient of the South African Patent for the Intrusion Detection and Prevention Systems. Embracing her experience in teaching & research with several publications in top journals and conferences for several years has given her a remarkable insight and credence for her academic discipline and research thrust. Her fields of research & study are Cybersecurity, Cyber forensics, Cyberpsychology, Cryptography, AI & Machine Learning, and Wireless/Mobile Communication & Networking. She is certified in both Research Ethics and Research Ethics Evaluation by the Training & Resources in Research Ethics Evaluation (TRREE). She was the past Head of the Department of Information and Communication Technologies at the UoM. She currently heads the CyberSecurity & Forensics Research Group (CSFRG) at the University of Mauritius.

Dr Sheeba Armoogum was part of organizing several international conferences and has served as a member of the Editorial Board of reputed International Journals and as a reviewer for several international Journals and Conferences. Moreover, to promote awareness and understanding of cybercrimes, their impacts, and cybersecurity, she was selected as a speaker for the Cybersecurity Awareness Workshop 2022. She also received recognition to be a guest speaker in Cybersecurity for ERASMUS+ in Lublin, Poland. She was a panelist speaker for the Mauritius Research & Innovation Council (MRIC) conference 2022, Women In Tech Week 2021 by Women In Tech Africa, Mauritius Chapter, and Opportunities & Challenges in FinTech & Cybersecurity 2021 organized by the Mauritius|Africa Fintech Hub (MAFH). She served as a subject specialist in the field of Cybersecurity for accreditation of the programs at the Higher Education Commission (HEC) Mauritius. She is also a Technical Expert for the Information Security Management System (ISMS) at the Mauritius Accreditation Services MAURITAS. Being an active member of International Committees like the Africa Region to International Cyber Security (AFRICC) Steering Committee and the International Cybersecurity Challenge (ICC) Steering Committee and representing Southern Africa as Deputy Secretariate for both the committees has escalated her international experience and leadership skills. She mentors and coaches the Mauritian participants in the International Cybersecurity Challenge (ICC) competition.

She is a recipient of the Women Icon Outstanding Academician Award 2022 and Asia's Innovative Award in Cybersecurity 2022.

Title of Speech: **Cybersecurity: You are a target.**

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Dr. Sameerchand Pudaruth is an Associate Professor of the ICT Department in the Faculty of Information, Communication & Digital Technologies, at the University of Mauritius (UoM). He has a PhD in Artificial Intelligence. He is the holder of an LLB from the University of London. He is a Senior Member of ACM and a Senior Member of IEEE. His research interests are in the fields of machine learning, deep learning, AI & law. Sameerchand is the author of a book in programming: Python in One Week.

Dr. Upasana Singh is a Senior Lecturer in the Discipline of Information Systems and Technology at the University of KwaZulu Natal, Westville Campus, in Durban South Africa. She lectures on a wide-range of IT-related subjects and she has a keen interest in Educational Technologies. In 2019 she completed her Fellowship in "Teaching Advancement in Universities" (TAU), from CHE. Her primary area of research is Digital Teaching and Learning in Higher Education.

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Sexual Crime Prediction in an African Context

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Abstract
The growth of sexual crime in Africa and the incapacity to control it have had a major physical and psychological impact on victims. Crime in general can reduce foreign direct investment in a country. This study was driven by the need to reduce sexual crime across the country. Data mining techniques were applied to a sexual crime dataset extracted from the South African crime statistics database on Kaggle to visualise sexual crime trends and create a model that predicts the occurrence of sexual crimes, thereby helping government and law enforcement agencies gain insights into the most common sexual crime hotspots across all the nine provinces of South Africa. This model may help law enforcement combat sexual crimes faster. We identified data analytics methods for sexual crime prediction and chose the best one. Because of a linear relationship between the dependent variable (sexual crime) and the independent variables (population and density), linear regression and decision tree classifier algorithms were used to predict main causes of sexual crime in South Africa. Accuracy, precision, recall, and F1 scores were used to test the decision tree algorithm's performance. Linear regression was measured using the R-squared score, which achieved 91% accuracy, indicating how well the model will predict sexual crime occurrences.

Keywords: data analytics, sexual crime, linear regression, data mining, prediction

1. Introduction

Crime is a socioeconomic issue that negatively impacts economic development and quality of life (Kim et al., 2018). Crime, in general, has resulted in the downgrading of South Africa's economy and sexual crime is a major contributor to the country's crime statistics. Homicide, sexual crimes, arson, and violent attacks are among the major crimes that lead to social issues (Chauhan & Sehgal, 2017; David & Suruliandi, 2017; McClendon & Meghanathan, 2015; Obagbuwa & Abidoye, 2021; Pednekar et al., 2018; Prabakaran & Mitra, 2018).

Sexual crime is a harmful occurrence in both the developing and developed parts of the world (Bondestam & Lundqvist, 2020). The negative consequences of sexual crimes cannot be overstated, as they have led to HIV/AIDS, abortions, murder, shame, grief, and psychological damage, to name a few outcomes (Meinck et al., 2017; Prabakaran & Mitra, 2018). Rape, sexual assault, sexual exploitation, sexual harassment, and human trafficking are all forms of sexual crime (Abrahams et al., 2014). Many cases of sexual crimes in South Africa go unreported, not only to private or government agencies, but also to the families and friends of the victims (Sigsworth, 2009; Watt et al., 2017). Research demonstrates a massive increase in sexual crimes in South Africa and cites a variety of causes for this increase, including poverty, racism, near-zero education levels, high levels of substandard housing, public intoxication, and lack of parental responsibility. In South Africa, the number of recorded sexual offences increased from 52,420 in 2018/19 to 53,293 in 2019/20, representing a 1.7% increase in sexual crimes cases, which is 873 more incidents than in the previous year (Africa Check, 2020; Cohen & Vecchiatto, 2019).

Law enforcement faces a difficult challenge when analysing large volumes of crime evidence without using assistive technologies (Chauhan & Sehgal, 2017; Yerpude, 2020). As a result, an effective analysing tool is required that can easily and swiftly analyse sexual crime data to provide some useful sexual crime trends. Crime analysis is a useful tool for detecting and analysing crime

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trends and for predicting crimes. Crime analysis usually consists of approaches and tactics aimed at reducing crime risk (Gahalot et al., 2020).

Under current circumstances, criminals are becoming more technologically savvy in their activities (Malathi & Baboo, 2011). Therefore, law enforcement agencies need crime analysis tools, such as the tool proposed in this study, to catch criminals and keep up with criminal activities in the never-ending race with law enforcement.

Governments usually support law enforcement officials to safeguard the people (Shearing & Johnston, 2013). The primary concern of law enforcement officials is to ensure the safety of citizens and infrastructure, and to maintain social peace (Wilson & Kelling, 2017). Everyone wants to feel safe where they live, and they trust that the government wants to maintain the peace and keep the country stable.

Because of the alarming rise in the number of sexual crimes committed in South Africa, it is now essential to understand what drives sexual crime to help lower the overall number of sexual crimes. This study was prompted by the growing need to curb sexual crimes across the country and in Africa, helping law enforcement agencies, citizens and other intelligence agencies to take the actions necessary to solve sexual crimes faster.

The process of analysing existing data to find trends, relationships and information is called data mining (Thongsatapornwatana, 2016). Analysing the data makes it easier to detect the factors contributing to the spike in sexual crimes and take action to reduce them. The sexual crimes dataset extracted from South African crime statistics (Wessels, 2019) is an example of a data mining method where enormous amounts of data are evaluated and analysed. Existing data is used to extract new information that can help prevent sexual crimes from occurring across the country. Existing data sets are used to predict the development of new information. A number of researchers have published articles on the application of data mining and machine learning algorithms in crime analysis (Chapman et al., 2000; Edoka, 2020; Obagbuwa & Abidoye, 2021).

The technologies and tools used for data mining are usually Python, R, Weka, and Orange (Insights Desk, 2020; Yerpude, 2020). Using the scikit-learn modules and Statsmodels packages, a predictive analytic model was developed and programmed in Python (Yerpude, 2020). "*Scikit-learn is an open-source, efficient data mining coding tool built on the Python modules NumPy, SciPy, and Matplotlib*" (Yerpude, 2020, 46). Statsmodels is a Python package for data exploration, estimating statistical models, and running statistical tests (Seabold & Perktold, 2010). It complements SciPy's (Seabold & Perktold, 2010) statistics module by providing a large number of descriptive statistics, statistical tests, graphing tools, and outcome statistics for a variety of data types and estimators.

A revolutionary system and new methods of crime analysis are needed to protect the South African population from sexual crimes. Figure 1 shows how data mining was used to predict the future rate of sexual crime. With this approach, all government and intelligence agencies will be able to guide the people in all provinces in a safe way. This linear regression prediction model was constructed using South African sexual crime data extracted from the South African Crime Statistics (Wessels, 2019), and provincial population data comprising the population, density, area, and sexual crime was analysed in this paper as shown in Table 1.

Table 1. Dependent and Independent Variables

	Province	**Population**	**Area**	**Density**	**Sexual crimes**
0	Gauteng	12,272,263	18,178	675.1	144,072
1	KwaZulu-Natal	10,267,300	94,361	108.8	122,885
2	Mpumalanga	4,039,939	76,495	52.8	45,538
3	Western cape	5,822,734	129,462	45.0	93,506
4	Limpopo	5,404,868	125,755	43.0	50,635
5	Eastern cape	6,562,053	168,966	38.8	101,394
6	Northwest	3,509,953	104,882	33.5	51,249
7	Free state	2,745,590	129,825	21.1	49,224
8	Northern cape	1,145,861	372,889	3.1	19,842

This paper is structured as follows: Section 2 reviews the literature on crime analysis; the methodology is discussed in section 3; section 4 explains the analysis and results of the experiment conducted; and section 5 provides the main conclusions.

ISBN: 978-99949-0-888-2

2. Related Works

Jangra and Kalsi (2019) created a crime prediction model using K-nearest neighbour (KNN) and naïve Bayes to predict crime in India. They compared the accuracy of the two models to see which one was better at predicting crimes. The proposed approaches were implemented in Python, and the algorithms achieved 77% and 96% accuracy, respectively, with Naïve Bayes proving to be better of the two (Jangra & Kalsi, 2019).

Shi et al. (2018) used a decision tree algorithm to predict the characteristics of criminals who will commit a crime. They also introduced other algorithms, such as Bayes network, logistic regression and naïve Bayes and compared the results to see how well they worked and that decision tree outperformed the other algorithms, with an accuracy of 80%.

Ingilevich and Ivanov (2018) used linear regression, gradient boosting, and logistic regression to predict frequently occurring crimes. The gradient boosting model did better, while linear regression tended to predict negative values. Kumar et al. (2020) used a KNN-based machine learning algorithm to model a crime prediction system.

Using the J48 decision tree approach of machine learning, Ivan et al. (2017) created a prototype crime detection model with a prediction accuracy of 94.3%. The method is ideal for predicting future criminal activity.

Pradhan (2018) examined the research and predicting of crime in the city of San Francisco by utilising San Francisco Police Department data. They created prediction models using Machine Learning methods (Pradhan, 2018). Their model predicts the sort of crime that will occur in each municipal district and can be used to allocate law enforcement resources in a smart city.

In the process of obtaining crime data from the database of crime statistics for South Africa's nine provinces, Obagbuwa and Abidoye (2021) used data mining tools. They then used a supervised learning technique (a linear regression algorithm) to build a crime prediction model, which produced accurate predictions with an R-squared accuracy metric of 84.7%.

Sukhija et al. (2020) performed a linear regression analysis to determine the correlation between traits linked to rape incidents in Haryana and to find pertinent variables that can better assist police personnel in crime prevention. When building predictive models with data analytics, linear regression and decision trees work well (Awal et al., 2016; Gonzalez & Leboulluec, 2019; Obagbuwa & Abidoye, 2021; Yerpude, 2020).

3. Methodology

For the purposes of this study, a Cross-Industry Standard Process for Data Mining (CRISP-DM) (Berwind et al., 2016)—a quantitative research methodology based on the post-positivist research paradigm—was used to collect and analyse data on the trends of sexual crimes in South Africa's nine provinces so that trends in sexual crimes can be predicted see Figure 1.

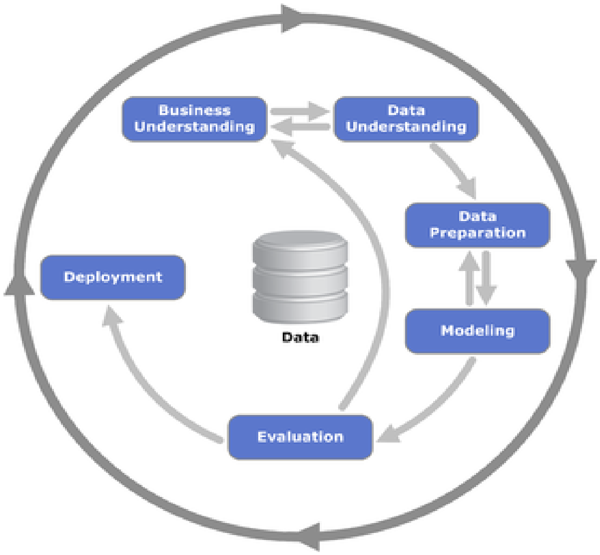

Figure 1. Cross-industry standard process for data mining (CRISPDM)

Literature shows that CRISP-DM is widely used in data mining research because of its efficiency and suitability for data mining projects (Chapman et al., 2000; Edoka, 2020; Obagbuwa & Abidoye, 2021). The CRISP-DM processes are described below.

Data understanding

An existing dataset obtained from the Kaggle database was used in this study. The dataset covered a period of 11 years (2005–2016) and contained an extracted 'sexual offences' comma-separated values (csv) file with 1,143 rows and 13 columns which was sufficient for achieving the research objectives. The file was uploaded to the Jupyter notebook, where it was cleaned and

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prepared for analysis. This was done to make sure the data were consistent before the experimental analysis. In this phase, activities such as data description, data exploration and data quality checking were carried out.

Data preparation
The dataset for the sexual crime was arranged and ready for statistical analysis. The Python library, scikit-learn, was used for data selection, cleaning, data building and data incorporation. Some attributes in the csv file had both string and numeric values.

Modelling
This is an important step in the data mining process because it allows the use of predictive data analytics algorithms to analyse data and construct predictive models based on undiscovered data trends. To create a model that can make predictions, appropriate modelling techniques, such as the appropriate machine learning algorithm to create a model, a test plan to assess its quality and validity should be selected. The modelling tool will then be used to build one or more models using the prepared data set, and the model(s) will then be interpreted using the domain knowledge, success criteria, and intended test.

This phase involved the implementation of algorithms for data analysis. The most common method for predicting and determining cause and effect relationships between variables is linear regression (Obagbuwa & Abidoye, 2021). There are many other methods that can be used for prediction, such as decision tree classifier, naïve Bayes, gradient boosting, support vector machine (SVM) and KNN; however, they may not all work well in all categories of prediction. Some methods are very good in finding association rules, classification, regression, and clustering (Edoka, 2020). Classification predicts a discrete class name, while regression predicts a continuous quantity. Regression was used in this study since our dataset was a continuous variable. The decision tree classifier was also used in this study to test whether it could work with our dataset as well, choosing the algorithm that predicts best of the two.

Linear regression
When doing linear regression of some dependent variable y on the set of independent variables $x = x_{1,....,}x_r$, where r is the number of predictors, equation 1 shows a linear relationship between y and x:

$$y = \beta_0 + \beta_1 X_1 + \cdots + \beta_r X_r + e \quad (1)$$

In this regression equation, $\beta_0, \beta_1, \ldots, \beta_r$ are the regression coefficients or parameters and e is the random error (James et al., 2013). Linear regression calculates the estimators of the regression coefficients or simply the predicted weights, denoted with $\beta_0, \beta_1, \ldots, \beta_r$ (James et al., 2013). Estimated regression functions are expressed in equation 2:

$$f(x) = \beta_0 + \beta_1 X_1 + \cdots + \beta_r X_r \quad (2)$$

This function adequately detects the interdependencies between the inputs and outputs. The estimated or predicted response, $f(x_i)$, for each observation $i = 1, \ldots, n$, should be as close as possible to the corresponding actual response y_i (James et al., 2013). The differences $y_i - f(x_i)$ for all observations $i = 1, \ldots, n$, are called the residuals (James et al., 2013). The goal of regression is to find the best predicted weights, i.e., the weights that correspond to the smallest residuals (James et al., 2013). The sum of the squared residuals (SSR) for all observations is often minimised to acquire the optimal weights $i = 1, \ldots, n : SSR = \sum_i (y_i - f(x_i))^2$. This approach is known as the ordinary least squares (OLS) method (James et al., 2013; Obagbuwa & Abidoye, 2021; Stojiljkovic, 2021).

The actual responses' variation $y_{i\,,}\ i = 1, \ldots, n$, occurs partly because of the dependence on the predictors x_i. There is, however, an additional inherent variance in the output (James et al., 2013). The coefficient of determination, represented as R^2, indicates how much variance in y can be explained by the dependence on x using the regression model (Stojiljkovic, 2021). A higher R^2 implies a better fit, denoting that the model can explain the variation of the output with different inputs better (Stojiljkovic, 2021). The value $R^2 = 1$ corresponds to $SSR = 0$, that is, to the perfect fit, since the values of predicted and actual responses fit completely to each other (James et al., 2013; Stojiljkovic, 2021). Scikit-learn linear regression enables the investigation of relationships between two continuous (quantitative) variables (James et al., 2013; Stojiljkovic, 2021), where one variable, represented by X, is the predictor (that is,

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population, density, and so on). The other variable, denoted y, is regarded as the response-sexual crime variable. Equation 3 presented below is for a linear regression line:

$$y = a + bX \quad (3)$$

where y is the dependent variable and X the predictor (independent) variable.

Decision tree classifier

Both classification and prediction can be performed using the decision tree. Functions that are constant at intervals defined by splitting individual attribute values can be trained for classification purposes. Dividing decisions based on the information gains metrics described for the class distribution of records before and after splitting are represented by internal nodes in the tree. Class attribute values (that is, class labels) are assigned to leaf nodes in the tree. The decision tree method for classification has been extended to output numbers for predictive purposes. The main difference is that the leaves have numbers, unlike classified trees with class labels. The decision tree algorithm is a supervised learning method of classification (Yerpude, 2020), as explained in a related study. The purpose of this classifier is to create an algorithm that predicts the value of a target variable by learning a simple decision rule derived from the data characteristics (Yerpude, 2020). A deeper tree shows more complex decision rules, which makes it a more adaptive model. If y is the predicted attribute and X is the attribute used for the prediction.

Measuring decision tree performance metrics can be done using cross-validation score (Yerpude, 2020). In cross-validation score, each dataset is used the same number of times for training and only once for testing (Yerpude, 2020). As a result, cross-validation scores for accuracy, precision, recall and F1 scores are tested to improve the performance of our model (Yerpude, 2020).

The performance of a model is measured by the reflection of well-observed actual events (Yerpude, 2020). The labelled dataset contains the actual values for the prediction to be used to train model. The concept of confusion matrix is presented in Figure 2 (Yerpude, 2020).

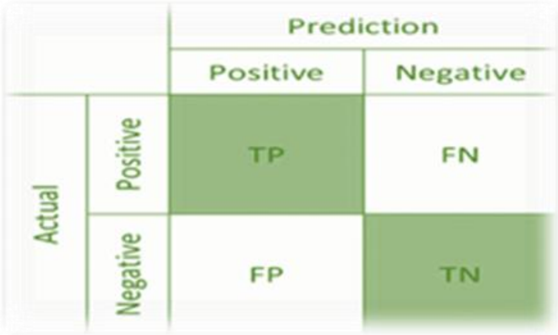

Figure 2. Confusion matrix

Evaluation

In this step, the model is assessed to determine how well it meets the project's objectives. After testing the algorithm's accuracy with the R^2 metric for linear regression, the precision, recall, F1 score, and accuracy for the decision tree classifier were as well determined. Then, the model that best meets the project's objectives is chosen.

Deployment

In this phase, which includes the final report, the strategies for the evaluation results are determined. In Python, Matplotlib was used to visualise the results of the project. A comprehensive review of the project was also conducted to ensure that the objectives of the project are met.

4. Experiments, Results, Evaluation, and discussion

This section provides a visualisation of the trends in sexual crime, as well as the results of the linear regression and decision tree predictions undertaken to meet the objectives of the research.

Figure 3 shows the percentage of population and sexual crime statistics per province in South Africa for the period 2005 to 2016. There is a correlation between population statistics and the rate of sexual crimes in South Africa; sexual crimes increase with population. Figure 3 shows that Gauteng, Kwazulu-Natal, Eastern Cape, and Western Cape have the highest population and sexual crime rates.

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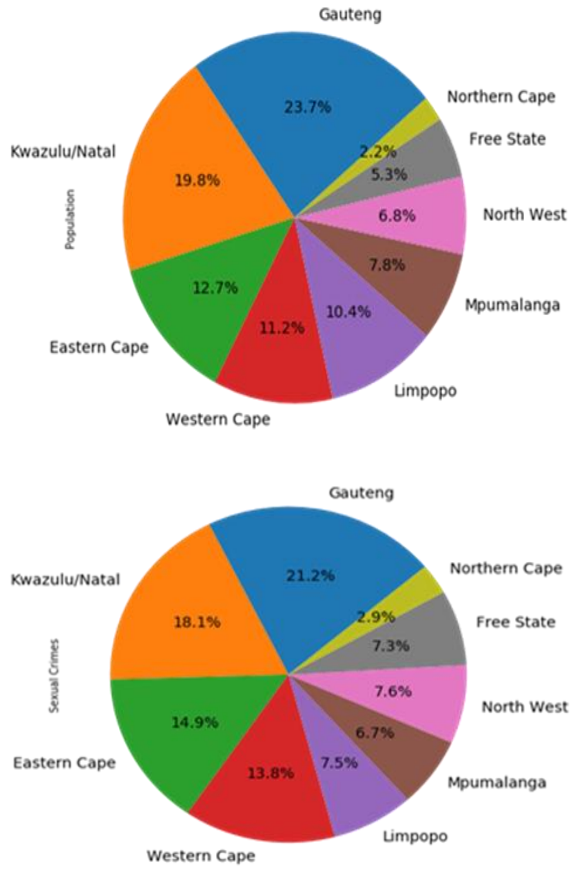

Figure 3. South African population and sexual crime statistics

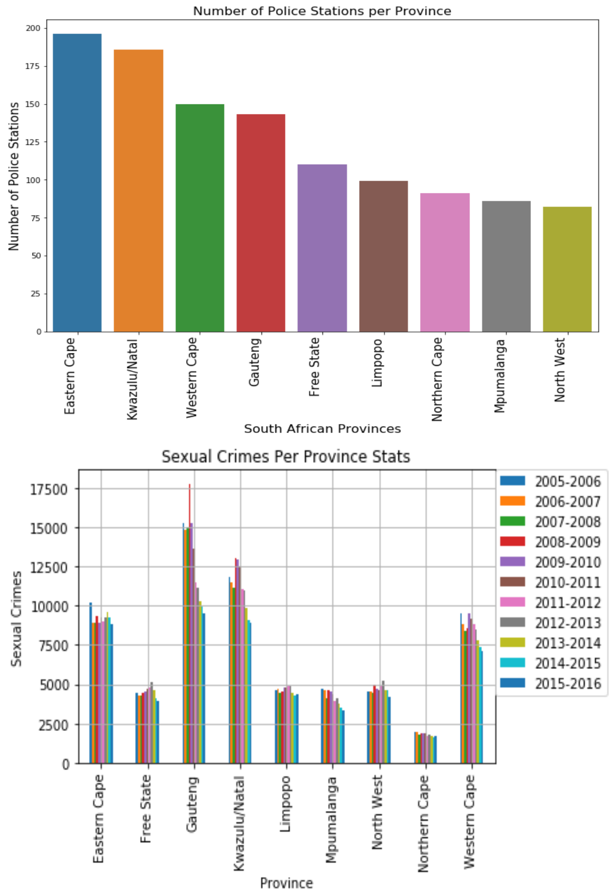

Figure 4. South African provinces' police stations and sexual crimes

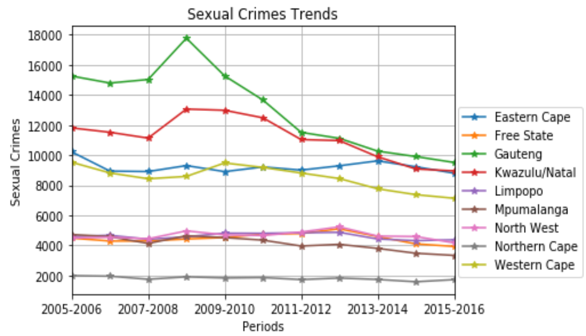

Figure 5. South Africa sexual crimes trends per province

The variables used for prediction were population, area, density, and sexual crimes. The number of sexual crimes for each province was summed using Python. The number of sexual crimes was then entered into a data frame, along with population, density, and area, as shown in Table 1 Population, density and area are the independent variables, while sexual crime is the dependent variable. Before running a linear regression model, it is crucial to make sure there is a linear relationship between the dependent variable (sexual crimes) and the independent variables (population, density, and area). Area was removed from the prediction because there was no positive linear relationship between the area and sexual crime as shown in Figure 9.

Figure 4 shows the number of police stations in each province and sexual crime statistics. There's no correlation between sexual crimes and province police stations. For instance, Figure 4 shows that Eastern Cape Province does not have the highest sexual crime rate but the most police stations. Gauteng has the most sexual crimes but not the most police stations.

Figure 5 shows trends in total sexual crimes in each province and Gauteng, Kwazulu-Natal, Eastern Cape and Western Cape are the provinces with the highest rates of sexual crimes. Conversely, the Northern Cape, Mpumalanga, Free State and Limpopo are the four provinces with the lowest crime rates. It is possible to display the sexual crime data on a graph, but the drawback is that the analysis of sexual crime trends can only aid the detectives and not replace them.

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Figure 6. Word cloud of the three highly prone sexual crime provinces

Word cloud shown in Figure 6, is a data visualisation technique that can be used to represent textual data. The size of each word indicates its frequency of occurrence. The more frequently a particular word occurs in the text, the larger and brighter it appears in the word cloud. For example, if we look at the word cloud for Gauteng, we see that the word 'Pretoria' is the largest and boldest word, indicating that sexual crimes are more common in Pretoria than in other places in the province.

Multiple linear regression (MLR) is a statistical technique that predicts the outcome of a response variable by combining numerous independent variables (Sukhija et al., 2020). MLR is used to represent the linear relationship between the predictor variables (independent variables) and the response variable (dependent variables) (Sukhija et al., 2020). So far, we have learned of simple linear regression, which models the response variable Y with a single predictor variable X. In different applications, multiple factors influence the response. Consequently, multiple regression models illustrate how a single response variable y is linearly related to a set of predictor variables. MLR is essentially an extension of OLS regression in which more than one (independent) predictor variable is considered (Sukhija et al., 2020).

Using the existing data on sexual crimes, population, density and area, a predictive data analysis model was developed using linear regression to predict the likelihood of occurrence of sexual crimes. The input variables in the linear regression should not be dependent on each other (multicollinear). Multicollinearity between other characteristics can be easily detected by a feature-feature correlation analysis. Figure 7 shows a positive correlation between total sexual crimes, population, and density on a heat map. The number of people per square kilometre is the density. Figure 7 shows a correlation between sexual crimes and provincial police stations. This might not mean that the more police stations, the more sexual crimes, but it does mean that more police stations can manage more sexual crimes. Figure 7 indicates a negative correlation between provincial area size and sexual crimes. Figure 8 uses a correlation gradient to depict linear correlations.

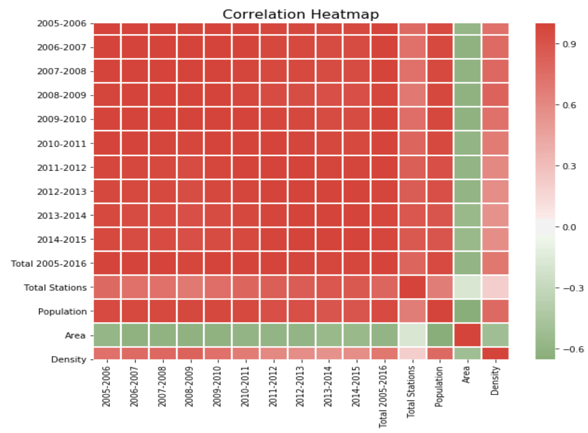

Figure 7. Sexual crimes correlation heat map

ISBN: 978-99949-0-888-2

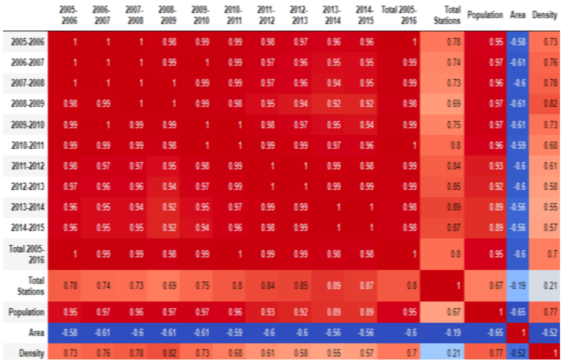

Figure 8. Sexual crimes correlation gradient

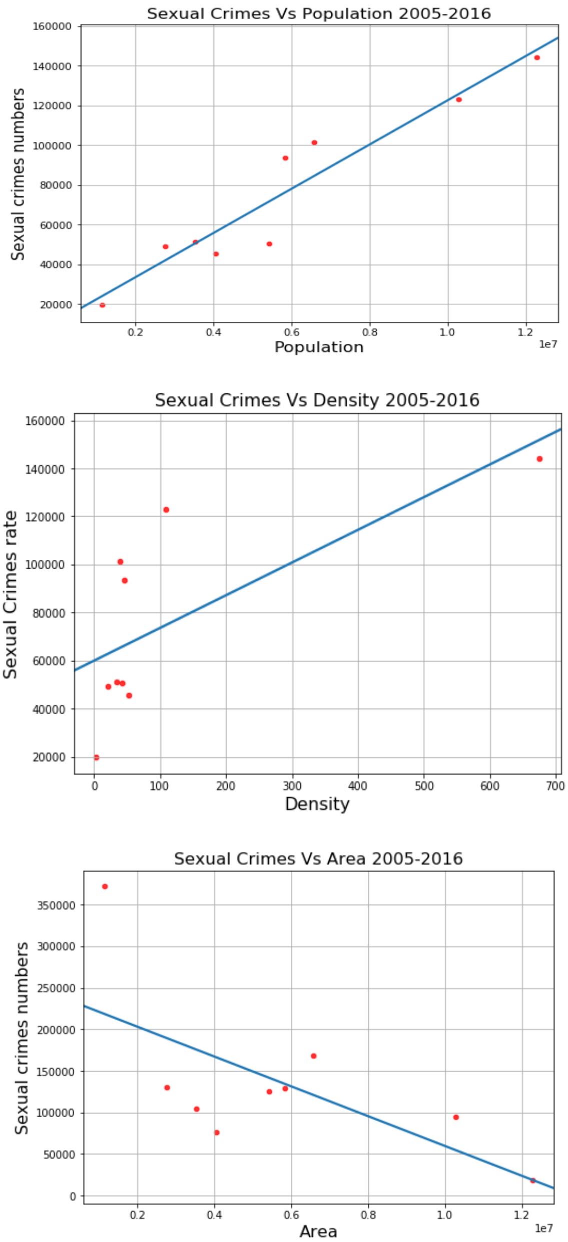

Figure 9. Scatter plots illustrating linear relationships

Ordinary Least Square (OLS) regression results

Linear regression is one of the most widely used and the simplest of modelling techniques (Obagbuwa & Abidoye, 2021). OLS makes very strong assumptions about the relationship between the predictor variables X and the response variable y. This relationship is assumed to be in **Error! Reference source not found.** form. The X variable is denoted as the predictor (factors). While the other variable, denoted as y is regarded as the response (Target), i.e., $Target = j + k$ (factors) (Yerpude, 2020). For example: $sexualcrimerate = j + k$ (population), $sexualcrimerate = j + k$ (density). "*Linear regression reduces the sum of squares of the variables predicted by linear approximation*" (Obagbuwa & Abidoye, 2021, 12). The simplest and most popular estimator is OLS, in which $j + k$ is chosen to minimise the square of the difference between the predicted and actual values (Yerpude, 2020). The technique is used to determine the relationship between one or more independent variables and a dependent variable by minimising the sum of the squares in the difference between the observed and predicted values of the dependent set of variables as a straight line (Yerpude, 2020). It can be used to predict the values of a continuous response variable using one or more predictors, as well as determine the strength of the correlations between them.

Table 2. OLS Regression Results

OLS Regression	*Output*
R-squared	0.914
Adj. R-squared	0.886
F-statistic	31.97
Prob (F-statistic)	0.000632
AIC	199.8
BIC	200.4
Population (p> |t |)	0.002
Density (p> |t |)	0.633
Prob (Omnibus)	0.881
Skew	-0.287
Kurtosis	2.322
Durbin-Watson	2.011
Jarque-Bera (JB)	0.296
Prob (JB)	0.863

When running multiple linear regression, the data is entered once into Python and both scikit-learn and Statsmodels are used to obtain the regression results. Both methods work well, as can be seen in

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Table 2, which shows the results of several tests performed with linear regression. Furthermore, the linear regression model developed in this study was used to predict future sexual crimes in South Africa. The results of the implementation of OLS regression were obtained using the Python programming language. The R-squared, Adj R-squared, F-statistic, coefficient, t-values and p-values of the intercept and independent variables, are all important output results. From the linear regression results in Table 2, the p-values of population (0.002) and density (0.633) are low and positively correlated with the rate of sexual crimes.

The R-squared value is the coefficient of determination. It is a statistic that indicates how well the regression line approximates the actual data values. It is the proportion of variance explained and is used to assess the fit of the relationship between model and the response variable. This indicates that the model explains a significant amount of the variability in the observed data. The R-squared value ranges from 0 to 1, with a high value indicating that the model can explain more variance. The R-squared value in this model, shown in Table 2 is 0.914, which means that about 91% of the variation in the sexual crimes rate (target variable) is explained by the population and density variables (characteristics). This is generally considered a good rate and does not reach the level of overfitting. Because the adjusted R-squared (0.886) reflects the complexity of the model (the number of variables) in relation to the data, the value is always slightly lower than the multiple R-squared values, so the adjusted R-squared is a more accurate measure of model performance.

The P-value for F-stat is 0.000632 below the significance level (0.005), indicating our model is very good. The Akaike information criterion (AIC) measures how much information a model loses (Obagbuwa & Abidoye, 2021). The less information a model loses, the better it is. Less AIC, better the model. The AIC and the Bayesian information criterion (BIC) values of the model of 199.8 and 200.4 show that the model is of good quality. The graphical representations of actual and expected sexual crimes are both linear. Consequently, the predicted sexual crime rate is almost equal to the actual sexual crimes rate, indicating that the linear model is correct. The Omnibus/Prob (Omnibus) is a test for the skewness and kurtosis of the residual feature. Prob (Omnibus) = 0.881 is near to 1 therefore the data is regularly distributed. Skew measures data symmetry and influences Omnibus. Low skewness (-0.287) indicates normal residual distribution.

Kurtosis measures data curvature. The higher kurtosis of 2.322 suggests a stronger model with fewer outliers. Durbin-Watson tests for homoscedasticity must be between 1-2. Durbin-Watson = 2.011 means the data are within limits. The Jarque-Bera test determines a fault's normality. Jarque-Bera (JB)/Prob (JB) tests for both skewness and kurtosis; the Prob (JB) score of 0.863 confirms the Omnibus test of 0.881. Table 2 indicated that the linear regression model can predict sexual crimes in South Africa (that is, the algorithm can be used to predict sexual crimes in any of the nine provinces). The prediction method analyses population and density to predict sexual crimes.

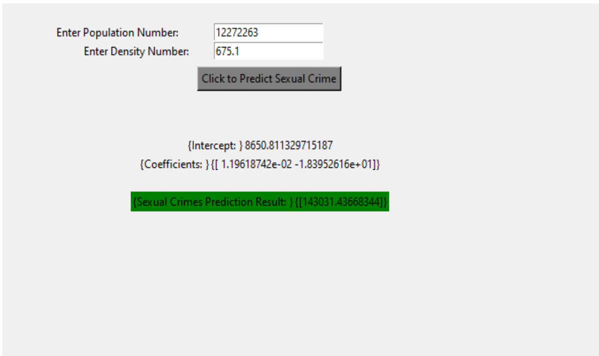

Figure 10. Sexual Crime prediction prototype using a linear regression method

The graphical user interface (GUI) created allows users to enter the independent variables to obtain the predicted sexual crimes outcome. The GUI was created using Python. The reason for creating the GUI is that some users may not know much about entering data into the Python code itself. Therefore, it is helpful to create a simple interface through which they can manage the data in a simplified way, as shown in Figure 10.

Decision tree output result

In contrast to the linear regression model, the decision tree was not a good fit for our dataset as its results of accuracy, precision, recall and F1 score was very poor. In this case, the decision tree was incompatible with our dataset. This is not to say that the decision tree classifier is not useful in research; the decision tree classifier can be very useful in classifying models. Classification involves predicting a discrete class name, while

ISBN: 978-99949-0-888-2

regression involves predicting a continuous variable. However, because there are so many approaches for prediction, they may not all function effectively in all situations. Some approaches are very good at finding association rules, classification, regression, and clustering. For example, in the case of our project, the appropriate model for prediction is linear regression because it is a function for predicting a continuous variable with which our dataset is correlated.

5. Conclusions

The technique of using data analytics algorithms can effectively reveal the unseen trends in sexual crime data that are useful and provide a good visualisation for predicting sexual crimes; hence, they can assist in the mitigation of sexual crimes in South Africa. Data analytics can extract unknown vital information from the raw sexual crime data, thus helping the government to speed up sexual crime mitigation measures. The model would enable the police, law enforcement agencies, and government gain a better understanding of sexual crime trends and curb them. When sexual crimes are prevented and the environment is peaceful, the country's economic growth is also sustained. This work presents a data analytics model trained with sexual crime data that can predict overall sexual crime in the South African provinces using population and density. In addition, linear regression output performance was very good, indicating that linear regression is compatible with our dataset whereas the decision tree performed poorly. Finally, a Graphical User Interface (GUI) experimental prototype for prediction output result was built using the linear regression method, which will allow users to input independent variables to obtain the predicted outcome of sexual crimes. Finally, research can be done on other serious crimes in South Africa.

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Towards Scalable Secure Syslog Compatible Remote Logging

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Abstract

This research explains both why logging is useful and why the integrity of logs and the logging process is important. This is followed by a discussion of the design and implementation of a high-performance secure logging framework, implemented in Golang (Go). This is implemented as a server-client for *nix-like systems, with a focus on security first. While a custom protocol is introduced for security, the server remains compatible with traditional syslog log messages, albeit without the added performance and security features. The functionality of the implementation is reflected on along with preliminary performance bench-marking. While most of the design goals are satisfied, one notable area of concern is the performance hit caused through the use of RSA encryption. Aside from this the system was found to perform well with logging rates in excess of 20 thousand events per second achieved. The work concludes with some suggestions for improvements and future work.

Keywords: Secure Logging, Syslog, Remote logging

1. Introduction

Working with the logs generated by the operating system and applications running on a computer is an integral part of its operation, security, and most commonly debugging of problems. A log can be defined as a stored record of an event. On a computer system, logs are created constantly by all kinds of events, like a user logging in, adding a network share, a configuration change or installing a program. By having a log for most of the events in a system, it is possible to retrieve both the current and previous status of a given system based on their logs. A set of logs gathered from a single system can be used for a number of different goals depending on what the role of person looking at them is, and what they are looking for. System administrators are probably the most frequent primary users of logs, using them to monitor the resource usage of the systems; that the systems are running as expected; or why a process crashed. Security Professionals (including Audit and Forensics) examine log data to look for attacks attempts, indicators of compromise and/ or exploitation signs. Logs are further critical to this group in being used to determine (or correlate) a chain of events or providing some insight on what might have happened in the system at a certain point in time. In general logs are used to correlate events across different systems or processes, which may often span multiple geographic locations (and time zones).

However, if the integrity of the logs is compromised, or indeed if the system on which they reside has been compromised, then it is not possible to trust the logs. Tampered logs may not be trusted because what they contain could have been manipulated, deleted or contain false information, rendering them worthless. This is particularly important where security incidents are being investigated, it is widely accepted and researched in the field of digital forensics (Cho, 2013; Koen & Olivier, 2008; Pieterse et al., 2015).

Complete security and tampering resistance in all devices in a network are not feasible (Accorsi, 2006), and it is well accepted that logs from a compromised device cannot be trusted any longer. Some systems therefore attempt to improve integrity of the logs while the system is being compromised and send an alarm before the attacker gains complete control. Storing and/or streaming logs remotely provides both a means of backup and for detecting any potential log tampering.

Having a centralised logging server receiving or retrieving the logs periodically from all the devices

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helps with the integrity of the local logs in the devices. This is because logs previously sent cannot be tampered locally anymore, as they are stored somewhere else. Traditional means of storing logs centrally have a vulnerability in that if the centralised logging server is compromised then none of the logs can be trusted. Without logging, it is not possible to reconstruct how a security breach happened or why a system failed. Without logging, a system that does not perform nominally is very difficult to diagnose or a security breach might never be discovered. This underscores the importance of having a trusted logging.

Since most of the Internet infrastructure and many Internet of Things (IoT) devices run on *nix derived operating systems, these are the targeted systems for the resulting compiled binaries. Compatibility with traditional syslog logging, is also important, as most network devices can use it, thus giving the system more flexibility, as well as support for the vast install base of legacy devices. The scope of our work is limited to the processing of these traditional plain text system logs as used by syslog and related applications and widely supported across all unix-like platforms (this includes Linux, the BSD family and others).

The contribution of this work is the development of a portable, scalable and secure remote logging system that can be used by a number of hardware architectures, platforms and operating systems. The system can be used to provide a drop in secure channel in addition to any existing logging and requires minimal resources. Logging rates are at around 20 000 per second with AES-256 encryption. RSA drops this significantly and is a point of future research.

The remainder of the paper is structured as follows. Section 2 provides a summary of work related to the project. Section 3 considers the design and implementation aspects of the system and forms a significant component of the paper. The results presented in Section 4, evaluates the initial proof-of-concept implementation in terms of functional completeness and how the server performance was tested. Finally, in Section 5, the results and significance of the work is considered along with some thoughts towards extensions to the current PoC.

2. Related Works

Before diving into the project design, some context is required to better understand why some design choices were made when scoping and proposing it.

2.1 Timestamp Importance

A timestamp is a date and time attached to a piece of data. By having correct timestamps, it is possible to look back at the logs and draw conclusions from them, as they should reconstruct a timeline of events. The main catch is that the timestamps usually depend on the system or operating system time. A common solution is to use NTP, or other direct time source (such as GPS signal, RTC or RF broadcast). System logs have a timestamp (typically as the first field). This is required or else it would not be possible or be complicated to put the logs into a timeline when inquiring a batch of logs when trying to reconstruct what happened in a given system or systems. When reconstructing an incident timeline, the importance of having correct timestamps is paramount, else the order of the events shown by the logs will not be in the order of what happened, thus making the logs misleading or difficult to interpret (Cho, 2013; Koen & Olivier, 2008; Pieterse et al., 2015).

2.2 NTP

The most common way to keep the time in sync between the different devices or systems is by using NTP (Network Time Protocol) created in 1981 (Mills, 1981). It has been in use since the early days of Internet and the fact that it is still in widespread used is proof of its stability and scalability largely due the approach of layered infrastructure (Mills, 2003). When undertaking distributed logging, or log aggregation, ensuring systems have a common and coherent view of time is critical for successful analysis and monitoring. This does not mean that NTP has been flawless, some vulnerabilities have been found in the protocol. For example, Malhotra et al. (2016) found it possible to dramatically change the time in clients by exploiting IPv4 packet fragmentation or to perform a Denial of Service attack to host in the network.

2.3 Syslog

Syslog was originally created in 1980 as part of the Sendmail project and was then rapidly adopted by many other applications. It has subsequently become the standard log format in Unix systems, although it was only formalised more recently in RFC-5424 (Gerhards, 2009). Syslog is a common baseline format used to send logs over the network, because it is supported by most devices and logging software even on on unix-like platforms. While not perfect, syslog is a cornerstone in monitoring because allows most devices and processes to delegate their logging into an external place with little effort. It is plain text, and thus human

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readable and can be processed with a wide variety of tools, while allowing developers freedom as to how they format their application messages. Due to syslog's widespread adoption and use there are many tools available to parse, create and collect syslog formatted data. A significant downside of syslog is that cannot verify the integrity and authenticity of the messages without the addition of extra modules or wrapper programs. Given that remote logging may occur via UDP, messages could be intercepted, modified and then forwarded again or dropped and the syslog server cannot be aware of this (Forte et al., 2005).

2.4 Some solutions to secure logging with trade-offs

Ma and Tsudik (2009) propose a different way to store the logs, defined in the paper as "forward-secure stream integrity", in which each log entry contains its own signature and the aggregate signature of all the previous entries. This is somewhat similar to a blockchain from modern technologies and helps to detect tampering on the logs. Ma and Tsudik (2009) further argue that having a centralised server collecting logs is a single point of failure and that batch-based systems are vulnerable to manipulation in the time period between batches, or the batching system stops completely.

Bowers et al. (2014) propose PillarBox, a software system design that could be a middle-ware or incorporated into an existing system to aid the monitoring of logs and alerts previous to a compromise, and during the compromise process. This design aims to send the alert to a central server before being fully compromised, based on an undefined set of rules. After an attacker gains full control, all monitoring processes can be killed, tampered or blocked. PillarBox proposes the use of a fixed buffer size, and a fixed timing to send logs, making difficult for the attacker to infer how the system rules work. The central server knows about these time windows, and sends heartbeat messages to all the clients as a way of acknowledging that the data is being received. If either the server or the client lacks data, compromise is assumed and an alert is raised (Bowers et al., 2014).

2.4.1 Hardware Based Logging

Some systems, particularly those aimed at medical devices or critical systems, have as a goal to run securely even on an unsafe network, basing their trust in two main technologies for the verification and storage of the logs: Intel SGX and TPM (Nguyen et al., 2016). Another approach for using Intel's SGX technology to securely store and verify logs as a module for syslog has been researched by Karande et al. (2017). This adds some overhead to the syslog process, between 4 to 6 percent, but it is relatively easy to add to an existing client. Both the Nguyen et al. (2016) and Karande et al. (2017) approaches rely on a TCP connection between the devices and the centralised server collecting the logs.

However, Intel's SGX has been compromised (van Bulck et al., 2020) and the solutions provided for it affects the performance of the processors in many orders of magnitude. Only the newer processor family of the Ice Lake (and later) design is unaffected, meaning that the older infrastructure will perform significantly worse or needs to be replaced. Also, the TPM modules from both Intel and STMicroelectronics have also proved to be vulnerable to attacks if unpatched (Moghimi et al., 2020). This makes the designs proposed by Nguyen et al. (2016) and Karande et al. (2017) less appealing compared to when they were published, due their reliance on such technologies.

2.4.2 Cloud Logging

Getting logs from the lower levels of the infrastructure from a cloud provider, such as the physical machines or networking devices, poses new challenges to forensics and logging. Zawoad et al. (2013) proposes a system in which all the logs created by the cloud provider are stored as proofs in a database, to which the investigators can interact with via an API. They revisited the same topic some years later (Zawoad et al., 2015), but only proposed a different way to hash the stored logs, leaving the underlying structure is the same as the previous model. Application and OS logs can be retrieved as usual from the cloud, as the customers have access to them via SSH, web console, etc.

2.5 Takeaway

Like most computing systems, logging systems have evolved and improved to become flexible and scalable as the systems that they need to monitor, such as IoT or cloud environments. Most current logging systems can use syslog, which is the baseline standard for older devices, IoT or networking devices, providing a common ground for logging. As with many other elements of computer systems, logging systems still need to make trade-offs when faced with the choices of ease-of-use *vs.* security, centralised *vs.* distributed or self-hosted *vs.* cloud. Because of these choices, there is not a single logging system that is perfect for all situations. The choice of which system to use,

ISBN: 978-99949-0-888-2

what to log and how to interpret the logs depends on the goal of the organisation or the project at hand.

Logging can potentially generate vast amounts of logs. However, for value to be gained, they need to be inspected just collecting logs does not provide any value or insights to the person looking at them. That is why within the emerging “DevOps” concept, this is called “observability” (Tamburri et al., 2018), which means how easy it is to track the metrics of interest in a complex system. A system with low observability can fail in some areas and go unnoticed, something that is not desirable. Conversely, a system with good observability can report its high level, and more detailed, status in a single report.

3. Design and Implementation

Considering the points raised above, this section puts forward the design principles, and a high-level overview of the implementation of the client and server components. This process is described through five primary phases in the sections following. An initial explanation of the system is presented. From this a set of objectives to be achieved by the project is determined. The implementation explains the programming language choice, how testing was done, as well as a general explanation of the encoders/decoders. The architecture for the server and client side designs are presented.

3.1 Project Design

The project is to develop a system that has a client that can run in many different devices and architectures, collect logs centrally in a secure way, and provide some interface for the user to see the arriving logs. The system is designed and tested to be used on *nix family of systems, it might work on Windows, provided that it keeps the convention of one log per line and the code is recompiled. This will not be tested, as Windows is not part of the scope of the project. The system stores data in three different formats: encrypted, csv and to a database. The last two are meant to be used most of the time, as they are easier to use. If there is any suspicion that the logs have been manipulated on the original system, the logging platform can read and replay the encrypted file. This will generate the same output as when logs arrived, so the suspicious file can be compared against the replay output for verification. If the replay file finds something wrong during the replay, such as missing lines or corrupted data, it will be flagged in the output and the replay summary. The server binary does not provide any way to edit a file, it treats all output as append only, so, if a file has been modified, it should catch that and flag the suspicious entry.

3.2 Project Goals

Before commencing with the design and implementation, a number of goals were determined in order to be able to support secure remote logging using a client-server architecture. Security is paramount, and there should be appropriate methods of ensuring that the confidentiality and Integrity of data are maintained, both in ’flight’ and at rest.

To aid with the integration in existing systems, a variety of outputs should be possible from the server - human readable text (as a csv file), a database input, and finally a secure encrypted on-disk storage which can be used to cryptographically validate any message in the future. The client side should operate on traditional ’syslog’ style plain text log files.

From a development perspective, a goal was to To provide an easy way to build and deploy binaries. The codebase should be well documented so that modifications can be made if required. The system should Support *nix type of OS with at least x86, AMD64, ARM and ARM64 arch support, so that it can be run on small devices like Raspberry Pi or other emerging IoT platforms.

3.3 Implementation

Because of the number of architectures to be targeted, and that it is a network based client-server application, Google’s Golang (Go) was the chosen language. Go compiles to machine code with static linking, so there is no need to install additional libraries or setup environments for the programs, only copy to the desired device: the binary, a configuration file and the encryption key(s). This also provided for an opportunity to gain familiarity with the language.

The server binary itself can generate the RSA keys, so can be deployed in bare minimum or constrained working environments. The server can run on the Alpine docker image[1], which is 5.6MB including the server binary, making for a total Docker image size for slog-server of only 12.6MB. This makes for an extremely lightweight footprint for a logging solution.

[1]https://hub.docker.com/_/alpine

ISBN: 978-99949-0-888-2

Figure 1: Client Message Memory

3.3.1 Database and Front-End choice

Influx[2] was chosen as a back-end database, primarily because is a time series database, and is a popular open source project for logging metrics over time. It is also written in Go and integrates perfectly with the front-end. While Influx is ideal, this could be integrated with or extended to support other data back-ends. As a front-end, Grafana[3] is another popular open source project, also written in Go and TypeScript, that integrates seamlessly with most modern databases (not only Influx). It allows a user to create plots, graphs and alerts to interrogate collected data. If this project is going to be used in real environment, it greatly helps to visualize the data.

3.3.2 Testing

Unit test driven development was a major focus of this project. The main functions like the client encoder/decoder, storage encoder/decoder, RSA encryption/decryption and AES-256 encryption/decryption have a relatively wide array of unit tests, while many complementary functions lack unit tests in this proof of concept.

The unit tests are meant to cover and crosscheck that the backbone functions and structs (memory structures) of the project work as intended and changes do not break functionality. With an “end-to-end” test in the *ClientEncoderV1* and *StorageEncoderV1*, which use all the underlying functions that are individually tested as well. The Go language includes a built-in test mechanism with the command "go vet". This was used to go through project code and try to catch errors that the compiler may have missed. Examples of this include wrongly formatted calls on “ printf ”, deadlocks or interface incompatibility. This tool runs as part of the build script ensuring regular testing. Finally, benchmark testing was done at several stages during the development, so the impact of performance of the main features added could be measured.

3.3.3 Encoding/Decoding

All the encoding/encryption functions have their corresponding decoding/decryption counterparts.

[2]https://www.influxdata.com/
[3]https://grafana.com/

Figure 2: Server log format on disk

In the secure storage, the ‘blob’ is the memory based representation of the log, base64 encoded and encrypted, not the text representation of it, as shown in Figure 1. The client messages and the secure storage encrypts the data with AES-256. The corresponding AES-256 password is encrypted with RSA asymmetric keys, as shown in Figure 2.

On the client side, a random nonce (single use password) is generated for each packet sent, while for the storage, the user provided password is used. This means that to decode/replay a secure file, only having the private RSA key for the storage or the password at runtime is not enough, as the replay mode needs both. The storage password is not used as is, but the SHA-256 hash of it is used to encrypt the data. When written to a file, the secure storage uses the format described in Figure 2.

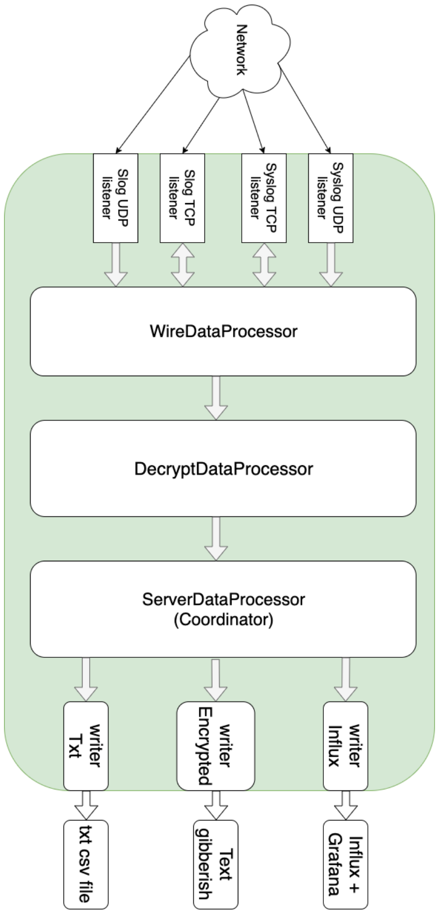

Figure 3: Server Architecture

ISBN: 978-99949-0-888-2

3.4 Server architecture

On startup, the logging server starts different, a dedicated listener for each one of the configured ports. The data that is received by these is passed as is to a second level of *goroutines* ('lightweight' threads). This allows the port to return directly for waiting for the next incoming message. On the TCP connections, even if the content is suspicious, the answer to the client is always "OK" and the connection is closed immediately. This approach is taken to avoid giving information about how the server works internally. If the arriving data is suspicious, it is stored "as is" and flagged, as it can still contain useful information.

The received raw data is then decoded if necessary (data received on the syslog compatibility listener is always stored "as is"), flagged if it's suspicious, enriched and passed down further to the third layer of *goroutines*. These act as a coordinator that sorts the data by time of arrival and then distributes it to the three writer *goroutines*, one for each output type (csv, database and encrypted). This is shown in Figure 3.

Timestamp	Source IP	Suspicious Incoming	Suspicious Replay	Decoded Client Data

Figure 4: Server log format plain csv

Encrypted Client Data	Timestamp of arrival	Source IP of the packet	Syslog packet flag	Decrypted Client Data	Suspicious Incoming	Suspicious Replay	Server Hostname	Previous log hash

Figure 5: Server log in memory

The idea is that the administrator can quickly skim or use traditional tools such as grep/awk against the plain text csv (Figure 4) or the database, and if there is any suspicion of tampering, replay the encrypted file and compare the replay output with the suspicious file using a diff or in a query.

In the replay mode, the server needs the storage private key and user password used at runtime, the file is read line by line, and each decoded structure compares its stored previous hash against the previous line in the file, so if there is line that has been tampered or removed, it is flagged in the replay output. The replay mode generates a plain-text csv and stores to Influx in the past timestamps, making comparisons via queries within the same timeline possible. The timestamp used by the replay is the one from the encrypted blob, not the one that is clear-text at the start of the line.

3.4.1 Server data structures

When a client message arrives, it is enriched with some extra data, so the timeline and integrity can be verified, the struct in memory is described in Figure 5. The server has the capability to compress the encrypted stored data, reducing significantly the amount of space required for storage in exchange of some extra processing. Tthis is the last field of Figure 2.

3.5 Client architecture

The client architecture is simple with an overview given in Figure 6 The configuration file specifies which log files are to be monitored. The program starts and reads all the files listed in the configuration from the beginning so earlier logs are also sent out upon client start. When the end of file is reached, it operates in a similar manner to "tail -f". Each new line is read when the file system notifies a change, then the enriched message is generated, encrypted and dispatched as soon as possible, reducing the chances of being manipulated or stopped.

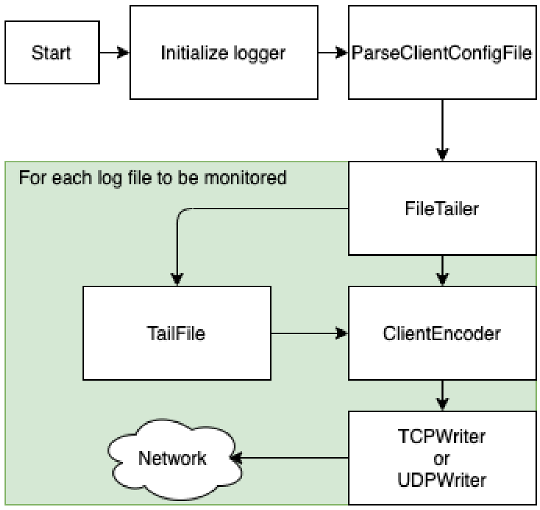

Figure 6: Client Logic Flow

3.5.1 Client message

For each line the client reads to transmit, random password is generated. The password is encrypted with the public key of the communication key pair and sent together with the message itself. While this provides some overhead, it does protect messages from compromise/tampering should a symmetric key be obtained by an adversary.

4. Results

The implementation of the system prototype was evaluated along two axes, the first of these is performance, and the second a reflection on the current state of the implementation of the proof of concept towards full functional completeness.

ISBN: 978-99949-0-888-2

Table 1: Averaged Benchmark script results

Feature	No. Messages	Time
Bare-bones, pass data ‘as is’	20 000	0,952s
Password Encryption before storage	20 000	0,983s
Compression (enabled)	20 000	1,182s
Compression (disabled)	20 000	1,030s
AES-256 Encryption	20 000	1,025s
RSA Encryption	1 100	1,246s
Replay time (with RSA)	1 100	1,054s

4.1 Benchmarking

The benchmark script used was updated as the project evolved, as the payload sent to the logging server had to change to comply with the progressive implementation of the features in the encoders/decoders.

Development used a MacBook Air M1 8 cores, 16 GB RAM, 512 GB SSD. This runs roughly runs twice as fast in the testing (except RSA decryption) compared to an older Intel i7-6820HQ CPU @ 2.70GHz system.

The benchmark script sends a message 10 000 times via TCP and UDP, which was able to process correctly until the introduction of RSA, which made the server crash on loads higher than 1 100 messages/seconds and identified an area for further development and investigation. Sending a malformed message that gets detected and thus RSA decryption skipped, ingests the 20 000 messages correctly. Hard-coding the correct password hash for the client message in the ClientDecoder, thus voiding the RSA call to get it, and jumping directly to decrypt AES-256 yields 20 000 messages ingestion in about 1,2 seconds in the i7 test. Running a modified unit test in the M1 which decodes 1 000 messages with RSA enabled, takes 0.925 seconds which is faster than the i7, but far from not using RSA encryption. The results in Table 1 are accumulative, each row contains all the previous features plus the one specified.

Adding more features to the project did not significantly impact the ingestion rate of the server. This is likely as each step works concurrently in *goroutines* (similar to a thread but lighter in resources) with channels (data pipes) between the functions that can be buffered, allowing to handle spikes in the traffic. The only exception to this is the RSA decryption, which does not scale well and bottlenecks the whole chain and is prone to crashes. There is a suspicion that this behaviour might be caused because the key is read once, and a pointer to it is passed to all decryption function calls that run concurrently. It is possible that the underlying struct in Go’s standard library for a RSA key is using a mutex, or some blocking mechanism.

If the RSA decryption is not considered, the server performed better than expected at about 20 000 logs/second, and using RSA at about 1 100 logs/second which is sufficient for many use cases, but a massive drop in performance and this is an area for further investigation.

4.2 Implementation progress

The following core functions were completely implemented as part of the proof of concept. Full network functionality is in place, along with compression, encoding and decoding for both the client and server. The client is able to consume legacy log files for secure transmission to the server. The server is able to store the logs in three different manners - csv, database, and as encrypted files (used for secure replay and verification).

To achieve this, a number of supporting functions needed to be implemented. Cryptographic functionality including a random nonce generator is complete. One challenge was developing the bi directional translation of in memory Struct binary data to base64 encoded JSON.

5. Conclusion

All the project goals as working proof of concept are in place, but some refinement is required, and the system has proved to be functional as a proof of concept implementation. Source code for this work is available at *https://github.com/barryirwin/securelogging.*

While the system is not perfect, nor does it support clustering instances of servers, it has a small footprint and can run in many architectures, so most users should be able to run it as is, or with little changes. The performance hit on the ingestion rate that the RSA decryption added was not expected to be as significant.

The high-level logic of the client and server are not

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overly complex, but the implementation had some challenges in the design and decisions, especially with the encryption in encoders/decoders and the message/log structures, as they went through some iterations. They are the cornerstone of the project, as the rest of the code are just wrappers and making the use of the encoders/decoders easier or directing the data flow from and to them.

The proof of concept has shown that the design of the client-server architecture is viable and can operate at a reasonable performance for certainly small to medium operations. While the features have been designed to treat the network as a hostile environment, these may not all be needed depending on the case. Reflecting on the output produced, in the design goals were met, and this provides a viable and scalable secure logging solution, that can be implemented across a variety of platforms with low resource requirements.

5.1 Future work

I/O to the file outputs can become a bottleneck, parallel writing to the same file increases the chances of inconsistency of the replay, queuing the write only moves the problem to the possibility of many tasks waiting (to memory), this is not in the scope, as the system works great as proof of concept and for small environments. A possible solution to this, if there is enough memory, is to increase the buffer sizes in the configuration file to queue many requests in different stages.

Further functional extensions that have been considered are:

- Log from which network protocol came the packet from, can show interesting statistics.
- Ability to replay from an arbitrary time range instead of the whole file.
- RSA performance for decryption is a bottleneck for the processing, making the server drop significant ingestion rate, investigate if this can be improved.
- Support for many slog-servers working as cluster is not supported, this would need a big architecture change.
- This project could also be expanded to support an API, which can be based upon the encoders and decoders being used as library for direct use by other applications.

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An Exploration of the Adoption of DNSSEC by Businesses within the Norwegian ccTLD

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Abstract

The Domain Name System Security Extension (DNSSEC) is a cryptographic extension to the Domain Name System (DNS). The DNSSEC gives the DNS hierarchy a chain of trust from the root zone all the way down to the domain. By utilising DNSSEC, the client can verify that the DNS server's response has not been tampered with in transit using strong trustworthy cryptographic algorithms. This paper presents a pilot research into the adoption of DNSSEC in Norwegian (.NO) ccTLD. The data set investigated in this researched a collection of Norwegian businesses that have a domain within the Norwegian ccTLD. This research found out that the Norwegian ccTLD adoption rate is amongst one of the highest compared to other ccTLDs. The DNSKEY resource records (RRs) collected in this research were used to identify some potential weaknesses. These possible weaknesses include the algorithm used, how long validity there was on the DNSKEY, and shared DNSKEY values across multiple domains.

Keywords: DNS, DNSSEC, DNS Security

1. Introduction

The Domain Name System (DNS) is one of the backbones of the Internet. In order to secure the DNS record's integrity DNSSEC was introduced. More than 92% of the TLD's support DNSSEC. Three key prior studies have been identified which have undertaken similar work considering ccTLDs and the adoption/prevalence of DNSSEC, namely Chung, van Rijswijk-Deij, et al. (2017), Le et al. (2018), and Roth et al. (2019). The results of these surveys however show a relatively low adoption of DNSSEC deployment in the .com, .net and .org domains. There are some ccTLDs in these reports that have a notably better deployment rate specifically .SE and .NL. The .SE domain had a deployment rate of 56.9% of DNSSEC, and the .NL had 54.1%. These are used as the baseline for comparisons to the results in this work.

DNSSEC defined in RFC4033 (Arends et al., 2005) provides a marked increase in security offered to the venerable global name resolution system that is DNS. DNS being at the core of almost all Internet communications, it is also vulnerable to interception, corruption and other attacks (Ariyapperuma & Mitchell, 2007; Dooley & Rooney, 2017; Kim & Reeves, 2020). DNSSEC provides a twin pronged approach for mitigating this. The first of these is the server-side cryptographic signing of the domain, and ultimately the DNS Resource Records (RR) that it contains. These allow the second component of the client-side interface to verify responses received through a public chain of trust, that they have not been compromised in transit.

This research builds on earlier work and evaluates (to our knowledge for the first time) the adoption of DNSSEC for business linked domains within the Norwegian ccTLD (.NO). Norway differs from many countries in that its business landscape consists predominantly of small and medium enterprises - amounting to 95% (Iversen, 2013). By implication, the majority are also dependent on external providers for their IT services, specifically their internet presence. This is an important step towards being able to gauge the adoption and more widespread use of the technology. While it is difficult to get a view into the client-side adoption, for this to work, there needs to be server-side implementation.

This work provides a contribution of the evaluation of the implementation of DNSSEC within business related domains in Norway. The finding that nearly 60% of the domains surveyed is encouraging. While these represent a small number of the

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total domains registered; they are all for active businesses. Furthermore, some areas of concern similar to those identified by (Chung, van Rijswijk-Deij, et al., 2017) are noted.

The remainder of the paper is organised as follows. Section 2 gives an overview about related work done in the field of DNSSEC. Guidelines for best practice that should be implemented when deploying DNSSEC are also presented. The gathering and analysis of the Norwegian ccTLD data is detailed in Section 3. The results arising from Section 3 are discussed in Section 4, particularly highlighting some identified bad practices that were observed. Section 5 provides a conclusion and reflection on the findings, along with presenting ideas on possible future avenues of research.

2. Related work

This section provides and overview of similar review studies on the adoption rate of DNSSEC, and details some of the implemented bad practice that has been observed. When working with DNSSEC, operators need to consider multiple RFCs. These together with other guides give recommendations on best practice as to how the system administrator or operator should implement DNSSEC. Le et al. (2018) lists the most accurate and latest guidelines as being NIST.SP.800-81-2 (Chandramouli & Rose, 2013) and NIST.SP.800-57 (Barker & Dang, 2015).

There are several research papers relating to DNSSEC adoption rates. Most of the research has been conducted at the TLD level, specifically .com, .net and .org. Work done at a national level is sparser, with .NL and .SE having been researched, and compared against TLD’s.

The core of prior research is contained in three works: Chung, van Rijswijk-Deij, et al. (2017), Le et al. (2018), and Roth et al. (2019). Le et al. (2018) used the OpenINTEL crawler to obtain their data sets. The data sets were collected between 28.02.2015 and 31.07.2017 for the .com, .net, and .org domains. The .NL data sets were started collected at 09.02.2016, and the .SE started at 07.06.2016 and both data sets ended at 31.07.2017. Table 1 shows the number of domains found to be signed during the period of the research conducted by Le et al. (2018). Given the date of these publications, and the data collection periods, it is noted that these statistics have likely improved in the interim. However no more recent statistics have been found to be available.

Chung, van Rijswijk-Deij, et al. (2017) and Roth et al. (2019) used the same collection method as Le et al. (2018). Both of the aforementioned started their collection of data on 01.03.2015 for the .com, .net and .org domains. The .NL started on 09.02.2016 and the .SE on 07.06.2016. The Chung et al. Chung, van Rijswijk-Deij, et al. (2017) ended their collection on all the domains on 31.12.2016. Collection of data in used in Roth et al. (2019) was ended on 19.06.2019.

Table 2 shows a difference in the DNSKEY deployment in the time span between Chung, van Rijswijk-Deij, et al. (2017) and Roth et al. (2019). Research shows that the rate of TLDs that are using DNSSEC is increasing. Roth et al. (2019) found an increase in the use of DNSSEC from 01.03.2015 to 19.06.2019 at a rate of 0.1% point in .com and .net TLDs. The .NL and .SE ccTLDs in the same period had an increase of 2.5% and 10.2% respectively.

Statistics from Norid (2020a) shows that the increase in the use of DNSSEC in the .NO domain from 2015 to 2019 was 3% points. The increased adoption rates were from 56% in 2015 to 59% in 2019. The same statistics show that the adoption rate is 61% by 14.04.2020. As the adoption of DNSSEC is reliant on all parts of the DNS chain, the different domain name provider needs to have DNSSEC enabled to be able to use DNSSEC. There are 84 domain name providers that delivers domain names to businesses or organisations that have a contract with Norid. Out of these 84, there are 51 domain name providers that provide DNSSEC (Norid, 2020c).

2.1 Poor Practice

Findings in Chung, Van Rijswijk-Deij, et al. (2017) show that some registrars have a high usage of DNSKEY sharing among their domains. DNSKEY sharing makes sense as it makes the key management easier for the registrars, but it can increase the risk to the domain’s security. A problem with shared DNSKEY is if one DNSKEY is compromised then all domains will be affected. This is examined as it related to the .NO data in Section 3.

When it comes to the type of algorithms recommended for use, RFC 8624 (Wouters & Surý, 2019) gives an overview of the algorithms recommended for current use. Le et al. (2018) researched the usage of recommended algorithms used in the .NL and .SE ccTLD. The results are divided in Le et al. (2018) into large and small operators to see if there are any differences. In the .SE ccTLD, the large operators have a 76.60% usage of the recommended algorithm, and in the small operators, there is an 87.36% usage. The use

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Table 1: Deployment of DNSSEC from Le et al. (2018)

Domains	Number of domains	Signed domains	% Signed
.com	116,814,548	936,413	0.80%
.net	13,011,428	141,087	1.08%
.org	9,373,214	105,508	1.13%
.NL	5,440,975	2,829,184	52.00%
.SE	1,440,244	737,326	51.19%

Table 2: Deployment of DNSSEC found by Chung, van Rijswijk-Deij, et al. (2017) and Roth et al. (2019)

	Chung et al (2017)		Roth et al. (2019)	
TLD	Domains	Signed domains	Domains	Signed domains
.com	118,147,199	0.7%	140,438,505	0.8%
.net	13,773,903	1.0%	13,408,301	1.1%
.org	9,682,750	1.1%	10,066,388	1.1%
.NL	5,674,208	51.6%	5,860,418	54.1%
.SE	1,388,372	46.7%	1,450,441	56.9%

of a recommended algorithm in the .NL ccTLD is even better, with a 100.00% coverage in the large operators and a 94.26% in the small operators. These numbers are excellent, but the Le et al. (2018) point out that the large operators perform poorly when it comes to key rollovers.

3. Data Gathering/Analysis

To determine the adoption rate of DNSSEC in the Norwegian (.NO) domain name space, it is essential to have a good selection of domains to research. The .NO ccTLD is managed by Norid (2022a). The initial approach to the research was to request the zone file for the .NO ccTLD, but this was unsuccessful. As the zone file from Norid was not obtained, another way to get data to research the adoption rate of DNSSEC in the Norwegian ccTLD as needed. As such a selection of known valid domains was generated as a valid proxy, representing a sample of around 8% of the registered domains (Norid, 2020b). These are however deemed to be active and have a clear commercial interest.

As the complete zone data for the .NO ccTLD was not obtained, it was necessary to use another way to get a list of domains to use for this research. A list of registered businesses in Norway was obtained, using public information from *Brønnøysundregistrene* (Brønnøysundregistrene, 2021). *Brønnøysundregistrene* holds information in the *Enhetsregisteret* (Brønnøysundregistrene, 2020) with basic data on registered commercial enterprises in Norway. Among the information in the *Enhetsregisteret*, there is the option for the enterprises to add their domain names. From the *Enhetsregisteret* (Brønnøysundregistrene, 2020) webpage, a JSON file was downloaded with all the public information on all main units. This file was used as the basis for further processing. The use of this dataset pivoted the initial research from its intention of being cross cutting, to being focused on business related domains.

The JSON file that was downloaded on 30.12.2020 contains a variety of information on enterprises in Norway and provides information of approximately 1 million registered companies. The home page field was extracted from the 1.1 GiB JSON file. This showed that there are 120 107 enterprises with a registered website in the *Enhetsregisteret*. Of the 120 107 websites, there were some that had a different TLD to that of the .NO ccTLD. All the domains that were not .NO were filtered out, and duplicate occurrences were removed from the list. After the list was processed there were 67 115 .NO domains remaining. This is the data set that was used for the remainder of the analysis in this paper.

3.1 Data Collection

The key information required to determine the adoption of DNSSEC for a domain is the presence of DNSKEY and RRSIG DNSKEY records within the domain DNS. When collecting the DNSKEY and the RSIG DNSKEY, it is important to get the information related to this DNSKEY. This includes the domain name, TTL, signature expiration, signature inception, algorithm, RR type and a flags field. The domain name verification to see if it used DNSSEC was done using a Python program developed by the researcher. The program takes the domain name list from the data set and checks if each contains a DNSKEY and if so, it is then verified. To gather the domain data, the program used the Google public DNS servers 8.8.8.8 and 8.8.4.4. Google DNS was chosen as it is independent of both the registrars and ISPs in Norway and it has a high rate limit of 1500 QPS (queries per second) which allowed for relatively quick collection of the dataset.

When initially running data collection using the program, queries for some domain names resulted in the program hanging, and thus collection taking a long time. The flaw was determined to be that the collection program could not resolve some domain names as they had missing information in their DNS records. To resolve the problem, the authors changed the program. The program collected data using two queries. The first collected the SOA (Start of Authority) information and the second collected DNSSEC specific information. If the connection hung and no response was received, the query was terminated after 5 seconds. This was in some cases related to rate limiting by the upstream resolving servers. All errors were logged. To ensure that the problem with getting a response from the DNS server was not just temporary, the domain names that were not answered were retried three times, and only marked as unresolvable if all three attempts failed. The retries were at approximately 24-hour intervals. This solved the problem on a small number of domains as shown in Table 3.

For all the (resolvable) domains in the data set, SOA records were collected. If the domain could be verified using DNSSEC, the program collected the DNSKEYs and the RRSIG DNSKEYs. The initial list of 67 115 .NO domains that were checked and 56 983 were able to be resolved and at least a SOA response received. This is 84% of the .NO ccTLD collected from (Brønnøysundregistrene, 2020). Out of the domains that were possible to query, 60% were determined to be using DNSSEC on the basis of having DNSSEC entries in their DNS zone. The program collected 83 632 DNSKEYs and 68 970 RRSIG DNSKEYs. The number of DNSKEYs and RRSIG DNSKEYs are higher than the domain totals because some domain names have multiple DNSKEY entries within the zone.

Summary data used in this research along with the collection scripts is available at *https://github.com/barryirwin/ICONIC22-NODNSSEC.*

3.2 Extracting known issues

As presented in Chung, Van Rijswijk-Deij, et al. (2017), some registrars share the same cryptographic key in the DNSKEY across multiple domains. To research, whether some of the registrars in the Norwegian ccTLD had shared DNSKEY RRs across domains, a Python program was developed that extracted the DNSKEY from the output of the collector program that did the DNSSEC validation. After extracting the DNSKEY, the program compared to see if there were any duplicates of the DNSKEY. If there were duplicates, then the program counted how many times the duplicate DNSKEY had been used. The DNSKEY values that were found to be shared were further evaluated to find out who they were registered to. Four different registrars were found to show this practice.

One of the best practices for DNSKEY is the signature validity period. Chandramouli and Rose (2013) suggest that the signature validity period should be between two days and one week. To find the signature validity period from the DNSKEYs collected in this report, a further script was developed that finds the signature validity period on the DNSKEY, then sorts by the signature validity period after how long it is since they were generated to their expiration time.

The specific algorithm chosen to be used when generating the DNSKEY is an important aspect that affects the security of the DNSSEC for a domain. Similar to the above, the algorithm used in the different domains were extracted from the DNSKEY file generated by the main program. The number of domains that use different algorithms does not match to the number of domains that use DNSSEC. The former number is higher as some of the domains have multiple DNSKEYs. According to both RFC8624 (Wouters & Surý, 2019) and the NIST guide (Chandramouli & Rose, 2013), all domains should have migrated from the legacy RSA/SHA-1 and RSA/SHA-256 algorithms to the recommended ECDSA or a similar algorithm by September 30th, 2015. This is asserted again in RFC9157 (Hoffman, 2021) in August 2022.

4. Results

The initial purpose of the research was to determine the degree of adoption of DNSSEC, and to be able to validate the number of domains utilising it. Due to the predominant use of UDP as a transport for DNS traffic, and the fact that some domain name servers could be offline, data collection and the enumeration of the input domain list for the collection of DNSSEC related RRs was done over

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Table 3: Domain Data Collection

Run	Error Resolving	DNSSEC Present Yes	DNSSEC Present No
1st run	13592	30757	22766
2nd run	10913	2481	198
3rd run	10279	610	24
4th run	10132	144	3
Combined runs	10132	33992	22991

four sequential runs. While 90% were resolvable in the first run, subsequent runs added around 3000 additional domains - a 10 % improvement on the first collection pass. These runs were done over a period of days, each time inputting the failed list from the prior run. The results of this are summarised in Table 3. The net result is that the 33 992 domains were validated as having DNSSEC related records. This is 60% of the domains that could be resolved - in that a valid response was received from at least one nameserver, and the domain was currently registered as active. Norid (2020a) has a slightly higher percentage of domains that could be validated, but it is just 1% point higher. This shows that the results are representative of the larger .NO domain. One reason that the .NO domain has a higher percentage than reported by other researchers for .SE and .NL may be because the largest registrar in Norway automatically gives their domains a DNSKEY and added them to the domain DS record (Domeneshop, 2021; Norid, 2022b). As most private persons typically use the big registrar as their domain providers, this may give account for the higher adoption rate.

Compared to the findings of Chung, van Rijswijk-Deij, et al. (2017), Le et al. (2018), and Roth et al. (2019) the Norwegian ccTLD has a higher adoption rate of DNSSEC. The results found in this report are collected one and a half year after Roth et al. (2019), so the .SE and .NL ccTLD might have seen an increased adoption rate in this time. There can also be some differences as the Chung, van Rijswijk-Deij, et al. (2017), Le et al. (2018), and Roth et al. (2019) all made use of the OpenINTEL platform to crawl all .SE and .NL ccTLD’s.

When using DNSSEC, the owner of the domain should implement some best practices. Some of the best practices relate to key length, time to live, and uniqueness of DNSKEY. Having the DNSKEY from the verified domains makes it possible to determine the degree to which operators are following best practices. These are discussed below.

4.1 Shared DNSKEY

One recommendation is not to use the same DNSKEY on multiple domains. Chung, Van Rijswijk-Deij, et al. (2017) shows that some registrars reuse the same DNSKEY across multiple different domains under their control, and this is flagged as a potential security risk. Findings in this report show that ten DNSKEY are being used across 1 192 domains. There are only 3.5% of the validated DNSSEC domains that are not following the recommendations, and four registrars shared DNSKEY with multiple domains. Three of the registrars are also present in the Chung, Van Rijswijk-Deij, et al. (2017), and these are loopia.SE, binero.SE and Cloudflare.com, and the last one is box.mailserver.rocks. Sharing DNSKEY’s throw multiple domains are not a security risk in itself. However, a more significant number of domains will be affected if the DNSKEY is compromised if it is used over many different domains. Using the same DNSKEY in many domains will give the operator a more manageable task when managing the DNSKEY’s.

The authors reached out to Cloudflare and specifically Ólafur Guðmundsson, the Engineering director at Cloudflare, Inc. and asked why they used shared DNSKEY’s on their domains. The reply from Ólafur Guðmundsson was, "Strictly speaking there is no extra security gained by using different keys, it only becomes increased cost of operations and increases chances of mistakes." (Johnsen, 2021). The answer suggested that Cloudflare weighs the chances of the DNSKEY to be compromised smaller than the likelihood that there are configuration mistakes made when customers need to manage their own set of DNSKEY. When using the same DNSKEY over multiple domains, the DNSKEY needs to be protected in a good manner so that they do not get compromised. RFC 8901 (Huque et al., 2020) gives the DNS provider guides on how to solve the problem with multiple DNS providers and to use DNSSEC.

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Table 4: Validity period of DNSKEY RRs

Days Valid	# Keys
0 - 7	6
8- 14	570
15 - 30	33067
31 - 60	295
> 60	7

Even if it is a small number, these registrars should follow the recommendations or at least conduct a risk analysis (as appears to be the case with Cloudflare) on the dangers of the DNSKEY to be compromised. There are only four registrars but ten DNSKEY that are shared, because every DNSSEC entry often got two sets of DNSKEY. One of the keys is signed with the zone-signing key (ZSK) and one with the key-signing key (KSK). This was taken into consideration when counting how many domains that were affected by DNSKEY sharing.

4.2 Algorithms and Signature Validity

The signature validity period is the time between the signature expiration and signature inception time when the signature is valid. In Table 4, the signature validity period in the DNSKEYs collected is seen to be mainly between 15 to 30 days. This is a longer signature validity period than recommended in Chandramouli and Rose (2013). Only 576 DNSKEYs are generated for the length of time that Chandramouli and Rose (2013) recommended. The signature validity period is the time period that the DNSKEY is valid in the zone. If the signature validity period is short, then the DNSKEY will needed to be update more often. The signature validity period might be higher than the recommended signature validity period, because it will increase the overhead/cost of the management of DNSKEYs.

Table 5 shows that the algorithm used in some DNSKEYs are not as strong as Chandramouli and Rose (2013) recommended. They highlight the assumption that all DNSSEC has migrated to ECDSA or a similar DNSKEY algorithm by September 30th 2015, as detailed in RFC 6605 (Hoffman & Wijngaards, 2012). The numbers in Table 5 show that some DNSKEYs have not been updated or the operator has chosen not to use a robust encryption algorithm. One possible cause is that there might be some old software that might not support a robust algorithm. Although it is now in excess of five years since the recommended algorithm should have been changed, one would expect this to have been eliminated. No further exploration was undertaken to determine why some DNSKEY are not using a robust algorithm. The most used algorithm and the second most used are as robust as the (Chandramouli & Rose, 2013) recommends. The two most used algorithms cover most of the DNSKEY resource records obtained, with 96% of the DNSKEYs using a strong algorithm. However, there are still 1 533 DNSKEYs using a weak, and thus deprecated algorithm. The recommended algorithms in Table 5 are the algorithms that are marked as **MUST** or higher in the RFC 8624 (Wouters & Surý, 2019).

When it comes to the signature validity period and the strength of the algorithm used, it is hard to say if using a weaker algorithm or a longer signature validity period is more insecure. If the algorithm is weak, but the DNSKEY is changed often the chance of being compromised is not as significant. When choosing how strong the algorithm needs to be there needs to be taken into consideration how long an adversary will take to crack the DNSKEY and how often the DNSKEY is changed and the resources they will need to use. Choosing signature validity period, it is needed to take the same consideration as when choosing an algorithm. As signature validity period and algorithm are dependent on each other to determine how strong the security of the DNSKEY is, it is difficult to determine from the findings in this report if the security is bad in the domains that do not follow best practices.

5. Conclusion

This paper presents a snapshot of the degree of adoption of DNSSEC within the Norwegian ccTLD. The research was carried out on more than 67 thousand Norwegian domains used by commercial entities. The key finding is that 60% of the domains surveyed make use of and were able to be verified using DNSSEC. While we recognise that this is a relatively small portion of the .NO domain overall, the list is deemed to be representative of active domains, given that they have been drawn from the national business register. Reflecting on the results, it would appear that business domains in Norway are ahead of the curve in comparison to other published research. It is recognised that a large part of this may be attributable to the automatic provisioning of DNSSEC and signing of zones by the various registrars at the time of domain provisioning and/or registration. In comparison to other domains like .com, .org and .net it would be preferable to see a higher number as the DNS is the backbone

Table 5: DNSKEY algorithms used

Algorithm	# DNSKEYs	Recommended
ECDSA Curve P-256 with SHA-256	17447	X
Ed25519	15366	X
RSA/SHA-256	6417	X
RSASHA1-NSEC3-SHA1	1527	
ECDSA Curve P-384 with SHA-384	7	X
RSA/SHA-1	5	
RSA/SHA-512	1	

when surfing on the internet. It was found that while some domains had DNSSEC enabled they but did not follow best practice in some areas. The domains that are affected by not following best practices should fix the problem. However, it is not certain that these practices affect the security of the DNSKEYs.

5.1 Future Work

It would be interesting for future work to see how the adoption rate of DNSSEC evolves in the Norwegian ccTLD through time. This would be dependent on having access to a reliable and hopefully expanded list of domains. An area of particular interest would be to undertake a longer term study into the domains that do not follow best practise to see if it affects the security of the DNSKEY and see if there are any changes in the number of domains that are not following best practices. When best practice is not followed, it would be interesting to reach out to the domain owner and determine why they are not using the best practice, possibly best coordinated though national bodies such as the Norwegian National Cyber Security Centre (NCSC), or even sector specific CSIRTs or industry fora.

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Exploring the Intelligent Attributes of Industrial 4.0: The Next Revolution and Beyond

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Abstract
Industry 4.0 places a strong emphasis on connection, automation, machine learning and real-time data. With these descriptions, intelligent/smart manufacturing that incorporates people, technology, and other resources has undergone a significant revolution leading the globe to the new era of Industry 5.0. Responding to disruption by employing intuition to decide what to do in a changing circumstance has grown to be highly attractive and exciting, even when it has never been utilized before. The domains of modern intelligent systems and computers have also made major strides in recent years. Examples include soft computing, computational intelligence, which encompasses evolutionary computing, neural networks, fuzzy systems, and the fusion of various paradigms. Others include immune-based systems, ambient intelligence, cognitive science, computational neuroscience and systems, perspective and vision, DNA, intelligent decision-making, and support etc. This technological breakthrough has also made room for new and emerging technologies that offer important advantages including extreme low latency, highly reliable connections, sufficient bandwidth, ample data storage, and powerful processing capabilities. This paper provides a comprehensive overview of what smart/intelligent systems include, as was observed in an ongoing project where such devices were designed, and what to anticipate from the 4.0, 5.0, and 6.0 industrial revolutions.

Keywords: Artificial Narrow Intelligence (ANI), Artificial General Intelligence (AGI), Artificial Super-Intelligence (ASI), Design Performance Measurement (DPM), General purpose technologies (GPTs).

1. Introduction

Intelligent systems include highly developed machines that can perceive their environment and react to it. They are systems with the capacities to compute, reason, recognize connections and analogies, learn from experience, memorize and access information, solve problems, comprehend complicated concepts, speak fluently in natural language, generalize, classify, and adapt to changing circumstances. Intelligent systems come in a variety of shapes and sizes, including autonomous vacuums like the iRobot, Amazon's customized shopping recommendations, facial recognition software, etc. The three different forms of intelligent systems are: Artificial Narrow Intelligence (ANI) which has a constrained set of skills, Artificial General Intelligence (AGI) which is on par with human abilities and Artificial Super-Intelligence (ASI) which is more intelligent than humans (Mokesioluwa et al. 2021; Sawangsri et al. 2018).

At this stage, it's crucial to think about the distinction between a smart system and an intelligent system. Since the two adjectives seem to be equivalent, many people do not distinguish between smart and intelligent. However, there are differences in the use and meaning of these words. Smart systems can be used to draw conclusions from knowledge, such as when making business or emotional decisions. It takes work to become smart.

Intelligent systems are highly developed machines that can perceive their environment and react to it. Can a system have both qualities? To that, I say YES. The idea of designing systems that are smart and intelligent isn't too far-fetched in this era of the fourth industrial revolution (it includes: 3D printing, digital platforms,

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augmented and virtual reality, big data (BD), internet of things (IoT) and artificial intelligence (AI)) or even the fifth industrial revolution as will be the case soon (Shrey et al. 2021; Ozdemir, 2018; Gandomi et al. 2015; Dai et al. 2020). With the advent of automation technologies, IoT, and the smart factory, Industry 4.0 was born. Industry 5.0 advances by utilizing the synergy between ever-more precise and powerful machinery and the distinctive creative capacity of the human being. Nanotechnology, quantum computing, biotechnology and artificial intelligence are examples of general-purpose technologies (GPTs) for the sixth industrial revolution (Bader et al. 2016; Kiran et al. 2020).

Industry 4.0 focuses on connectivity via cyber-physical systems, whereas Industry 5.0 is in line with the platforms that Industry 4.0 has made feasible (Dai et al. 2020). It also discusses how “man and machine,” usually referred to as robots or cobots, interact. We are becoming more reliant on Industry 4.0 technologies, which are bringing about the fifth industrial revolution in unexpected ways. These technologies: big data (BD), artificial intelligence (AI), digital platforms, the internet of things (IoT), augmented and virtual reality, and 3D printing and lots more are included. According to (Ozdemir, 2018, Anawar et al. 2018, and Piccialli et al. 2018), this connectedness entails the idea of harmonious human-machine cooperation with a concern on the satisfaction of the many stakeholders (i.e., employees, society, businesses, and customers). This paper covers the aspect of the intricate design features of smart devices (imagery sensors features, how to avoid loss of data during transmission to data process units via the use of recent queuing techniques, expected features to watch out for and expected postulate in the new emerging industrial revolution) of a just concluded design work on smart devices design needed in a unique segment of smart city design just covered.

This paper proceeds as follows. Section 1 covers the introduction. Section 2 describes the process of building an intelligent system, while section 3 relates the important features and characteristics of an intelligent system. Section 4 is on smart/Intelligent system queuing strategies applications. Industry 5.0 & 6.0 and the World Beyond with its expectation perspective was addressed in section 5, and Section 6 provides the conclusions.

2. Building an Intelligent System

The first area of consideration should be implementation; we need to be able to focus all our abilities on this to execute, manage, and evaluate the intelligence practically. The second step is to create, which typically entails designing using a variety of methods, including machine learning. The final step is to orchestrate, which frequently entails bringing the components together throughout the project's life cycle and producing the desired result. In this paper, we'll pay greater attention to how an intelligent system can be created. However, this uses machine learning knowledge heavily. Deep learning is part of this focus area (Dargan et al. 2019; Mokesioluwa et al. 2021; Sawangsri et al. 2018).

Learning techniques are deep neural network with intricate architecture that attempt to precisely estimate the ideas and locations of objects in each image as well as sort various images. Deep neural networks can be compared to deep models. The development of intelligent smart systems was launched with the introduction of Design Performance Measurement (DPM). It is a versatile approach for merging object components with distortion cost to manage extreme deformations. In DPM, part decompositions and carefully crafted low-level characteristics are merged with the help of a graphical model. However, shallow learnable architectures and discriminant local feature descriptors are evolving.

With PASCAL VOC object identification competition, state-of-the-art discoveries then emerged thus with reduced hardware need, real-time embedded systems were obtained. Small advancements were made between 2010 and 2012, though, using solely ensemble systems and slight iterations of proven techniques. Due to the necessity of Deep Neural Networks (DNNs), the introduction of Regions with CNN features (R-CNN) also resulted in a more significant increase (Zhong-Qiu et al. 2019; Woschank et al. 2020).

Faster R-CNN, which uses a second subnetwork to generate region proposals, and YOLO that performs object detection using a fixed-grid regression, are improved models which have been proposed since the release of R-CNN. Fast R-CNN simultaneously optimizes classification and bounding box regression tasks. Very deep neural networks can be trained relatively effectively with batch normalization (BN). While

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this is going on, numerous network architectures, including Overfeat, AlexNet, VGG, ResNet and GoogleLeNet, have been thoroughly researched to boost performance. To varied degrees, they all improve detection performance over the fundamental R-CNN, increasing the viability of real-time and accurate object detection (Szegedy et al. 2015).

Identifying the locations of items in an image (object localization), as well as the category to which each object belongs, constitutes one of the core computer vision tasks (object classification). Feature extraction, informational region selection and classification are the three steps in the pipeline for traditional object detection models. The capacity to convey knowledge that is significant for semantic understanding of images and videos makes object detection relevant to a wide range of applications, including face recognition, image categorization, human behavior analysis and autonomous driving. But even with an additional item localization assignment, it's challenging to precisely complete object detection because of the wide range of views, positions, occlusions, and lighting conditions. In recent years, this field has drawn a lot of interest (Li et al. 2014; Zhang et al. 2020).

Generic object recognition using bounding box regression and salient object detection using local contrast enhancement and pixel-level segmentation are the two main areas of focus for object detection in smart intelligent systems. Both are based on fundamental CNN architectures.

The essential components of a generic object detection system can be divided into two groups, namely the classic object detection pipeline, which prior to classifying each proposal into different item classes first creates region recommendations. Fast R-CNN, R-CNN, Faster R-CNN, SPP-net, FPN, R-FCN and Mask R-CNN are the main region proposal-based approaches. Some of these techniques are connected to one another (e.g., SPP-net modifies RCNN with a SPP layer). The second method employs a unified framework to rapidly arrive at the desired results (categories and locations) and views object identification as a problem of regression or classification. The main algorithms used in regression classification include AttentionNet, MultiBox, YOLO, G-CNN, SSD, DSSD, DSOD and YOLOv2. The anchors included in Faster R-CNN provide a link between the correlations between these two pipelines (Tom'e et al. 2016).

It is crucial to note that, for a smart intelligent complex system application, the employment of both conventional object detection and regression (or classification) based object detection is absolutely necessary and unavoidable (for security control terminals, smart labels, intelligent detection units and smart devices), as well as their appropriate placement of application within the smart complex system network, which is believed to be of utmost importance. This is true because each has benefits and drawbacks. The structure used typically with this framework is shown in Figure 1.

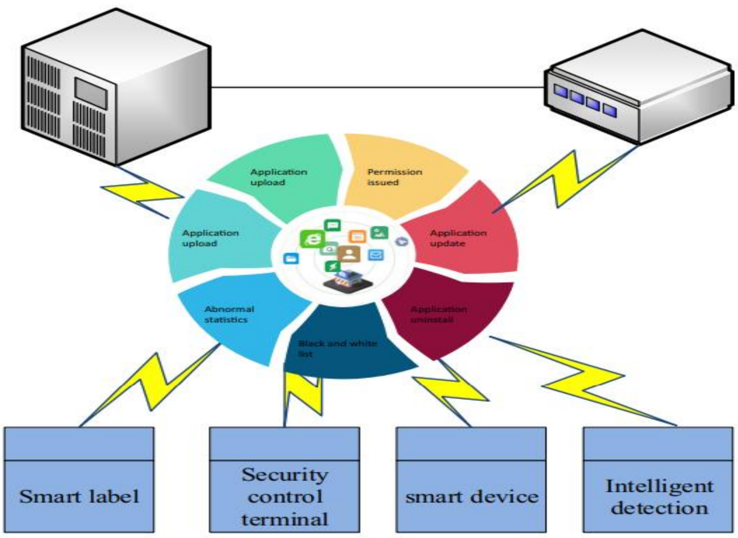

Fig 1. Trend framework with IoTs in an intelligent system (Dandan et al., 2020)

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It is crucial to design these devices and Iots of the most recent smart intelligent system solely on the most recent regression/classification-based technologies. This is because end users' gadgets, including Internet of things (Iots), smart devices, are made to operate on region proposal based deep neural layer structures networks and on salient object detection methods (including shallow neural layer structure networks such as; semantic segmentation, yolo etc.. networks and salient object detection methods such as; R FCN, Mask R-CNN, FPN, CNN etc.) with the most recent significant Object detection methods based networks which may then be deployed on them based on their unique qualities that cannot be overemphasized here, for speedy and effective output findings that can subsequently be transferred via intelligent network architectures to gigantic processing units (Li et al. 2014 and Li et al. 2017). Regardless of how the region proposal is formed during the training of all network layers, Fast R-CNN can be processed under the region recommended based application in a single step with a multi-task loss. While increasing accuracy and efficiency with more rational training approaches, it lowers the cost of additional storage space. For the most part, modern object detection networks use additional methods like Edgebox and selective search to generate a candidate pool of isolated region recommendations. The computation of region proposals likewise has limitations on its utility. (Anawar et al. 2018) created the Region Proposal Network (RPN) which is a second region proposal network, to address this issue. The RPN works in a relatively cost-free manner with the detection network to share full-image convolution features.

A fully-convolutional network that can simultaneously predict item boundaries and scores at each point is employed to achieve RPN. Similar to this, RPN generates a list of probable ideas for rectangular objects from an image of any size. While RPN utilizes a particular communication layer, object detection network utilizes the layers that came before it (Eigen et al. 2015; Zhang et al. 2020).

While the most recent evolution emerging under the regression/classification-based category tends to involve low computational time, in the regional proposal basis category the layers of structure engaged in the network might range into the hundreds. These characteristics, to name just a few, are crucial to the creation of intelligent systems as shown below (Tom'e et al. 2016). An intelligent system network is depicted pictorially in Figure 2.

Fig 2. An intelligent system network (https://www.istockphoto.com/vector/smart-city-gm1260560206-369164722)

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3. Important Features and Characteristics of an Intelligent System

The crucial traits that an intelligent system frequently demonstrates include (Woschank et al. 2020; Huang et al. 2017; Pinheiro et al. 2015):

1. The ability to simulate and emulate in-close-to real-time: A simulator builds an environment that mimics the behaviors, variables, and configurations found in a real-time production environment, whereas an emulator simulates all the hardware and software features for a real device's production environment.

2. Automated learning and machine learning functionality refer to the process of automating the processes involved in applying machine learning to address real-world problems. AutoML may cover any step in between, from starting with a blank dataset to producing a machine learning model that is ready for deployment. It is a method of artificial intelligence that draws inferences from data.

3. Digital feedback loops that affect product development: Feedback loops are situations in which knowledge of an action's results is utilized to modify a future action. Digital technology, which is widely utilized to collect feedback data due to its speed and reach, supports the process of digital feedback loops.

4. Based on algorithms and sensory data, the external environment has a physical impact on our subjective senses (raw sensory stimuli), which are then selectively filtered through the supposedly five senses of sight, smell, touch, taste, and sound. These five senses are frequently used as the foundation for sensory algorithms.

5. Cloud-based personalized device experience: Big data, which is currently produced globally on an hourly basis and from which conclusions may be drawn to study or learn, analyze systems, predict future events and recommend viable solutions, has driven the development of cloud computing and storage.

6. Task adaptation based on reprogramming through the cloud: In this age, where task operations are carried out at accelerating high speeds, cloud engines freely available in the cloud (satellite) make massive data processing incredibly simple and effective. Results that used to take a few days or months to come by can now be obtained in a matter of seconds.

7. The capacity to foresee pressures and failures: Unlike in the past, when specific work types and characteristics were not quantifiable, such task parameters are now measurable with thanks to the recent development of psychological models. Intelligent systems can now carry out behavioral tasks that were previously challenging for machines or robots to replicate.

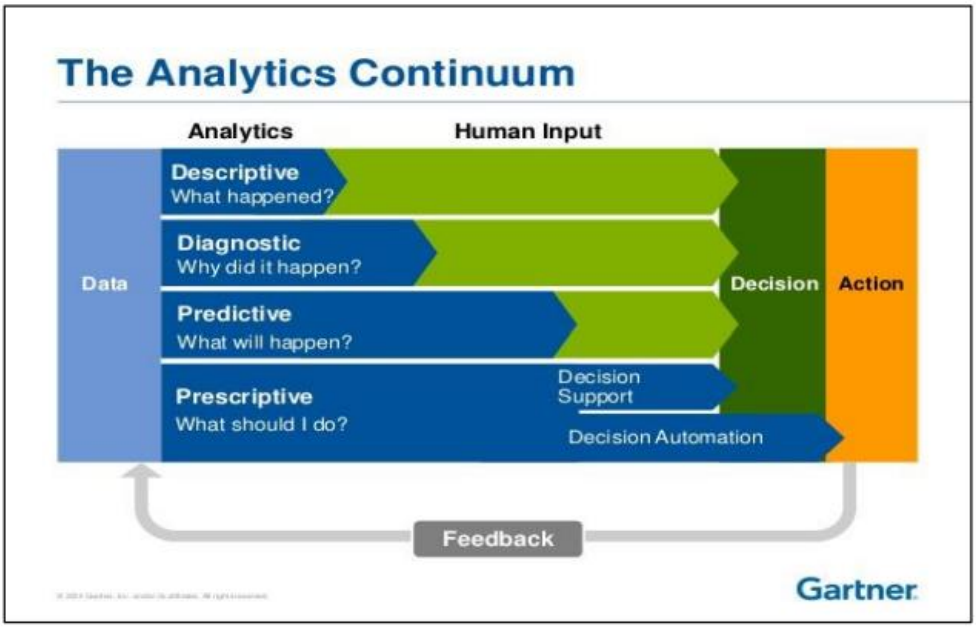

Fig 3. Digital Feed Back Loop of an intelligent system (Itisha et al., 2020)

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8. Event detection and resolution: A challenging vision challenge is high-speed target recognition in low light, low Signal-to-Noise Ratio (SNR) circumstances, with high accuracy requirements and complex scene dynamics. This is due to the difficulty in detecting and resolving events caused by stochastic atmospheric processes, which typically involve clouds. A good intelligent system must be able to successfully address this problem.

9. Complete automation: We are slowly advancing toward a time when complex tasks will be entirely automated. The introduction of autonomous vehicles is an illustration of this in the age of the fourth industrial revolution. Due to the full-scale deployment of the 5G network, traffic systems will soon be fully automated and managed by computers.

10. A region is said to have an ecosystem when there is a haze of life produced by plants, animals, and other organisms interacting with the environment, weather, and other variables. Ecosystems contain both biotic and abiotic factors or living and nonliving elements. Species such as plants, animals and others are biotic forces. Most ecosystems around us today are artificial. Ecosystems for smart houses are example. Google Home, Apple HomeKit, Samsung SmartThings, and Amazon Echo are the top smart home ecosystems.

11. Workflow platform for real-time collaboration: Real-time collaboration simply refers to people working together at the same time, even if they are in separate locations. The goal of a collaborative platform is to facilitate communication and interpersonal contact in corporate project work. It is a virtual workspace where resources and tools are centralized.

4. Smart/Intelligent System Queuing Strategies Applications

Since their introduction, queuing theories and methodologies have been widely utilized to examine computer, logistic, telecommunication, manufacturing systems and transportation (traffic flow). However, most systems are still constrained by its shortcomings. These drawbacks include: being difficult to comprehend and being complex; theoretical distribution applications frequently developed to specific queuing conditions are more frequently unknown; and queuing difficulties typically become more challenging if the "first in, first out" principle is not followed. The importance of these issues in the design of smart devices, IoTs and in system integration cannot be overstated because of the rapid advancement of technology.

Intelligent systems (including smart devices and target workstations processing units) must be made to function with current queuing models in the 4^{th} and 5^{th} industrial revolutions and beyond, where the speed of data transmission, collection and sizes are tending towards microns seconds and in Giga bytes respectively, to prevent the loss of sensitive data or information (Evjemo et al. 2002; Anawar et al. 2018; Dandan et al. 2020).

The queuing discipline (rules for adding and removing consumers to/from the queue) describes how the queue is set up. Among these ways are:

1) FCFS (First Come First Serve), often known as FIFO (First In-First Out), is an ordered queue.

2) Stacking with Last In-First Out (LIFO), is also referred to as LCFS (Last Come First Serve).

3) SIRO (Serve In-Random Order).

4) The priority queue, which is a group of queues with various priorities.

5) There are numerous, more intricate queuing strategies that frequently modify the position of the consumer in the queue in accordance with how long they have been waiting, how long the service is expected to take and/or their priority. Most computer multi-access systems use these techniques.

M/M/1, M/M/c, M/G/1 and G/M/1 are a few examples of modern queuing models that are the center of interest in conventional queuing systems.

A queuing system is described using a unique language called Kendall's notation. A/B/c/K is the form of the notation.

A: explains the distribution of inter-arrival times.

B: the distribution of service time

c: the quantity of servers.

K is the system capacity's size (including the servers). The standard abbreviations for A and B

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are M for Markov's exponential distribution and D for deterministic distribution. G stands for general application. When the symbol A/B/c is used then the system capacity is limitless (K = 1).

To make things easier to comprehend, the M/M/1 queue defines the size of the queue in a system with a single server, where arrivals are controlled by a Poisson process and task service times have an exponential distribution. This queuing system finds great application in smart city network architect. Since, many of its important metrics can be represented in closed form. The model, which is the most fundamental of all queuing models, is intriguing to examine.

The current trend in technology is data processing, which uses processors that can be understood as servers when compared to queuing systems. It is crucial to frequently use queuing techniques when interacting with these servers as a unit (processors). A lot of research is being done on queuing and how it may be used for data processing, one example is as found with the FreeRTOS Queue code readily available.

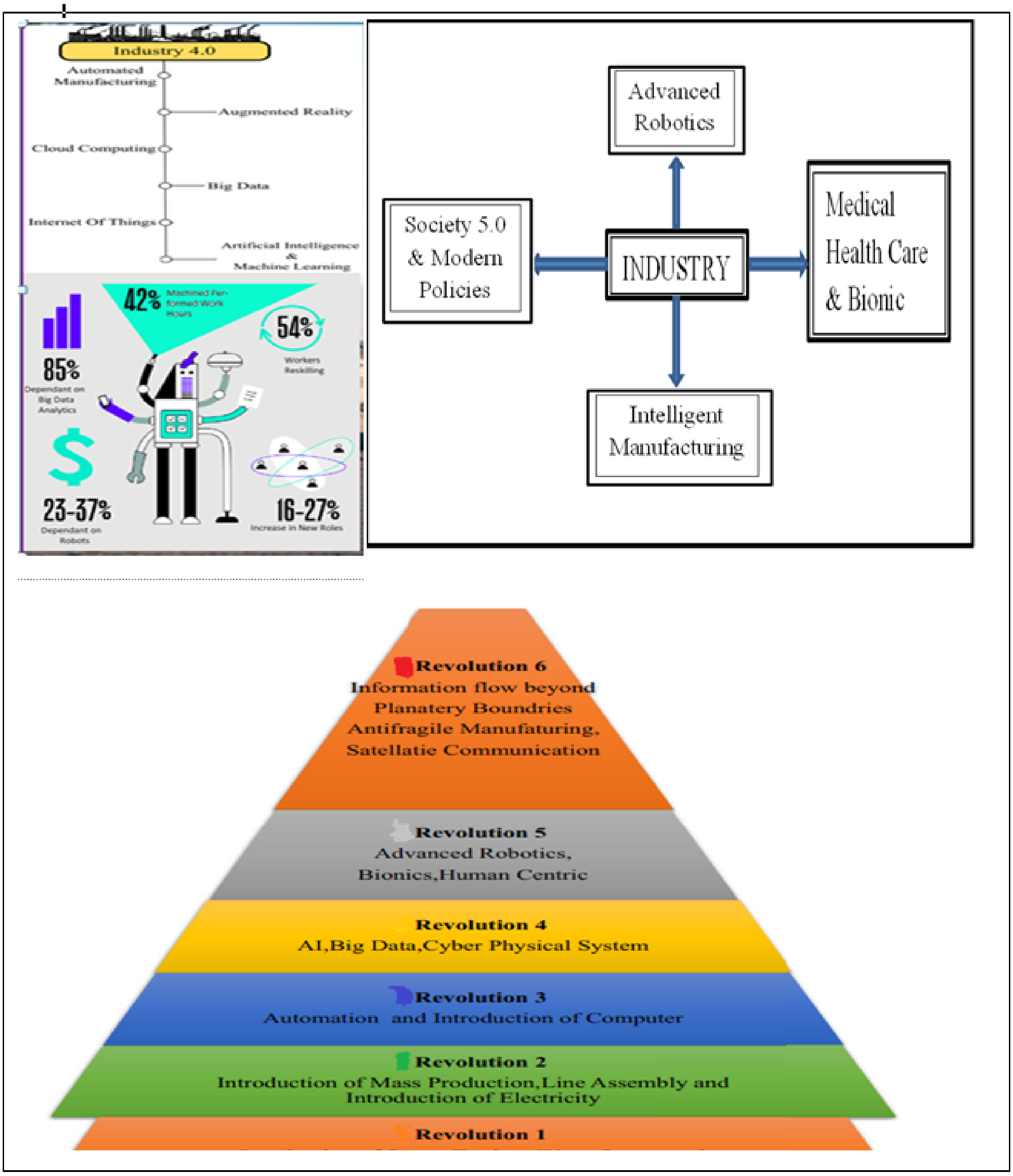

Figure 4. Trends of the Industrial Revolution from 4.0 to 6.0 (Itisha et al., 2020; Chourasia et al., 2022)

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5. Industry 5.0 & 6.0 and the World Beyond with its Expectations

It is claimed that Industry 5.0 will benefit businesses, employees, and society as a whole. It has a great chance of empowering people and addressing their changing training and skill requirements. Additionally, it will make the sector more competitive and aid in luring the top people. The Industrial Revolution trend is depicted in Figure 4 below. Fields and regions that will greatly benefit when the revolution progresses past version 4.0 includes the follwoing (Huang et al. 2017; Wollschlaeger et al. 2017; Glassman et al. 2014):

1. Improvements in the usage of machine online analysis: With the advent of industrial revolution 5.0 to 6.0, machine designers will abandon big data (BD) and offline analysis for machine (condition base) maintenance. Its' technology will basically utilize small data, which will enable better machine fault detection and prediction (preferably known as online analysis). Instantaneous data collection as the machine is utilized will enable this technique of analysis.

2. Geographical exploration: Significant progress will be achieved in this area. Unthinkable feats that enhance astronomy will be accomplished. With the likelihood of the development of advanced machinery and equipment in this field, this will be made possible.

3. Developments in defense: Already in the recent era of the 4.0 Industrial Revolutions, the defense industry has made great strides thanks to the development of sophisticated tools for long-range missiles to been launched effectively and accurately. This is only the beginning, as more potent super ballistic missiles and machines will enter the market with the arrival of the 5.0 and 6.0 Industrial Revolutions (Bistron et al. 2021).

4. Advanced Communication System: Satellite communication is the most recent technological development in the communication sector. Over the years, satellites have been utilized for a wide range of activities, such as radio communications, weather forecasting, mapping, earth observation and many more. The satellite communication bands often includes; Ku-band (12-18 GHz), C-band (4-8 GHz), S-band (2-4 GHz), X-band (8-12 GHz) and Ka-band (26–40 GHz). The 60 GHz bands' enormous bandwidth has been welcomed as being suitable for the transfer of very large amounts of data, even though millimeter-wave frequency bands have been investigated and defined for use in satellite communications. Due to the availability of 5 to 7 GHz of bandwidth and the advantage revealed in the fundamental relationship between antenna size and signal wavelength in satellite communication, gigabit data rates can be easily accommodated with relatively simple radio structures toward gigabit communication. We're in this position right now. However, highly efficient and effective smart antennas for satellite communications are bound to be developed during the 5.0 and 6.0 Industrial Revolutions.

5. With the arrival of the 5.0 and 6.0 Industrial revolution, space flight and travels will see a major explosion. The functionality and designs of spacecraft will undergo significant advancement, and flight times will be cut.

6. Medicine: The development of machine learning and artificial intelligence will have a positive impact on our understanding of the chemistry of medicine. In the medical industry, the usage of hybrid smart, intelligent gadgets that can detect, predict, and suggest treatments for illnesses will be widely used. Additionally, these gadgets will be able to do online diagnostics quickly due to the utilization of small data.

Postulates to the Emergence of 6.0 Industrial Revolution (Hybrid Smart Intelligent) Systems

Current developments in the emergence of the fifth into the sixth industrial revolution, (i.e., extending into the start of the 6.0 industrial revolution) point to the possibility that it will begin within this decade, possibly in the latter five years of the 2025 to 2030s. The fifth industrial revolution will pass quickly, giving way to industrial 6.0, which is crucially transitioning from micrometer-scale to nanometer-scale gadgets (Sartal et al. 2020). There will be a strong emphasis towards the development of automated mechanisms and the pursuit of manufacturing process excellence thereby, focusing its acceptance of technology developments to be based on the use of small data sets and the harmonization of processes around best practices. Its procedure will support existing high value chains and end-to-end engineering integration. End-to-end engineering will result in increased reliability, lower costs, safety, reusability, and sustainability for product integration (Bechtsis et al. 2018; Sukhbaatar et al. 2015).

6. Conclusions

This article is focused on how the industrial revolution has evolved. The history of the industrial revolutions and the integrity involved with the related components needed to guide the construction of its systems, were first covered in the article. It predicted the emergence of hybrid intelligent and smart gadgets with skills and functionalities that extend beyond what we can now observe, and also dealt with Artificial Super-Intelligence (ASI), which is superior to human intelligence. The sixth industrial revolution will see a crucial transition from micrometer size to nano-scale devices, according to the postulate given here about what to anticipate in that revolution. Additionally, it emphasized how the 6.0 Industrial Revolution will completely do away with the usage of big data for machine analysis in favor of employing small data, which would advance online machine analysis. Sensitive design aspects, such as the use of advance queuing theorems for intelligent systems were also taken into consideration. The time frame within which these occurrences are most likely to occur was also in focus.

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A Bridge to Machine Learning for Zero Computer Science Community: A Machine Learning Path with Linear Regression

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Abstract
Based on LinkedIn poll results, professionals from non-computer science backgrounds have developed an interest in data science and most intend to enter the field through Machine Learning, but do not know where to start (Webb et al., 2021) The aim of this study is to introduce an ideal systematic approach and workflow to get started with Machine Learning. Since the Linear Regression algorithm is the main algorithm used to introduce the concept of Machine Learning, it was chosen for this study to lay a fundamental platform. Using the proposed algorithm and appropriate python libraries, efficient methods of explanatory data analysis and procedural steps towards model training are also explained. Briefly, this study gives an insight on how to approach other Machine Learning algorithms as well. The first steps in Machine Learning involve data pre-processing. The dataset was chosen to meet data manipulation techniques suitable for people without a computer science background.

Keywords: Python, Regression, Scikit-learn, Machine Learning, LinkedIn.

1. Introduction

Machine Learning (ML) is an area of Artificial Intelligence (AI) where data plays an important part when used with ML algorithms to make predictions. Simply put, ML is the process of constructing machines for accessing data, applying algorithms to that data and then practice inferring valuable information from those underlying data sets. Big business companies and institutions rely on ML algorithms for their improved profits and management of budgets. Since ML is applicable in any field, if there are data available, everyone became interested in learning ML. However, some of the ML newbies are always faced with a problem of getting started after they had learned the theory behind this field. This study aims to introduce a systematic approach and workflow to the development of ML projects. The proposed systematic approach was implemented by choosing a dataset that met the skill level of the targeted audience. The overall structure of this paper takes the form of five sections, including this introductory section. Section II of this paper reviews the literature of ML's areas of application. The third section is concerned with the methodology used in this study. The fourth section focuses on how to present the results by using the proposed systematic approach, focusing on the predicted results when compared against the test data set. The results are discussed in Section 5. Finally, the conclusion gives a summary in Section 6.

2. Related Works

According to (Shinde and Shah, 2018), AI is about making machines to be as smart as human beings. In computer science, AI means the study of "Intelligent Agents": any device that perceives its environment and takes action that maximizes its chances of achieving its goals. This means AI devices involve "Learning" and "Problem Solving" to achieve their goals. Advancements in AI were made, and that made ML to be not the only subfield of AI, as Deep Learning (DL) was later discovered. DL involves the use of artificial neural networks, and the word "Deep Learning" emanated from the depth of neuron layers in the neural network (Shinde and Shah, 2018). The deep network has more than one hidden layer, while a shallower network has only one. Figure 1 shows the summary of AI and its subfields. This section reviews the application of AI subfields

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(ML and DL). The review will be limited to business applications for the sake of accommodating the type of the data sets that were chosen for this study. There is a plethora of evidence in the literature that ML was used in business applications.

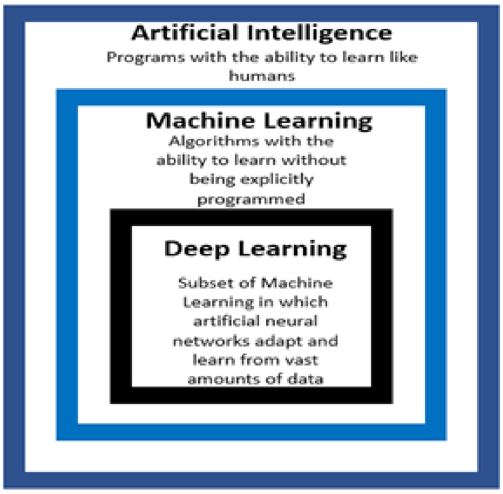

Figure 1. Summary of AI and its subfields

For instance, (Bose and Mahapatra,2001) made early endeavors to use ML in business institutions were made by authors such as Bose and Mahapatra, who wrote a paper to inform information systems (IS) managers and business analysts about the role of machine learning techniques in business data mining. The trend of using ML in business applications grew until researchers such as (Shaaban et al., 2012). developed a ML churn model that could detect customers who intended to leave a service provider. Similar churning models were developed by researchers such as (Kolomiiets et al., 2021, Ahn et al.,2020, and Mustafa et al., 2021). ML also found an application in business and institution departments that deals with budgeting (Jang, 2019).

This was after successful research works by researchers such as Jang, who were able to use ML for budgeting purposes. In his work, (Jang, 2019) used ML in assisting government funding agencies to make decisions on research and development (R&D) budget allocation to support an increasing number of research proposals. Among many ML budget applications available in the literature, the latest involved the works of researchers who used ML for budget-related applications in the COVID-19 pandemic. For instance, (Nguyen et al., 2021) leveraged electronic health record (HER) data to develop an ML-based tool for predicting adverse outcomes that optimizes clinical utility under a given cost structure. A large and growing body of literature has investigated the use of ML in price predictions. More recent attention has focused on the use of ML in price predictions for stock, houses, and Bitcoin. For instance, researchers such as (Vijh et al., 2020) used ML algorithms to predict the stock closing price. In the literature, there is evidence that house prices were predicted by means of ML algorithms (Zulkifley et al., 2020 and Varma et al.,2018). Since the era of Bitcoin, a plethora of Bitcoin related data has been readily available. This enabled researchers, such as (Demir et al.,2019), and (Loh and Ismail,2020) to use ML algorithms for Bitcoin price predictions. Fraud is the main factor affecting any business development. Due to that, companies have massively invested in the prevention of fraud by any means necessary.

However, ML has proven to be the best tool that most researchers used in the prevention of serious fraud cases, such as credit cards. In the literature, there is evidence that several researchers, such as (Dornadula and Geetha,2019) and (Maniraj et al.,2019) have used ML algorithms for credit card fraud detection. The latter mentioned that ML applications require a skilled data scientist to become possible. Some ML enthusiasts developed an interest in ML engineering after they specialized in their fields. Their endeavors to make the career switch have not been easy for many as the ML field is found in most Computer Science syllabi. Researchers such as (Jordan, M and Mitchell, 2015), covered the trends, perspectives, and prospects of ML in their study. However, in the literature, there is no evidence of research papers that aim to introduce the strategic implementation of end-to-end ML projects. This study aims to introduce a systematic approach to the development of end-to-end Machine Learning projects in Python. This systematic approach is presented in the Methodology section using data sets that were downloaded from the Kaggle website (Kiehn, 2019, Bojer and Meldgaard, 2021, Tauchert et al., 2020 and Carpita et al., 2019). In the literature, there is evidence that the Kaggle dataset was used by other researchers to develop ML models that predicted real world scenarios.

3. Methodology

A standard personal computer (PC) with Windows operating system is ideal for the

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development of ML projects. ML, when developed in the Python programming language, a plethora of dependencies must first be installed in the PC. To make sure that all these dependencies are installed, most data science practitioners install a package called Anaconda. It is advised that Anaconda be installed before attempting any ML problem to be solved in a Python integrated learning environment (IDE). Figure 2 shows the steps to be followed from Anaconda installation to opening Jupyter as a Python IDE.

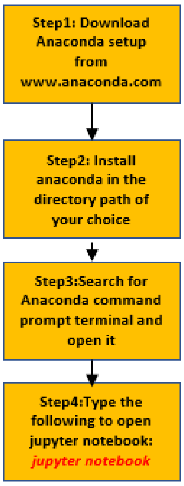

Figure 2. Anaconda package installation guidelines.

A. Data Analysis

There are seven steps that any ML practitioner must follow to understand their data to get the best results. To illuminate this uncharted area, we used the USA housing dataset available in Kaggle. The USA housing dataset is available by accessing the link, which leads to Kaggle https://www.kaggle.com/vedavyasv/usahousing The next seven sections explain how the ML practitioners must understand their data to get the best results.

I. Peeking at your data

The examination of the data may bring ideas that cannot be obtained otherwise. One of the benefits of peeking at the dataset is to plant seeds that may later grow into ideas on how to better pre-process and handle the data for ML tasks. Using the latter data set, the first five rows of the data set were examined using the head () function of the Pandas Data Frame. Figure.3 shows the results of the head () function on the USA housing dataset chosen for this study.

	Avg. Area Income	Avg. Area House Age		Price
0	79545.458574	5.682861		1.059034e+06
1	79248.642455	6.002900		1.505891e+06
2	61287.067179	5.865890	•••••	1.058988e+06
3	63345.240046	7.188236		1.260617e+06
4	59982.197226	5.040555		6.309435e+05

Figure 3. Data Frame results of the head () Panda's function.

In the same way, the tail () function on the Pandas Data Frame was used to understand how many data entries there were in the dataset as the data was reviewed, showing the last five data entries. Since Python indexing starts from index 0, it then means that the USA housing dataset contains 5000 entries as the last entry in the dataset was at index 4999.

II. Data Dimensionality

ML practitioners must have a good handle on how much data they have, both in terms of rows and columns. This is important because a data set with too many features can result in some ML algorithms being distracted or suffering from poor performance due to the dimensional curse. The shape and size of the dataset can be reviewed by printing the shape property (df. shape) on the Pandas Data Frame. The shape property was used on the USA housing dataset chosen in this study and resulted to (5000, 7).

III. Attribute/Feature Data type

The type of each attribute/feature is important. Strings may require conversion to floating-point values or integers to represent categorical or ordinal values. One can get a sense of the attribute types by looking at the raw data using the dtypes property on Data Frame (df. dtypes). Figure 4 shows the results of using the dtypes property on our USA housing dataset.

```
Avg. Area Income                float64
Avg. Area House Age             float64
Avg. Area Number of Rooms       float64
Avg. Area Number of Bedrooms    float64
Area Population                 float64
Price                           float64
Address                          object
dtype: object
```

Figure 4. Attribute datatypes of the USA housing dataset.

ISBN: 978-99949-0-888-2

VI. Descriptive Statistics

Descriptive statistics can provide one with an excellent sense of the shape of each attribute. More summaries than one has time to review, can be created often. Pandas Data Frame's describe () function lists eight statistics properties of each attribute as follows.

- Count.
- Mean.
- Standard Deviation.
- Minimum Value.
- 25th Percentile.
- 50th Percentile (Median).
- 75th Percentile.
- Maximum Value.

When one describes one's data in this way, it is worth taking the time to look at the observations of the results. In the same way, the describe () method was used for statistical analysis in the USA housing dataset that was used in this study. The 25th percentile is the value where 25 per cent of responses are lower than this value, and 75 per cent of responses are higher than this value. The fiftieth percentile is also referred to as the median. The median cuts the dataset by 50 per cent. Half of the responses are less than the median, and the other half is more than the median. The 75th percentile is also understood to be the third, or upper, quartile. The 75th percentile is the value at which 25 per cent of the responses are over this value, and 75 per cent of the responses are below. Figure. 5 shows the plot of descriptive statistics that was generated from the USA dataset.

	Avg. Area Income	Avg. Area House Age		Price
count	5000.000000	5000.000000		5.000000e+03
mean	68583.108984	5.977222		1.232073e+06
std	10657.991214	0.991456		3.531176e+05
min	17796.631190	2.644304	.....	1.593866e+04
25%	61480.562388	5.322283		9.975771e+05
50%	68804.286404	5.970429		1.232669e+06
75%	75783.338666	6.650808		1.471210e+06
max	107701.748378	9.519088		2.469066e+06

Figure 5. Descriptive statistical analysis of the USA dataset.

V. Correlations between Attributes/Features

Correlation is the relationship between two variables, and a way in which they can or cannot change. The most used method for calculating correlation is the Pearson correlation coefficient, which assumes a normal distribution of the relevant attributes. A relation of -1 or 1 denotes a total negative or positive relation, respectively. In contrast, a value of zero shows no correlation. Some machine learning algorithms, such as linear regression and logistics, can experience poor performance if there are highly correlated attributes in the dataset. Therefore, it is recommended to look at all the correlations by attributing pairs in the data set. The corr () function can be used in Pandas Data Frame to calculate correlation matrix. In the US housing dataset used in this study, the corr () function was used within the Seaborn's heatmap function to generate the heat map that describes the correlation between variables as shown in Figure 6.

Figure 6. A heat map to show feature correlation.

B. Model Selection

Since, in this study, a regression problem was to be investigated, all the regression algorithms were tested against the dataset using a K-fold cross validation method to select the best model. This implies that the first step to implementing any ML project is model selection. In this study, a USA housing dataset that is available at Kaggle https://www.kaggle.com/vedavyasv/usa-housing was used to address the aim of this study.

Kaggle is a dataset repository that many learning machine enthusiasts and practitioners consult for a variety of datasets. The available datasets are both numeric and image datasets. In this study, a numeric dataset in the comma separated value

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(CSV) format was chosen. Figure 7 shows how model selection is performed.

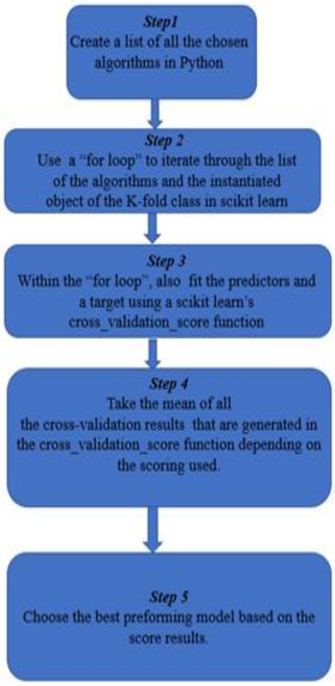

Figure 7. The procedure for selecting ML best model

Figure 8 shows the performance of six regression algorithms that were used to select the best performing model.

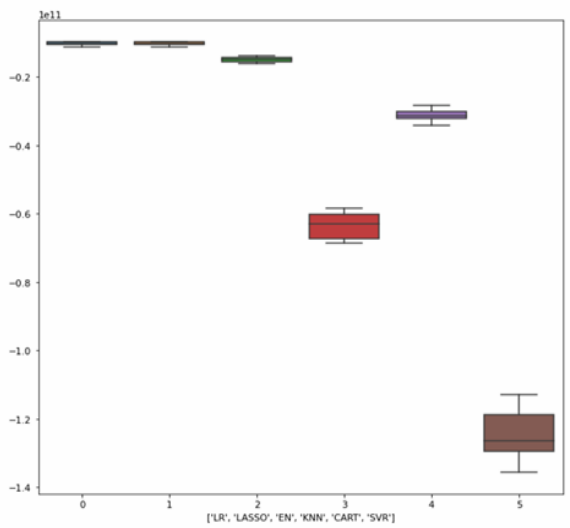

Figure 8. Box plots used show the best performing algorithm.

These ML algorithms were Linear Regression (LR), Lasso, Elastic Net (EN), Classification, Regression Trees-CART-Decision Tree Regressor, and the Support Vector Regressor. In the cross-validation score function, the "score" parameter was set to 'neg_mean_squared_error'. The resulting performance score was low for both Linear Regression and Lasso algorithms as they scored -1024 of the negative mean- squared error. As much as the LR and Lasso demonstrated equal performance results, the LR was chosen to meet the aim of this study. The visualization of the resulting negative mean squared error for the tested regression algorithms is shown in Fig. 8 by means of box plots. The x-axis in Fig. 8 shows the models that were tested. The first model is situated at index 0, while the sixth one is situated at index 5.

Cross validation, which is the method used for model best selection is explained by means of Figure 9. In each iteration, some of the data batches are used for testing, while the rest of the batches are used for training. As the iteration cycle continued, the testing batches were changed until all the batches were used for either training or testing.

Figure 9. The concept of cross validation used for best model selection.

Table 1 summarizes the Python code functions used in Figure.8 to select the best ML algorithm. Each column shows the steps that are being followed when implementing the cross-validation method to select the best performing model. In step 1, the lists of variables called "Models" and "names" are created. The models and the model names are then appended in the created list variables. In step 2, a for loop that loops through these list variables is created, and each model is returned with the appropriate matching name. Through steps 3 and 4, the scoring parameters for each model are created. In step 5, the function calculating the performance of the tested algorithms through the "for" loop is created. The

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algorithm with the lowest negative mean squared error is chosen. As seen in Figure 8, the algorithm with the lowest negative mean squared error was LR.

Table 1. Summary of Python code functions for model selection.

Step 1	Step2	Step3	Step 4	Step 5
Models = [] names = [] #Creates the list for appending the algorithms under test. # Creates a list for appending model names.	A "for" loop. #The "for loop" loops two variables through the created list "Models". #The first variable returns the names given to the models while the second returns the actual algorithm.	A "K-fold" class. # A K-fold object is instantiated. The instantiated object is assigned to a KFold() function. # The KFold() function takes the list of the models through the "for loop" and fits their predictors with their targets.	A "cros_val_scor" function. # It takes the KFold() function parameter settings created in step 3 as a "CV" parameter. # It also takes the scoring metric of "neg_mean_sqaured_error" as a "score" parameter.	# A "cros_val_score" function in step 4, calculates the performance of the tested algorithms through the "for loop". # The algorithm with the lowest negative mean squared error is chosen as the best ML model.

C. Training the selected model

The Scikit-learn library is the ideal Python library thus far that most Data science practitioners and engineers use. The function, called train_test_split () in Scikit-learn, was imported, and used for separating the data into 67 per cent of the training data, and 33 per cent of testing data. This function randomly shuffles the data before it splits it by assigning a value to its random state positional argument that determines how the provided data must be randomly shuffled before it is split.

D. Mathematical intuition behind linear regression

In the above sections, a workflow approach for linear regression projects in Python was explained. Linear regression Project was used to meet with the aim of this study as it is the best algorithm that provides a pathway when the concept of ML is introduced to beginners. In this section, the intuitive underpinning of linear regression is addressed through its mathematical formulas of governance. In supervised learning, we are given a set of data and we already know what our right outcome should look like, having the notion of a relationship between the input and the output.

Supervised learning problems are classified according to "regression" and "classification". In a regression problem, we try to forecast the results in a continuous output, which means we try to match the input variables to a continuous function. In a classification problem, we try instead to predict the outcomes of a discrete output. This means that we try to map the input variables into discrete categories. In this section, the mathematics on predictive continuous output (regression) is described using a single variable for the sake of simplicity. The general form of the hypothesis function is given by equation (1).

$$\hat{y} = h(x)_\theta = \theta_0 + \theta_1(x) \tag{1}$$

Equation (1) is more like a straight line. Hypothesis $h(x)_\theta$ is given the values for θ_0 and θ_1 to get the estimated output $\hat{y}$. All in all, a linear regression algorithm tries to create a function called h_θ that figures out how to map the input data (x values) to the output data (y values).

The accuracy of the hypothesis function is measured through a function known as the cost function. The cost function takes the average of all the results of the hypothesis with the inputs of x in relation to the actual output y.
This is shown in equation (2).

$$J(\theta_0, \theta_1) = \frac{1}{2m}\sum_{i=1}^{m}(\hat{y}_i - \hat{y}_i)^2 = \frac{1}{2m}\sum_{i=1}^{m}(h_\theta(x_i) - \hat{y}_i)^2 \tag{2}$$

$m =$ Number of training examples,
$x =$ Input variable/Features,
$y =$ Output variable/Features
The cost function is otherwise referred to as "Squared error function", or "Mean squared error". The mean is therefore halved $\left(\frac{1}{2m}\right)$ as a

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convenience for the computation of the gradient descent since the derivative term of the square function will cancel out the $\frac{1}{2}$ term. A linear regression tries to compute a straight line (defined by $h_\theta(x)$) which passes through the scattered set of data. Overall, the objective is to get the best possible line to fit through the scattered data set. The best possible line will be such that the average vertical square distance of the scattered points in relation to the line will be the smallest. Ideally, the line should go through all points in the training dataset. In such a scenario, the value of $J(\theta_0, \theta_1)$ will be 0.

The parameters in the hypothesis are estimated by using a method called gradient descent. Gradient descent simply means repetition of training until convergence in (θ_0, θ_1) parameters. Gradient descent for linear regression is applied as shown in combined equations that form Equation (3).

repeat until convergence: {

$$\theta_0 := \theta_0 - \alpha \frac{1}{m} \sum_{i=1}^{m} (h_\theta(x_i) - y_i)$$

$$\theta_1 := \theta_1 - \alpha \frac{1}{m} \sum_{i=1}^{m} ((h_\theta(x_i) - y_i) x_i)$$

}

(3)

4. Experiments and Results

The methodology sections explain how the experiments were conducted to explain the proposed workflow of implementing ML projects with Python. After the training stage, the model predictions were achieved by computing the input testing data sets through a Scikit-learn predict function known as predict (). Once the predicted $\hat{y}_i$ values (Predicted price) were achieved, as explained in the latter sentence, the model's performance was checked by plotting a scatter plot of the predicted $\hat{y}_i$ values (Predicted price) against the y_test values (Actual price). The resulting scatter plot was computed in seaborn library by using the scatterplot () function. The resulting scatter plot as shown in Figure 10 shows a high correlation between the two axis values, a sign that the linear regression model resulted to a hypothesis function that computed predicted values of prices closer to the actual price values. If the price predictions were not close to the actual house prices, the scatter plot would result in scattered predictions distributed far from the actual house prices in the 2-dimensional plane. So, the models with low negative mean root squared in Figure 8, would result in such distributions with anomalies.

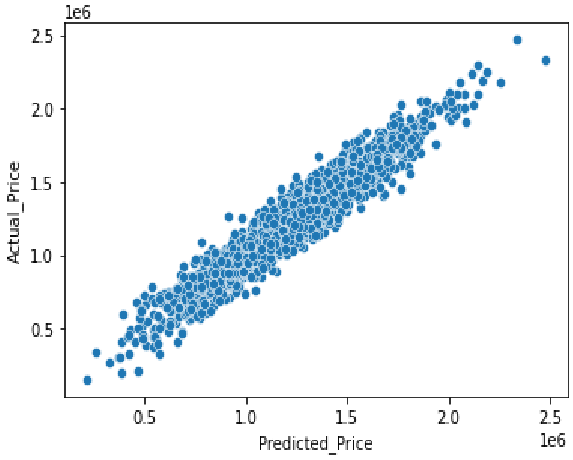

Figure 10. Scatter plot of predicted price values against actual price values.

Figure11 shows a few lines of code for the first ten entries of predicted price values and actual prices values.

```
In [28]:  prediction_1[:10]
          executed in 42ms, finished 19:46:09 2022-03-31

Out[28]: array([1310035.96931558, 1238811.85458523, 1245265.83079157,
                1229442.73657082, 1059067.48928404, 1542540.30796579,
                1096297.80142114,  833030.74689251,  789822.68304102,
                1468678.94514036])

In [29]:  y_test[:10]
          executed in 17ms, finished 19:46:23 2022-03-31

Out[29]: 1501    1.339096e+06
         2586    1.251794e+06
         2653    1.340095e+06
         1055    1.431508e+06
         705     1.042374e+06
         106     1.555321e+06
         589     1.250882e+06
         2468    1.039381e+06
         2413    8.324752e+05
         1600    1.420648e+06
         Name: Price, dtype: float64
```

Figure 11. A Python code for comparing the predicted prices against the actual prices.

Table 2 shows the comparison of the first 10 entries of predicted prices and actual prices. The predicted prices in Table 2 were derived by using the predictors taken from the testing data set. For instance, to get the predictions in index 1501 of the testing data set, all the predictors in the row of that index were used. So, to make the LR model's predictive analysis, a few predictions had to be made from the predictors of the indices shown in Table 2. In Table 2, the testing predictors were randomly chosen as their indices are not in the numeric order from index 1501. As seen in Table 2, the predictions made were close to the actual house prices, a reason that would encourage the model deployment.

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Table 2. Tabulated comparison of predicted prices and actual prices.

Index	Predicted price value	Actual price value
1501	1310035,9	1339096,00
2586	1238811,8	1251794,00
2653	1245265,8	1340095,00
1055	1229442,7	1431508,00
705	1059067,4	1042374,00
106	1542540,3	1555321,00
589	1096297,8	1250882,00
2468	83030,7	1039381,00
2413	789822,6	832475,20
1600	1468678,9	1420648,00

The results show that the model is more accurate as was determined in the section on choosing the best algorithm among the available algorithms of regression.

5. Evaluation and discussion

The LR model was used for making the prediction of prices, and the cross-validation method of model selection proved it to be the best model as can be seen in Figure 8 that it scored the lowest negative root mean squared error when compared to other regression models. Figure 10 shows the correlation plot of the predicted prices against the actual prices, and the results show that the two are highly correlated. This high correlation signifies the model's high predictive accuracy when it comes to estimating the house prices. The testing data set was used to generate the tabulated list house prices in Table 2. The fact that the predicted price figures are close to the actual prices the house prices, simply shows the model's reliability and the need for its deployment if it needed to be.

6. Conclusion

Before this study was conducted, a LinkedIn poll was conducted to understand the percentage of people who wished to study ML but were prohibited by knowledge that is often covered in the field of computer science, such as coding. Figure12 shows the LinkedIn poll results of 4006 votes. It can be seen in Figure12 that only 17 per cent could not code, but 83 per cent who did not see coding as a barrier, did not know where to start leaning ML.

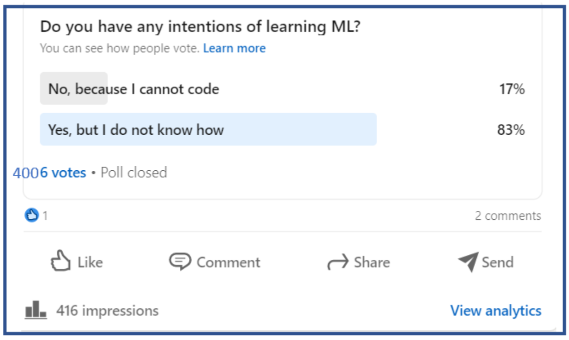

Figure 12. A LinkedIn poll analysis to understand the prohibiting factors for people who wished to study ML.

The approach used in this study was focused on accommodating the professionals from other fields who would like to learn ML for use in their professional fields such as health and business applications, to mention but a few. The systematic workflow to follow when working on ML projects in Python is covered in detail and provides a fundamental platform for learning other algorithms of ML that are not covered in this study as well. For the aim of this study, a Linear Regression algorithm was adopted, since Linear Regression is a gateway algorithm to ML. For instance, the approach to learning Neural Networks utilizes the Linear Regression approach to explain the concept of a perceptron that does not utilize an activation function. The important Python functions involved in the execution of the workflow are written in condensed bold text.
As there are many algorithms for performing regression in the literature, subsection B of the methodology section explains how the best algorithm was chosen using the cross-validation method. A closer look at the results was taken by using a scatter plot to plot the predicted prices against the actual prices. The results of the plot showed high correlation between the predicted prices and the actual prices, a sign that the model predictions were much closer to the values of the actual prices. Finally, the workflow approach proposed in this study can also be applied to ML classification projects provided that the metrics of classification model performance are taken into consideration.

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Cryptojacking Malware Detection in Docker Images Using Supervised Machine Learning

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Abstract
Nowadays, Docker Containers are currently being adopted as industry standards for software delivery, because they provide quick and responsive delivery and handle performance and scalability challenges. However, attackers are exploiting them to introduce malicious instructions in publicly available images to perform unauthorized use of third-party's computer resources for Cryptojacking. We developed a machine learning based model to detect Docker images that lead to cryptojacking. The dataset used is composed of 800 Docker images collected from Docker hub, half of which contains instructions for cryptomining, and the other half does not contain such instructions. We trained 10 classification algorithms and evaluated them using the K-Fold Cross Validation approach. The results showed accuracy scores ranging from 89% to 97%. Stochastic Gradient Descent for Logistic Regression outperformed the other algorithms reaching an accuracy score of 97%. With these results, we conclude that machine learning algorithms can detect Docker images carrying cryptojacking malware with a good performance.

Keywords: Cryptojacking, Docker images, Machine Learning, Cryptomining, Cybersecurity

1. Introduction

Docker containers are virtualization technology based on the operating system level, where applications and all their dependencies and source code are packaged in a single resource called image (Karn et al., 2021), from which multiple containers can be initiated. Containers provide huge advantages when managing a complex infrastructure (Şengül et al., 2021), and because of that, their use is on the rise. However, cybercriminals found an opportunity to exploit them to introduce malicious activities such as attaching instructions in Docker images to trigger unauthorized activities. For instance, due to the popularity and increasing value of cryptocurrency, malicious cryptomining tends to be a common attack on docker images (Carlin et al., 2020). This type of attack is also known as Cryptojacking, which is defined as the unauthorized use of computational resources to mine cryptocurrency (Carlin et al., 2020).

From a cybersecurity point of view, malicious cryptomining is a threat. It affects the victims not only by illegally using and wasting their CPU resources but also by causing financial damages due to extra electricity costs (Hong et al., 2018; Tekiner et al., 2021). Cryptojacking attacks can be carried out by different attack vectors, such as websites, operating systems, Random Access Memory - RAM (Varlioglu et al., 2022), and docker images (Liu et al., 2020; Karn et al., 2021). We focus on the application of supervised machine learning approach to detect cryptojacking in docker images. We collected 800 Docker images from Docker hub – a public repository provided by Docker, where 400 images had instructions for cryptojacking. The remainining 400 images were free of malicious instructions. We trained and evaluated 10 classification algorithms, using K-Fold Cross Validation sampling, and found that Stochastic Gradient Descent for Logistic Regression had the highest accuracy scores (97%), and K-Nearest Neighbors (KNN) algorithm had the lowest accuracy scores (89%).

The paper is structured as follows: Section 2 presents research done by other authors related to criptojacking attack mitigation, while the methodology used to carry out this research: data set collection, data set preprocessing, data set transformation, and model evaluation is described in Section 3. Section 4 describes the experiments:

training and testing aspects. This section also presents the results obtained and the discussion. The paper conclusions are presented in Section 6.

2. Related Works

Compared to hypervisor-based virtualization, containers showed to be lightweight systems that rationalizes hardware usage, provide performance nearly equal to non-virtualized systems. Because of that, they are being widely adopted (Kwon & Lee, 2020). Nevertheless, Docker containers are known to be vulnerable (Wenhao & Zheng, 2020; Huang et al., 2019), as they share operating system kernels, and run on root user by default. This fact allows containers to easily execute privileged operations, as well as easily access hardware resources. This way, computer attacks, such as criptojacking, can easily succeed via containers.

With the proliferation of cryptojacking attacks (Yulianto et al., 2019), especially through docker containers (Karn et al., 2021; Liu et al., 2020) cryptojacking defense has become on high demand. Different detection mechanisms have been proposed in literature ever since. For instance, Lachtar et al. (2020) worked on a solution that relies on tracking instruction executed within CPUs, an approach that can detect cryptojacking attack regardless of vector application type. Tanana (2020) researched cryptojacking detection by monitoring CPU loads caused by application software; his work focused on web pages and executable cryptojacking types. They achieved a success rate of 82% , and was designed by following the decision tree algorithm. Hong et al. (2018) developed a cryptojaking detection and prevention tool named CMTracker. For this work, they collected 853,936 pages as dataset on the web, and were able to detect 2,770 scripts for cryptojacking.

The literature also shows an increasing interest to use machine learning approaches as they allow computers the ability to automatically learn from its experience by feeding them with the appropriate data while identifying patterns to later make predictions from related unseen data with minimal human intervention. For example, Wang et al. (2018) have proposed a solution named SEISMIC, for interrupting cryptojaking based on web browsers. The proposed method relies on semantic signature-matching, by monitoring application software behavior instead of syntax analysis, which makes it more robust to evade code obfuscation techniques. They used supervised machine learning approach, and tested Support Vector Machine classifier, and achieved a F1 score greater or equal to 98%. Carlin et al. (2018), worked on supervised Machine Learning for cryptojacking detection and experimented with Random Forest classifier; they aimed to dynamically analyse opcode on non-executable files. The results showed scores achieving an accuracy of 100% on the test dataset. They created four different datasets namely: cryptomining (with 296 data points), deactivated cryptiminig (containing 194 samples), canonical (with 359 observations), and canonical injected (57 samples). Saad et al. (2019) proposed a solution that uses an unsupervised machine learning approach to mitigate the cryptojacking attacks via browsers. They collected dataset published from Pixalate and Netlab 360. They collected a total of 5,703 observations. They worked with Fuzzy C-Means (FCM) clustering algorithm to group the observations in categories such as, malicious, and benign, and they obtained an accuracy of 96.4% .

Tahir et al. (2019) proposed a real-time cryptojacking detection on browser code based on hardware-assisted profiling using supervised machine learning approach. They collected 590 data points for their dataset by recording Hardware Performance Counters values and used Random Forest classifier. They achieved an accuracy score of 99.35%. Nukala (2020) worked with machine learning to detect website based cryptojacking based on CPU activity data; they experimented with five classification algorithms while collecting cache hit and cache misses information, and achieved an accuracy of 96.25%. Lachtar el al. (2021) presented a solution for dynamically criptojacking attacks detection, along with other techniques. They used supervised machine learning approach and evaluated five classification algorithms, the dataset was composed of 272 observations composed of CPU instructions, and achieved an accuracy score result of 100% on the detection of cryptojacking for Zcash and Monero cryptocurrencies. Karn et al. (2021) developed a research work where they designed a framework based on supervised machine learning approach to detect containers that launch cryptomining activity, by collecting legitimate pods syscalls along with cryptomining hijacked pods syscalls as dataset. They tested four classifiers and obtained 97.1% as the highest accuracy score.

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Hu et al. (2021) worked on a solution to cryptojacking detection based on network traffic using supervised machine learning approach, and experimented five classification algorithms. Their result on this research achieved an accuracy score of 99.91%. Their dataset was composed of captured network traffic, which contained cryptojacking traffic for bitcoin currency. They collected 400,000 samples and added USTC-TFC2016 dataset to their dataset. Wang et al. (2021) presented a solution called MineDetector, they used supervised machine learning to detect web browser-side criptojacking scripts. They constructed a dataset containing features from javaScript source code. They had two datasets, one with 130 cryptomining JavaScripts, obtained from virusshare.com and Wayback machine, and another with 2,668 benign JavaScripts, obtained from BootCDN. They experimented with five classification algorithms and achieved an accuracy score of 99.41%. Gomes and Correia (2020) worked on cryptojaking detection based on the machine learning approach – they evaluated and tested various classification algorithms, and obtained an average precision score of 92.5%. The research focused on web page CPU usage monitoring. They obtained the training dataset by crawling web pages.

Our research differs from the works reported in the literature because it is based on detecting cryptojaking instructions directly from Docker images, i.e. before the instantiation of containers, while most of the related works we found were focused on detecting fileless, scripting, and operating system based cryptojacking attacks by monitoring CPU load, opcode, etc. With exception of one research that focused on network traffic monitoring, and another one that focused on monitoring pods system calls. Although all the related work used its own dataset, most of the datasets were collected from CPU behaviour, and almost all studies used the same classification algorithms: Naive Bayes, Support Vector Machines - SVM, K-Nearest Neighbor - KNN, Logistic Regression and some related work used Random Forests, and Decision Trees.

3. Methodology

3.1. Data set

We installed a VMware Workstation 16 Pro Virtual Machine (VM), with Ubuntu 18.04 LTS operating system where we installed Docker 20.10.7. We then composed a bash script instructed with the "docker pull" command, and we were able to download Docker images from Docker hub to our local VM 800. The dataset was balanced between two classes (i.e., cryptojacking, not cryptojacking) each with 400 cryptojacking examples. Subsequently, in our local VM we used the "docker history" command for each Docker image to extract all the image instructions into a plain text file. We obtained 800 different text files. Figure 1 illustrates four observations from the resulting text file, which contained 800 observations in total. A sample of the dataset is depicted in Table 1 (the ellipse inside the square brackets means there is more text).

Table 1: Illustration of subset of the resulting dataset file after joining all the image text files into one text file

image	**class**
ENTRYPOINT [". /xmrig"] nop [...]	1
CMD ["bash"] nop […]	0
nop CMD ["-origin" "url" "-user" …]	1
nop WORKDIR /home/user […]	0

3.2. Data Preprocessing

Data preprocessing was carried out as an initial step prior to training. We preprocess the data using Jupyter Notebook with Python 3.8 scripting language. We followed the consecutive steps listed below:

- Lowercasing - casing can be problematic when it comes to text data. For instance, the words/tokens "copy" and "COPY" can be recognized as different words. So, to avoid this problem and to minimize the number of features in the dataset we applied lowercasing to the text.

- Noise cleaning - we identified URLs in each image. Here we kept unique URLs to avoid too many URLs which could increase the number of features in the dataset. Thus, using regex we substituted all the URLs in the text by the word "*URL*". The regex used for matching URLs was: r'http[s]?://(?:[a-zA-Z]|[0-9]|[$-_@.&+]|[!*\(\),]|(?:%[0-9a-fA-F][0-9a-fA-F]))+';
- Removal of punctuations - Similarly, we removed all the punctuations and special

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characters using regex instructions by matching the following pattern: r‘[,.\"!@#$%^*(){}?;`~:<>_]’;

- Tokenization - we used regex expressions to split the text into small units/tokens. These tokens were then used as features to feed the algorithms during training. The regex rule used for the tokenization was: ‘r[\w’]+|[""!"#$%&’()*+,-./:;<=>?@[\]^_‘{|}~""\\]’;

3.3. Data Transformation

To perform the train and test, we first needed to transform the text dataset to numerical representation. For that, we experimented with two approaches: Bag of Words (Qader et al., 2019) and Term Frequency-Inverse Document Frequency - TF-IDF (Qaiser & Ali, 2018).
Bag of Words allows the representation of text data in fixed-length numeric vectors. We experimented with n-gram models to represent the features of the data set; however, uni-gram was chosen to represent the features, since it was showed to provide better results. TF-IDF on the other hand, is a statistical approach that measures the relevance of each word in a textual data. Table 2 shows one record from the resulting dataset after transformation using the Bag of Words approach; for the sake of space management, we only display one data point. Table 3 illustrates the same subset features of the same data point after applying the TF-IDF approach to transform the dataset.

Table 2: Bag of Words representation of three features of one data point from the dataset

xmrig	**cpu**	**miner**	**…**
4	1	3	…

Table 3: TF-IDF representation of three features of one data point from the dataset

word	**TF**	**IDF**	**TF-IDF**
xmrig	4	2.387544	0.091413
cpu	1	3.466353	0.033179
miner	3	3.279142	0.094162
…	…	…	….

3.4. Model evaluation

The performance of the models was measured using classification accuracy. The evaluation of the model was conducted in two phases: firstly, we trained and tested the algorithms, and we stored both training and testing scores. Then, we compared the two scores (training and testing scores) for each algorithm, for overfitting and underfitting analysis. Along with the testing accuracy, we used confusion matrices to better analyze the number of false positives and false negatives for each algorithm, to better choose the algorithm that performed better. Figure 1 illustrates the system diagram that shows the method of detecting the cryptojacking malware.

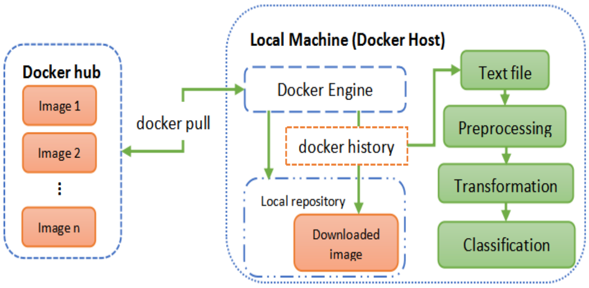

Figure 1: System diagram showing the cryptojacking malware detection method

4. Experiments and Results

4.1 Experiments

Our experiments were carried out using Jupyter Notebook. After transforming the dataset, we split it in two, 80% for training, 20% for test. Then, using the K-Fold Cross Validation sampling approach (with k = 5), we submitted the training dataset (80%) to 10 classification algorithms. From the 10 algorithms 6 were the same algorithms used by the related work, and we added 4 more algorithms namely: Stochastic Gradient Descent for Logistic Regression - SGD (LR), Stochastic Gradient Descent for SVM - SGD (SVM), Gradient Boosting Classifier (GBoost), and Adaptive Boost Classifier (AdaBoost). These algorithms were added because they are known by the literature to perform well on binary classification problems, which is the case of our research task.
To automate the experiment workflow, we used grid-search, and pipelines. Grid-search was used to tune algorithms parameters, to tune the appropriate number of folds to K-Fold Cross Validation, as well as to find the better approach between Bag of Words and TF-IDF, before feeding the data to the algorithms, while pipelines were used to orchestrate the experiments sequence operations during the algorithms training.

4.2. Results

The training results are illustrated in Table 4. The second column (*Acc*) represents the accuracy score for each algorithm, it is the arithmetic average of the five folds performed by K-Fold

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Cross Validation. The third column (*std*) represents the standard deviation of the respective accuracy, and the fourth column (*CI*) represents the confidence interval in which the accuracy falls, with a confidence of 95%.

Table 4: Training results for each classifier

Algorithm	*Acc*	*Std*	*CI*
LR	0.928	0.026	[0.896; 0.960]
SGD (LR)	0.948	0.021	[0.922; 0.975]
SVM	0.948	0.014	[0.930; 0.966]
SGD (SVM)	0.950	0.021	[0.924; 0.976]
NB	0.953	0.023	[0.924; 0.982]
KNN	0.917	0.021	[0.891; 0.943]
RF	0.941	0.020	[0.916; 0.966]
DT	0.933	0.011	[0.919; 0.946]
GBoost	0.948	0.009	[0.937; 0.960]
AdaBoost	0.958	0.020	[0.913; 0.962]

Table 5 shows the testing results, the accuracy (*Acc*) column is the main evaluation metric in this research, it is presented with other evaluation metrics, namely: precision (*Prec*), recall (*Rec*), 1-Measure (*F1-M*).

Table 5: Testing results for each classifier

Algorithm	*Acc*	*Prec*	*Rec*	*F1-M*
LR	0.912	0.946	0.875	0.909
SGD (LR)	0.969	1.000	0.938	0.968
SVM	0.963	0.987	0.938	0.962
SGD (SVM)	0.950	0.986	0.912	0.948
NB	0.944	0.986	0.900	0.941
KNN	0.894	0.920	0.863	0.890
RF	0.950	0.986	0.912	0.948
DT	0.938	0.986	0.887	0.934
GBoost	0.944	1.000	0.887	0.940
AdaBoost	0.925	0.925	0.925	0.925

We used confusion matrices along with the testing accuracy to better judge the results. Our intention was to see how balanced the classification task was, by analysing the amount of well classified and misclassified data points. Figure 2 illustrates the confusion matrix for the SGD (LR) algorithm whereas, Figure 3 shows the confusion matrix of the SVM. SGD (LR) achieved the best accuracy score between them.

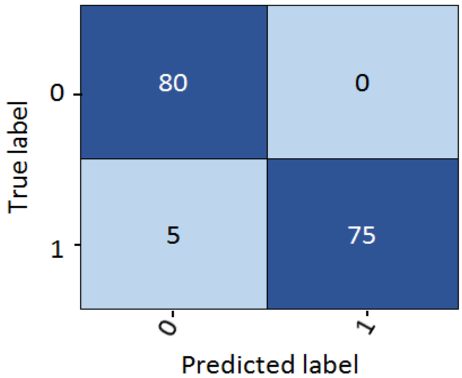

Figure 2: Confusion matrix of Stochastic Gradient Descent for Logistic Regression classification results

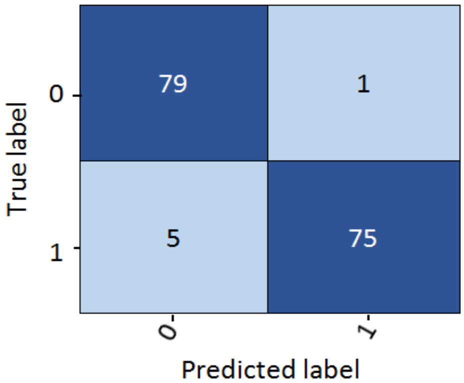

Figure 3: Confusion matrix of Support Vector Machine classification results

For the two confusion matrices, the values in the main diagonal (the dark blue squares), express the values that were well classified, while the values in the secondary diagonal (the light blue squares) represent the misclassified values (the false positives and the false negatives).

4.3. Discussion

The testing results (Table 5) illustrates that SGD (LR) achieved the best result – it achieved 96.9% accuracy, while SVM achieved 96.3% accuracy. These results are close to each other, however, observing the respective confusion matrices (Figure 2 and Figure 3), we find that SGD (LR) had 5 false negatives in its classification, while it did not have any false positives, while SVM had 1 false positive, making this algorithm less accurate than SGD (LR). On the other hand, we observed that all the obtained results fell within the calculated confidence interval. We also observed that the accuracy of GBoost in the training phase, obtained the least standard deviation (0.009), meaning that the algorithm had the least dispersion among the various accuracies. Table 4 and Table 5 present the results achieved

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by using the TF-IDF model, which produced better results in the experiments. This can be justified by the presence of a considerable amount of noise in the dataset, so it needed to define the importance of the terms.

Since containers are commonly adopted in cloud data centres, our research can minimize the unauthorized use of the data centre's hardware resources by cryptojacking attackers. Our proposal is illustrated in Figure 4 — a system diagram showing how to minimize the unauthorized use of cloud data centre's hardware resources. The cloud data centre pulls the Docker images from Docker hub to a server within the data centre. After that, the downloaded images are submitted to the verification process to ensure that the images do not contain cryptojacking instructions. If the safety of the image is verified, the image is stored in the local cloud data center repository where the data centre's tenants can transparently request to instantiate their containers.

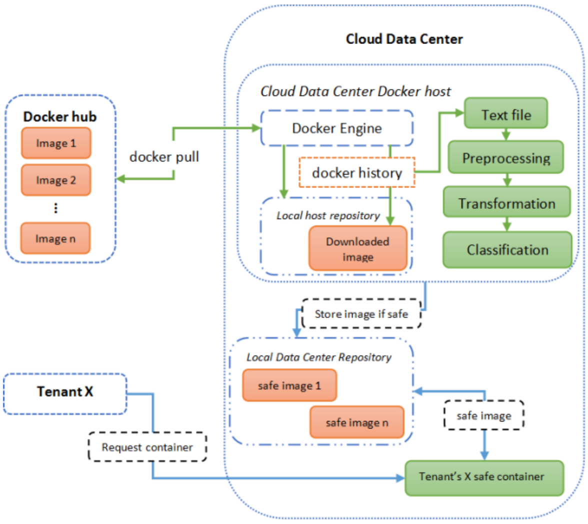

Figure 4: System diagram showing how to minimize the cryptojaking on cloud data centers

6. Conclusion

This research aimed to develop a predictive model based on Machine Learning to detect cryptojacking malware in Docker images. To achieve this goal, we first built a dataset using the "docker history" command for Docker images collected from Docker Hub. We pre-processed and transformed the dataset and performed several experiments using supervised Machine Learning classification algorithms. The experiments showed that the Stochastic Gradient Descent algorithm for Logistic Regression SGD (LR) outperformed the other algorithms in terms of performance, achieving an accuracy score of nearly 97%. With a confidence of 95% it can be said that the highest average accuracy for SGD (LR) is between 92.2% and 97.5%. With these results, we conclude that Machine Learning classification algorithms can detect Docker images carrying cryptojacking malware with an acceptable performance (accuracy). The study demonstrated that the "docker history" command can serve as a basis to feed a cryptojacking malware detection system. It also demonstrated that different Machine Learning algorithms can be used to build a predictive model for detecting cryptojacking malware in Docker images.

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Effects of Demographic Characteristics on the Electronic Health Management Information System (eHMIS) Functions in Tanzania

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Abstract
We assessed the use of Electronic Health Management Information – eHMIS – and the influence of demographic characteristics on the eHMIS functions. In particular, we explore changes in the usage of eHMIS among health workers. We also determined the effects of demographic characteristics on the usage of eHMIS and assessed any improvement in the ability to use eHMIS after its development. A mixed research design approach was adopted. The respondents were the clinical and non-clinical staff. Data was collected using interviews and questionnaires in three phases: baseline, midline, and final survey. The findings revealed an increase in the frequency of use of the eHMIS for entering and searching data entry from the midline to the final review. Apart from entering data, browsing, and retrieving previously recorded data, other eHMIS functions were not affected by demographic characteristics. On self-efficacy, there was an increase in health workers who felt comfortable using the system in the final survey compared to the baseline survey. In conclusion, enough training, user experience, and support from the management are very important in effective eHMIS implementation.

Keywords: eHMIS, Demographic, CCBRT

1. Introduction

The electronic Health Management Information System (eHMIS) is a system used to increase patient satisfaction concerning health services delivered to them by considering certain magnitudes of service quality (Shaikh & Rabbani, 2005). The benefits of eHMIS are that it makes record keeping easy, allows faster record retrieval, improves communication and process flow, performs calculations, supports decision making, attaining competitive advantage, better management of diseases, increases productivity, stimulates research and information dissemination in different formats (Namakula & Kituyi, 2014; Winter et al., 2010). WHO states that an eHMIS is among the six components of a health system that produces, analyses, and disseminates timely and reliable health information on health status, determinants and systems performance (World Health Organization, 2007). eHMIS constitutes modules that deal with health management information reporting, finance, administration operations, and drugs inventory management (Amin et al., 2011; Ismail et al., 2013).

For many years, several countries have devoted significant funds to improving eHMIS (Amin et al., 2011; Ismail et al., 2013; Littlejohns et al., 2003; Mahundi et al., 2018; Wilms et al., 2014). Despite all their efforts, it has not been easy to integrate eHMIS to fully operate in health facilities. In Tanzania, the early version of eHMIS known as Mfumo wa Taarifa za Uendeshaji wa Huduma za Afya (MTUHA), had challenges such as data inconsistencies, data duplication, and other parallel information systems (Nyamtema, 2010; Wilms et al., 2014).

The benefits of eHMIS are not very vivid to most users for several reasons. The first being that some health facilities have not implemented all the eHMIS modules (Humba, 2015; Kawila & W., 2017). The second reason is user demographic components or characteristics such as age, professional cadre or occupation, gender, and experience (Kingston et al., 2004; Lawton & Parker, 2002). Chang & Hsu. (2012) highlights that the age and gender (specifically male) of a user affects negatively his/her intention to use the system, while years of work experience and professional cadre (specifically a nurse) of a user affects positively his/her intention to use the system.

Regardless of the institutional and operational challenges, eHMIS can still serve multiple users and a wide array of purposes that can be summarized as the generation of information to enable decision-makers at all levels of the health system to identify problems and needs, make evidence-based decisions on health policy and allocate infrequent resources optimally.

The objectives of this study are:
1. To explore any changes in the usage of eHMIS by health workers at the surveyed health facility.
2. To determine the effects of demographic characteristics on the usage of eHMIS among health workers.
3. To assess any changes in the ability to use eHMIS after implementation of eHMIS.

The results of this study will be important in improving practice and policies on the implementation of eHMIS in a hospital setting in Tanzania and other countries with similar conditions.

2. Related Works

For decades, a huge amount of time and money have been invested by different countries in eHMIS. In South Africa, the first integrated eHMIS was installed in Limpopo (Northern Province) in September 1998 (Littlejohns et al., 2003; Nolwazi et al., 2002). In Malaysia, the early stages of eHMIS implementation started between 1991 and 1995 under the 6th Malaysian Plan (MP) (Amin et al., 2011; Ismail et al., 2013). In Tanzania, eHMIS has existed since 1993, whereby a semi-electronic system called Mfumo wa Taarifa za Uendeshaji wa Huduma za Afya (MTUHA) was introduced (Mahundi et al., 2018; Wilms et al., 2014). Many challenges, such as data inconsistencies, data duplication, and other parallel information systems, arose using MTUHA (Nyamtema, 2010; Wilms et al., 2014).

With respect to the services it offers, eHMIS consists of two subsystems: the Patient Management Information System and the Hospital Management Information System. The first subsystem deals with patients' treatment, prescriptions, and billing. The second subsystem deals with the administration aspect of the hospital, including services like accounting, finance, human resource management, record keeping, stock management, and asset management (Macharia & Maroa, 2014). A combination of these subsystems leads to improved health care service delivery. A study at the Kenyatta National Hospital (KNH) reveals that eHMIS can be a solution for managing complex healthcare challenges and addressing growing information needs at the facility (Omambia & Odhiambo-Otieno, 2016). The success of eHMIS at the health facility level depends significantly on the health workers' eHMIS usage. Studies at KNH in Kenya and East Wollega in Ethiopia revealed that more than 57% of workers agreed that eHMIS is used in the routine delivery of health services and for decision-making purposes (Omambia & Odhiambo-Otieno, 2016; Yarinbab & Assefa, 2018).

eHMIS has a lot of features but not all the features are used in most health facilities. Literature highlights that some health facilities in Ilala, a municipal in Tanzania were using eHMIS mainly for planning, decision making, budgeting, and allocation of resources monitoring. eHMIS is not fully utilized in most facilities because some of the modules of eHMIS are not yet implemented (Humba, 2015). Another study reported that eHMIS was designed to gather clinical and administrative data for purposes of effective and efficient decision-making, and planning for the new hospital but the latter has not implemented all the modules including bed management, nursing, human resource management, and medicine management (Kawila & W., 2017).

Demographic components such as age, professional cadre or occupation, gender, and experience have been used to determine how users use an information system (IS) (Kingston et al., 2004; Lawton & Parker, 2002). A study in Taiwan concerning users' intention to use an online Patient-Safety Reporting System (PSRS) reported that the age of a user affects negatively the intention to use the system whereby for each additional year of a person's age, his/her intention to use the system decreases by an average of 0.388 points. The perceived positive consequence of using the system for nurses was higher than for non-nursing staff, this increased the nurses' intention to use the system by 0.27 points on average. Meanwhile, male staff had a higher perceived negative consequence of using the

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system, this reduced male staff intention to use the system by 0.247 points on average. Furthermore, for each additional year of work experience, the user's intention to use the system increased by 0.523 points (Chang & Hsu, 2012).

3. Methodology

The study combined qualitative and quantitative data collection methods to assess the development of eHMIS and its usage at the Comprehensive Community-Based Rehabilitation in Tanzania (CCBRT). The project directly involved 218 clinical staff and 195 non-clinical staff – the end users of the eHMIS. The study combined interviews and a questionnaire survey to collect data for the study in three phases:

1. The baseline survey assessed the status quo of the implementation of eHMIS before the commencement of the intervention (i.e. development of eHMIS) at the surveyed health facility. Therefore, the study conducted in-depth interviews with ICT staff during March and April 2019.
2. The midline survey assessed the usage of eHMIS and the ability to use the eHMIS at the surveyed health facility by using a questionnaire survey. This survey was conducted between June and July 2019. A total of 69 participants (71.9%) participated in the questionnaire (66 from tablets and 3 from online survey) out of 96 employees.
3. The final survey was carried out at the end of the project to explore any changes in the usage of eHMIS and the ability to use eHMIS after the development of eHMIS at the surveyed health facility. The questionnaire survey was conducted between October and November 2019. A total of 70 employees responded to the survey.

3.1 Sampling

The sampling method was snowball sampling, i.e., sampling done by collecting a sample of respondents from a network reference (Hartono & Yap, 2011). Therefore, we communicated with the External Affairs officials at the surveyed health facility to assist with survey participant lists and arrange survey appointments. Then we distributed the online questionnaires to physicians, while we distributed questionnaires on tablets to other clinical and non-clinical staff.

3.2 Data analysis technique

We did a descriptive analysis to look for any changes over time in the usage of eHMIS and the ability to use eHMIS after the development of eHMIS at the CCBRT. We performed this analysis by using means, percentages, and frequencies. Further, by using chi-square, we also assessed the relationship between demographic characteristics and usage of eHMIS. Qualitative data collected through interviews were transcribed verbatim. We applied a thematic analysis method to analyze the study results. The data was analyzed by examining and categorizing the opinions of the respondents. The analysis was conducted in three phases: the first phase involved transcripts and coding of field notes to understand the thoughts and meanings; the second phase involved thorough inspection and interpretation of the resultant codes into descriptive themes and; the third phase involved interpreting the descriptive themes into more abstract analytical themes.

3.3 Technology Description

The surveyed health facility used OpenClinic software to develop eHMIS. OpenClinic was specifically designed by Vrije Universiteit Brussel (VUB) to meet the needs of countries with fewer resources and with a patient-centered approach. OpenClinic was developed on an open-source platform that enables the wide spread of the application. OpenClinic is currently installed in over 500 health facilities. Apart from electronic medical reporting, it also increases hospital efficiency and productivity. The OpenClinic operates well in not only in small health facilities but also in large hospitals with more than 2,000 beds. OpenClinic has been in use in production environments for years. Today, there are numerous implementations of OpenClinic in Rwanda (University Teaching Hospital of Kigali, district hospitals of Muhima, Kibagabaga, Rwamagana, Rutongo, Nyamata, Gihundwe, the neuropsychiatric reference hospital of Ndera, Hôpital de la Croix du Sud, Polyclinique du Carrefour, Polyclinique la médicale, Polyclinique Bien Naître, Biomedical Center of Kigali), in the Democratic Republic of the Congo (University Teaching Hospitals of Kinshasa, Lubumbashi, Kisangani and Bukavu, District hospital of Dondo) and Burundi (Centre Médico-Chirurgical de Kinindo) (Karara et al., 2017).

4. Experiments and Results

4.1 System Development

The findings from the interviews with ICT technical personnel revealed that the number of modules that were implemented in eHMIS increased from 12 during the baseline study to 16

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modules in the final evaluation (Table 1). The facility has four clinical services: plastic and reconstructive surgery; ophthalmology; orthopaedic and physical rehabilitation clinical services; and maternal, newborn, and child health. eHMIS was covered in two clinical services by the end of the evaluation, from one clinical service during the baseline survey. The reports generated from eHMIS were only sent to the government authorities (i.e., DHIS2) once per month through paper printouts and email. eHMIS was integrated with the SMS reminder system for club foot and surgery patients and the National Health Insurance Fund (NHIF). Another implemented system was the human resources management information system.

Table 1: CCBRT eHMIS modules during the baseline survey and final survey

Result	**Indicator (Quantitative Measure)**	
	Baseline survey	Final survey
Analysis of the implemented eHMIS business processes	Implemented 12 out of 26 business processes, which are diagnostic services (laboratory, radiology, and imaging), outpatient registration, user management, patient billing and payment, store/inventory management, security features, and picture archival and communication system (PACS).	Implemented 16 out of 26 business processes. Additional modules were pharmaceutical management, inpatient, Electronic Medical Records, and surgery.
Clinical services covered by eHMIS	One clinical service was covered which is orthopaedic and physical rehabilitation clinical services.	Two clinical services were covered which are physical rehabilitation clinical services; orthopaedic and ophthalmology.

4.2 Demographic characteristics

There was no gender inequality among participants in both midline and final surveys. The mean age was similar for both groups. More health workers with bachelor's degrees participated in the baseline, while most diploma holders agreed to be participants in the final evaluation. A large percentage of non-clinical staff (62.3%, n = 43) participated in the midline survey as compared to the final evaluation (Table 2).

Table 2: Respondents' demographic characteristics

	Midline survey	**Final survey**
Sample size	69	70
Gender		
Male	52.2% (n=36)	52.9% (n=37)
Female	47.8% (n=33)	47.1% (n=33)
Age	Mean = 39.5	Mean = 39.11
Education		
Certificate	(17.4%, n = 12)	(22.9%, n=16)
Diploma	(27.4%, n = 19)	(38.6%, n=27)
Bachelor	(29%, n = 20)	(28.6%, n=20)
Postgraduate Diploma	(5.8%, n = 4)	(7.1%, n=5)
Masters	(18.8%, n = 13)	(2.9%, n=2)
• PhD	(1.4%, n = 1)	None
Professional cadre		
• Clinical	37.7% (n = 26)	50% (n=35)
• Non-clinical	62.3% (n = 43)	50% (n=35)

ISBN: 978-99949-0-888-2

4.3 Use of eHMIS

The results indicate an increase in the frequency of use of the eHMIS among CCBRT employees (from 81.2% staff at the midline review to 87.1% staff at the final evaluation). Further, the results indicate an increase in how CCBRT employees spent time on the system (from 58% of staff during the midline survey to 77.1% of staff during the final evaluation). The results revealed that all clinical and non-clinical supported the deployment of eHMIS at CCBRT during both surveys (midline survey 98.6%, n=68) and final evaluation (100%, n=70).

On scoring the system function, there was an increase in the frequency of use of eHMIS for entering and searching data from the midline to the final review. CCBRT employees were using eHMIS for data entry very frequently (from 55.1% of staff to 71.4% of staff at the final evaluation). They were also using eHMIS for searching data very frequently (from 55.1% of staff at the baseline to 72.1% of staff at the final evaluation). There was a slight decrease in the frequency of using eHMIS for browsing or retrieving previously recorded data. For instance, the percentage of staff who browsed previously recorded data decreased from 53.6% staff at the baseline to 55.1% at the final evaluation. There was a slight decrease in the frequency of using eHMIS for retrieving previously recorded data among CCBRT employees (from 53% of staff at the baseline to 48.6% of staff at the final evaluation).

However, there was low use of eHMIS for downloading and printing reports among CCBRT employees. Only one-third of participants acknowledged using eHMIS to print or download the report in both surveys (Table 3).

Table 3: eHMIS use during the baseline survey and the final survey

	Midline survey	Final survey
1. Entering data	(55.1%, n=38), Mean = 3.4	(71.4%, n=50), Mean = 4.0
2. Searching data in the system	(55.1%, n=38), Mean = 3.5	(72.1%, n=49), Mean = 3.9
3. Browsing previously collected data	(53.6%, n=37), Mean = 3.5	(55.1%, n=38), Mean = 3.52
4. Retrieving previously collected data	(53%, n=36), Mean = 3.4	(48.6%, n=34), Mean = 3.30
5. Downloading reports	(28.9%, n=20), Mean = 2.8	(30%, n=21), Mean = 2.54
6. Printing reports	(34.8%, n=24), Mean = 2.6	(29.9%, n=20), Mean = 2.52

4.4 Influence of demographic characteristics on the eHMIS functions

A chi-square test revealed that the eHMIS function on "Enter data" was positively associated with the highest level of education in both surveys. This implies that the better-educated employees were better users of eHMIS for data entry in both surveys. Although they were not significant at the baseline, a chi-square test revealed that the eHMIS function on the "Browse previously recorded data" and the "Retrieve previously recorded data" were positively associated with the highest level of education in the final survey only (Table 4).

Table 4: Influence of demographic characteristics on the eHMIS functions

	Midline survey	Final survey
1. Entering data	χ^2=42.2; p = 0.003	χ^2=36.334; = 0.003
2. Searching data in the system	Not significant	Not significant
3. Browsing previously collected data	Not significant	χ^2=26.477; p = 0.048
4. Retrieving previously collected data	Not significant	χ^2=27.117; p = 0.040
5. Downloading reports	Not significant	Not significant
6. Printing reports	Not significant	Not significant

4.5 Analysis of the participants' ability to use the system (Self-efficacy)

Two-thirds of the respondents agreed that the training that they received was relevant to how they should use the system in both surveys. There was an increase in health workers who felt comfortable using the system (from 72.5% of staff at the baseline to 80% of staff at the final evaluation). There was an increase in the number of staff (from 65.3% to 72.9%) who felt that they

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can accomplish a task in the system even if there was person around to show/tell them what to do. Three-quarters of staff felt that they can accomplish a task in the system if they can call someone to help them if they got stuck. There was a slight decrease in the number of staff (from 73.9% to 67.1%) who indicated that they could complete a task using the system if they had the built-in help facility for assistance (Table 5).

Table 5: Participants' ability to use the system (Self-efficacy)

	Midline survey	Final survey
1. The training I received was relevant to how I should use the system.	(60.9%, n=42), Mean=3.6	(62.3%, n=43) Mean = 43
2. I feel comfortable using the system.	(72.5%, n=50), Mean=3.9	(80%, n=56) Mean= 4.2
3. I can complete a task using the system even if there was no one around to show/tell me what to do.	(65.2%, n=45), Mean=3.7	(72.9%, n=51) Mean = 4
4. I can complete a task using the system, if I can call someone to help me if I got stuck.	(73.9%, n=51), Mean=3.9	(75.7%, n=51) Mean=4
5. I can complete a task using the system, if I had the built-in help facility for assistance.	(73.9%, n=51), Mean=3.9	(67.1%, n=47) Mean=3.8

5. Evaluation and discussion

This study was limited to a single privately-owned hospital in Dar es Salaam. Despite the limitation, the findings remain valid for other health facilities with similar conditions. Our study has revealed that there was a significant increase in eHMIS usage in the final evaluation compared to the baseline evaluation. A notable increase was observed in the following; frequency of using the eHMIS, the time spent on the system, frequency of using eHMIS for entering and searching data, and comfortability to use the system. However, there was a minor decrease in the frequency of using eHMIS for browsing or retrieving previously recorded data, and low use of eHMIS for downloading and printing. The study also reveals that, compared to the baseline evaluation, all respondents supported the deployment of eHMIS at the facility. Several trainings done and support from the facility management which is parallel with Chang & Hsu's (2012) suggestions.

Considering the nature of activities performed by the personnel at the health facility, the demographic aspects had little impact on the usage of eHMIS. Apart from the level of education, there were no observed significant effects of demographic components on the usage of eHMIS. Better educated respondents were better users of eHMIS on data entry in both surveys, retrieval of previously recorded data, and browsing of previously recorded data in the final survey. Similar to Chang & Hsu (2012), better-educated respondents are likely to have been subjected to a lot of training hence they possess much experience in the usage of eHMIS.

The training was very crucial to the health workers' self-efficacy (Chang & Hsu, 2012). Almost 73% percent of the respondents felt that they can complete a task in the system even if there was no one around to show/tell him/her what to do. Further, the respondents revealed that they can complete a task in the system if they are able to call someone to help them if they got stuck. However, there was a slight decrease in the number of respondents who were able to use the system's built-in help facility for assistance.

6. Conclusion

The findings of this study unfold very important considerations for the successful deployment of eHMIS. The findings revealed an increase in the frequency of use of the eHMIS particularly to enter and search data entry from the midline to the final review. Apart from the level of education, there were no observed significant effects of demographic components on the usage of eHMIS. On self-efficacy, there was an increase in health workers who felt comfortable using the system and they can accomplish a task using the system even if there was no person around to show/tell them what to do from the baseline to the final evaluation. Keeping in mind that a number of heavily invested eHMIS have failed to reach the organization's expectations (Hassan & Zuhairy, 2013; Littlejohns et al., 2003), this study asserts that enough training, user experience, and support

ISBN: 978-99949-0-888-2

from the management are very important in effective eHMIS usage. Further research is needed to assess the usage of eHMIS in other settings such as government hospitals in rural and urban areas.

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The Influence of the National E-Procurement System on Employees' Performance in Selected Public Institutions in Tanzania

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Abstract
The study assessed the influence of the Tanzania National E-Procurement System (TANePS) on employees' performance in the selected public institutions in Tanzania. Specifically, we investigated the extent to which TANePS is being adopted, and its influence on employee performance at the following institutions: Government Procurement Services Agency (GPSA), and the Public Procurement Regulatory Authority (PPRA). We conducted a self-administered questionnaire survey to 200 employees at the selected institutions, with a rate of return of 66 per cent. The study found that most respondents (84%, n=168) frequently completed their daily tasks easily by using TANePS. In particular, most of the respondents frequently used TANePS for e-tendering, and e-payment, while user registration and e-contract management had low use. On factors enabling adoption of TANEPS, the software design had a positive impact on the IT readiness (b=0.696, p=0.042). Management policies negatively affected internal resistance (b= -0.517, p=0.002), and internal resistance negatively affected adoption of TANePS (b= -0.506, p=0.002). At the same time, two factors (i.e., management policies (b= 0.649, p=0.002) and IT-readiness (b= 474, p=0.002)) had a positive effect on adoption of TANePS. Consequently, adoption of TANePS had a positive effect on the effective procurement (b=0.674, p=0.007), and the reduction of imperfections (b=0.721, p=0.001). The study further found that the use of TANePS led to better performance (p>0.045 [F (2, 183=26.737, p=0.045]), increased accuracy of production capacity (p>0.045 [F (2, 183=3.190, p=0.045]), and shortened process cycle times (p>0.024 [F (2, 183=17.347, p=0.024]). The study recommends that government procurement authorities and public institutions in Tanzania and other countries of similar environment should ensure that an e-procurement system is designed based on user needs; there are supportive management policies, there is a regular system review and maintenance, adequate technical user support and training, user-friendly software design, a secure system, and stable network. These suggestions will increase the number of bidders and enhance stiff and fair competition among them.

Keywords: E-Procurement System, TANePS, PPRA, GPSA, Employee, Performance

1. Introduction

The development of Information and Communication Technology (ICT) has seen numerous technological breakthroughs that have turned the wheel. Every industry has recently experienced a paradigm shift. Governments and private organizations all over the world are struggling to provide electronic services. Procurement is a common activity undertaken by both private and public organizations. It entails buying and selling goods and services to, and from their customers, and the activity has been done manually for many years. The advancement of ICT has extended to the procurement sector and e-procurement has come into being. E-procurement is said to have numerous advantages such as simplifying the procurement process, shortening the time spent in the tendering processes, and

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reducing costs involved in tenders of standardized commodities and services that can be specified and evaluated in terms of price (OECD, 2016). Other institutions prefer the online tendering process because it reduces the barrier of entry (Boateng & Asare 2020). Participants can submit an offer in the absence of their physical presence (Boateng & Asare 2020).

The European Union, through its Pan European Public Procurement Online (PEPPOL) project has made notable contributions to the usage of e-procurement across the globe (Pedersen et al., 2018). The work of this union resulted in the adoption and advancement of public e-procurement systems in various countries such as Chile, Guatemala, India, Italy, Panama, the Philippines, Romania, South Korea, and Thailand (Zarnekow, et al., 2002). Noting the successes of the e-procurement systems in those areas, International Organisations such as the World Bank, Asia Pacific Economic Cooperation (APEC), Asian Development Bank (ADB), Inter-American Development Bank (IDB), and African Development Bank (ADB) began to encourage developing countries to adopt and implement e-procurement systems. These Organizations offer financial and technological assistance and guidance to the countries that desire to adopt the e-procurement systems (Pedersen et al., 2018).

Since the enactment of the Public Procurement Act (PPA) in 2001 (Nkinga, 2003; Suleiman, 2015), Tanzania has seen an increased use of e-procurement. The establishment of the Tanzania National e-Procurement System (TANePS) in June 2018 was among the long-awaited efforts for improving the operations of the e-procurement system in the country. TANEPS is a fully-fledged e-procurement system supporting the entire public procurement cycle in Tanzania, from planning, user registration, e-tendering, e-payments to e-contract management. It is based on Tanzanian public procurement laws, particularly Part XI of Government Notice (GN) No. 446, which provides regulations governing procedures for electronic procurement in Tanzania (PPRA, 2020). Many studies have looked at the general factors that influence the use of e-procurement, and most of them have focused on the context of developed countries (Ahmad *et al* 2019; Asare & Prempeh 2017; Shatta *et al.*, 2020a; Shatta *et al.*, 2020b; Shatta *et al.*, 2020c; Suleiman, 2015). In Tanzania, research indicates that the adoption of the e-procurement process was influenced by many factors, including, among others, the organisation's size, top management attitudes and support characteristics, relative advantage characteristics, and user involvement characteristics (Mchopa 2013). Consequently, another study found that legal framework, employee competency, technological infrastructure and security of data are a challenge in e-procurement implementation in Public sectors (Fanuel 2019). Another study found that most organizations were ready to embark on e-procurement if they had the existing in-house IT infrastructure, expertise, management willingness, and skills they had in their organizations (Nziku & Siwandeti, 2019). Despite the existence of these studies on adoption of e-procurement, there is limited evidence on the influence of e-procurement on employment performance. Therefore, this study assessed the adoption and influence of TANePS on employee performance at the following institutions in Tanzania: Government Procurement Services Agency (GPSA) and Public Procurement Regulatory Authority (PPRA).

2. Theoretical Framework

In this research, the adoption of technological diffusion theory was used. Technology is adopted by organizations based on the ease of its usage and its effectiveness (Padhi and Mohapatra, 2010). In some firms, the implementation of technology is by vote, while in others, it is by authoritative decisions. This theory has a huge effect on explaining the implementation of technology in an organization. The diffusion of innovation theory has had a considerable impact on information systems and has, therefore, been a widely used instrument to explain and predict rates of information technology innovation diffusion. It derives from rational theories of organizational existence and has its roots in economics, sociology, and communication theory, and has attempted to explain most individual adoption decisions (Padhi and Mohapatra, 2010). Past findings show that technology diffusion influences compatibility as well as simplicity in the application of new technology (Padhi and Mohapatra, 2010). The ability of firms to build on their competitiveness constantly is based on how efficient they are.

Employee performance is critical for the organization because the success of the organization is dependent on the employees' creativity, innovation, and commitment (Furnham & Ferrari, 1998 as cited in Nduka (2016). Good job performance and productivity growth are also

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important in stabilising our economy through improved living conditions, high wages, and an increase in the availability of goods for consumption. Nduka (2016) argues that research into individual employee performance is important to society in general. Employee production and employee job performance seem to be related. For instance, in the United States (U.S.), performance, in some cases, is measured as the number and value of goods produced. However, in general, productivity is associated with production-oriented terms such as profit and turnover (Nduka, 2016). Performance, on the other hand, is linked to efficiency or perception-oriented terms such as goal accomplishments (Nduka, 2016). Indicators of employee performance include a reduction in imperfections and procurement effectiveness (Padhi & Mohapatra, 2010).

The study evaluated implementation of TANePS and the performance of Tanzanian public sector officials using the model developed by Padhi and Mohapatra (2010) as indicated in Figure 1. In this model, user-friendly software design boosts IT readiness, evokes positive emotions in end-users and reduces end-user's internal resistance, and further enables staff adoption of new technology (i.e., e-procurement). Further, IT readiness might have a positive effect on end-user satisfaction, and therefore it positively influences industry internal resistance, and eventually it has a positive effect on e-procurement adoption. Management policies that aim to enlighten employees about the advantages of new technology also have a positive effect on the internal resistance of the department, and eventually they have a positive effect on e-procurement adoption. However, internal departmental resistance hinders the adoption of e-procurement. Finally, adoption of e-procurement might lead to procurement efficiency and reduce imperfections.

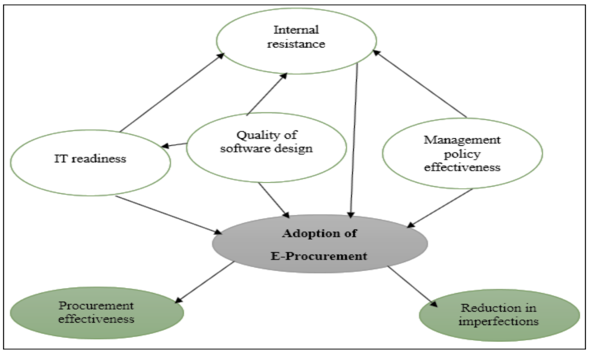

Figure 1: Research model adapted from Padhi and Mohapatra (2010)

3. Methodology

The study employed a case study design approach, where the study collected data from GPSA and PPRA. The study used the questionnaire survey to collect data from 200 employees, with a response rate of 66 per cent from the following categories: accounts, procurement, ICT, user and administration departments, and tender board. A five-point Likert scale, which ranges from strongly agree to strongly disagree, was used to measure all four independent variables. The independent variables were measured as follows:

The first variable was internal resistance (IR). The variable was measured by using three items from Padhi and Mohapatra (2010), which were: use of TANePS has increased non-cooperation of fellow officers due to changing power structures; use of TANePS has increased resistance from office staff to adopting new operational procedures; and use of TANePS has increased resistance from contractors.

The second variable was the quality of software design (QSD), which was assessed using three items from Padhi and Mohapatra (2010): use of TANePS has a user-friendly design of e-procurement software; use of TANePS has incorporation of high-level software security, and use of TANePS has compatibility of the software with the traditional procurement procedure.

The third variable was the IT-readiness (IT-R) variable, which was measured by using four items from Padhi and Mohapatra (2010), which were: use of TANePS has an effective training program to develop the IT skills of employees; use of TANEPS has the availability of adequate software and hardware resources; use of TANePS has the deployment of information system specialists; and use of TANePS has the availability of skilled personnel and financial support.

The fourth variable was the management policy effectiveness (MPE), which was measured by three items from Padhi and Mohapatra (2010): use of TANePS has the leadership and continued support of policymakers and top executives; use of TANePS has continuous monitoring and evaluation of the system; and use of TANePS has devised a plan to meet resistance to change.

The dependent variables of this study were adoption of TANePS, reduction in imperfections

ISBN: 978-99949-0-888-2

and procurement effectiveness. For determining the extent of TANePS use, this study first used a multiple-choice question from questionnaires about the percentage of people who use TANePS. Secondly, six items with a five-point Likert scale, ranging from never used to often used, were used to measure the usage of TANePS. A five-point Likert scale was used, with anchors ranging from 5 = very often, 4 = often, 3 = very rarely, 2 = rarely, and 1 = never.

The items for measuring the other two dependent variables were adopted from Padhi and Mohapatra (2010), which were reduction in imperfections and procurement effectiveness. A five-point Likert scale, which ranges from strongly agree to strongly disagree, was used to measure these variables.

On one hand, the reduction of imperfections was measured by using three items: the increased number of bid participants, reduction in tender fixing activities, and unethical practice by staff. On the other hand, procurement effectiveness was measured by using five items that looked on whether the use of TANEPS had enabled the following: centralized procurement, accrelerated achievement of higher process efficiency (less staff, reduced cost and time), easier implementation of variants of basic procurement process, efficiently made work order and work contract preparation, and easily simplified evaluating the procurement process to analyze contractor performance.

The employees' performance was measured using 14 items depending on the extent to which they agreed with the outcomes of the TANePS on employees' performance as explained above. A five-point Likert scale ranging from 5=strongly agree to 1=strongly disagree was adapted. The items to measure this variable were adopted from Panda & Sahu (2018). The study further assessed the use of various services in TANEPS by using a five Likert scale (i.e. from never to very often) on the following: user registration, e-tendering, e-payment, and e-contract management.

To increase the reliability of the data, the questionnaire was sent to the two senior researchers to check if the questions were correctly formulated and could be easily understood by the respondents. Reliability tests were conducted using Cronbach alpha. Further, data was validated using Exploratory Factor Analysis (EFA) to reduce data to a smaller set of summaries and is used to explore the underlying theoretical structure of the phenomena. A principal component analysis was performed using varimax factor rotation to group the factors and thus determine the category of factors (constructs). The values for the constructs in the validity tests using EFA surpassed the cutoff of .50 (Hair et al., 2014), and the Cronbach alpha thresholds of 0.7 (See Appendix A)

Furthermore, Confirmatory Factor Analysis (CFA) was performed to examine the measurement model's validity. We analyzed data using descriptive and inferential statistics. CFA was conducted with the measurement items that passed the EFA process. The measurement model reasonably fit the data ($\chi 2$ = 714.48, df = 186, p < .01, RMSEA = 0.084, CFI = 0.981), and standardized loadings were all equal or above 0.6 and significant (See Table 1). The Average Variance Extracted (AVE) values surpassed the cutoff of .50 (Hair et al., 2014) as indicated in Appendix A. The squared correlation between a pair of variables was less that the AVE values. Thus, convergent and discriminant validity were established.

Table 1: The measurement model

Model fitting parameters	Recommended value	Model result
Chi-square ($\chi 2$)		714.48*
Degree of freedom (DF)		186
Chi-square ($\chi 2$)/df	≤ 3.00	3.841
Goodness of fit index (GFI)	≥ 0.90	0.945
Normalized fit index (NFI)	≥ 0.90	0.906
Root mean square error of approximation (RMSEA)	≤ 0.08	0.084

The structural equation modelling (SEM) approach was used to validate the research model (see figure 1). AMOS version 26.0 was used to analyse the hypothised relationships generated from the research model (Figure 1). Furthermore, the descriptive and inferential statistics were used to present data. ANOVA tests were used to assess the degree of agreement on how TANePS had improved employee's performance in both organizations. ANOVA determines whether there was significance difference between the means.

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4. Study Findings

Adoption of TANEPS

The finding indicated that most respondents (67%, n=168) frequently completed their daily tasks easily by using TANePS, in the categories of often, mostly, and always. The study assessed the use of various services in TANEPS using user registration, e-tendering, e-payment, and e-contract management. On user registration, the study found that almost half of respondents at GPSA (47%, n=47) and PPRA (48.5%, n=47) used TANePS for registration, at the often and very often categories. With regards to e-tendering, findings indicated that two thirds of respondents agreed that they used TANePS for e-tendering both at PPRA and GPSA (88%, n=176) at the often and very often categories (See Table 2). On e-contract management, more than half of the respondents did not use service at GPSA (60%, n=60) and PPRA (59%, n= 60), as illustrated in Table 3. The use of TANePS for e-payment service are illustrated in Table 4.

Table 2: TANePS use for E-Tendering

E-tendering		Frequency	Percent	Mean	Std. Deviation	Mode
Valid	Very Rarely	24	12	2.89	0.61	3.00
	Often	46	24			
	Very Often	130	64			
	Total	200	100			
Missing	System	0	0			
Total		200	100			

Table 3: TANePS use for e-Contract management

	E-contract Management		Frequency	Percent	Mean	Std. Deviation	Mode
GPSA	Valid	Never	60	60	1.62	0..97	1.00
		Very Rarely	19	19			
		Often	11	10.5			
		Very Often	10	10			
		Total	100	99.5			
	Missing	System	1	0.5			
	Total		101	100			
PPRA	Valid	Never	60	59			
		Very Rarely	11	20	1.62	0.97	1.01
		Often	19	10			
		Very Often	10	10.5			
		Total	100	99.5			
	Missing	System	1	0.5			
	Total		101	100			

ISBN: 978-99949-0-888-2

Table 4: Use of TANePS for e-payment service

TANePS for e-payment		Frequency	Percent	Mean	Std. Deviation	Mode
		GPSA				
Valid	Never	18	9	3.50	1.01	3.00
	Rarely	22	11			
	Often	20	10			
	Very Often	40	70			
	Total	100	100			
Missing	System	0	0			
Total		100	100			
		PPRA				
Valid	Never	18	9	3.50	1.01	3.00
	Rarely	22	11			
	Often	30	20			
	Very Often	30	60			
	Total	100	100			
Missing	System	0	0			
Total		100	100			

Factors influencing the adoption of TANePS

We utilized the IBM SPSS AMOS 26 realistic program to perform SEM for the reason of speculation testing. Table 5 gives the computed values of different lists. Row1, 2 and 3 gave the chi-square (χ^2), Degree of Flexibility (DF) and their proportion, individually. Push 4, 5 and 6 gave the values of the Goodness of Fit Record (GFI), Normalized Fit Record (NFI) and Root Cruel Square Mistake Estimation (RMSEA) of the demonstrate. The parameters shown that the demonstrate was solid and we may utilize this show to foresee the connections among the builds (Shatta *et al.*, 2020a).

Table 5: Model fitting parameters for SEM

Model fitting parameters	Recommended value	Model result
Chi-square (χ^2)		714.48*
Degree of freedom (DF)		186
Chi-square (χ^2)/df	≤ 3.00 (Hair et al., 2014)	2.84
Goodness of fit index (GFI)	≥ 0.90 (Hair et al., 2014)	0.945
Normalized fit index (NFI)	≥ 0.90 (Hair et al., 2014)	0.906
Root mean square error of approximation (RMSEA)	≤ 0.08 (Hair et al., 2014)	0.084

Note N=200, p<0.05*

ISBN: 978-99949-0-888-2

The path investigation displayed in Table 6 indicated that the software design had a positive impact on the IT readiness of the divisions (b=0.696, p=0.042). Further, management policies had negative effects on inside resistance of the division (b= -0.517, p=0.002), and internal resistance had a negative effect on adoption of TANePS (b= -0.506, p=0.002). On the adoption of TANEPS, two factors had a positive effect on e-procurement adiotion, which were IT readiness (b= 506, p=0.002), and management policies (b= 0.474, p=0.002). Consequently, the adoption of TANePS had a positive effect on the effective procurement (b=0.674, p=0.007) and the reduction of imperfections (b=0.721, p=0.001).

The following factors were not significant. The IT-readiness had no significant effect on inner resistance of the divisions (b=0.689, p=0.106). Software design also had no positive effects on inner resistance of the organization's offices (b= -0.732, p=0.301) and adoption of TANEPS (b=-0.707, p=0.596).

Influence of TANePS on employee performance

The results of the one-way ANOVA, grouped by the outcome of TANePS on employee performance, indicated there were statistical significance differences between the grouped means on the following: performance was better when using TANePS than that of their previous performance (before TANePS) p>0.045 [F (2, 183=26.737, p=0.045]; TANePS increased accuracy of production capacity p>0.045 [F (2, 183=3.190, p=0.045]; and TANePS use shortened process cycle times p>0.024 [F (2, 183=17.347, p=0.024] (See Appendix B).

Table 6: Result of path tests with a regression weight

Hypothesis	***Path***	***Critical ratio***	***Sig. level***	***Standardized Estimate***	***Comment***
Ha	SD → ITR	1.567	0.042	0.696	Sig.
Hb	SD → IR	-2.056	0.301	-0.732	Not Sig.
Hc	ITR → IR	5.266	0.106	0.689	Not Sig.
Hd	MP → IR	4.592	0.002	-0.517	Sig.
He	MP → aTANePS	2.142	0.002	0.474	Sig.
Hf	ITR → aTANePS	0.947	0.002	0.506	Sig.
Hg	IR → aTANePS	5.383	0.002	-0.315	Sig.
Hh	SD → aTANePS	7.027	0.596	-0.707	Not Sig.
Hi	aTANePS EP →	7.843	0.007	0.674	Sig.
Hj	aTANePS RI →	6.573	0.001	0.721	Sig.

Note; b is the standardized estimate

Key*:* *SD= Software design, ITR= IT-readiness, IR= Internal Resistance, MP= Management Policies, aTANePS= Adoption of TANePS, EP= Effective Procurement and RI= Reduction of Imperfections*

ISBN: 978-99949-0-888-2

5. Discussion

On the use of TANEPS, the results showed that most of the respondents at both entities used TANePS frequently for e-tendering, and e-payment, while almost half of the respondents used user registration, and e-contract management had low use. These findings are in line with a number of scholars (Shatta et al, 2020b; Suleiman, 2013) who reported a similar trend on the extent of adoption of TANEPS in Tanzania. Indications are that although the system has been deployed, it has not been fully utilized. On the user registration, the results have high implications in the sense that no users can participate in the tendering process if they are not registered. Moreover, regarding the full adoption of e-registration, it has been confirmed that the use of the system poses challenges due to technological and semantical problems in the registration process. While some users lack understanding of the use of such a system, and some questions are somewhat ambiguous (Suleiman, 2013), the system at times makes it difficult for the registration to be effective due to its being slow and the laxity of users themselves (Shatta et al, 2020b; Suleiman, 2015).

With regards to e-tendering, the findings indicate high use of e-tendering has cut down the mistakes that people made when the tendering process was done manually. The findings are in line with those of Murphy and Eadie (2019) who mentioned that the use of such technology in tendering and the entire process of procurement has the potential to reduce human errors encountered during manual processing. However, in the process of tendering, it was revealed that some questions were ambiguous and required more precise answers than the reality. The presence of such facts has led a number of people to shy away from the use of this system. This has also been in line with the conceptual framework adopted from Padhi and Mohapatra, (2010) in which the use of a certain technology by end users has been associated with good software design, which, in most cases comes about in positive sentiments for end-users, and program plan quality diminishes end-user inner resistance to utilize e-tendering. The inverse continuously leads to more resistance and paper.

With regards to e-payment, the findings indicated the high use of e-payment were in line with other studies, which indicated that e-payments eliminate human errors and are always transparent (Suleiman, 2015), thereby improving and increasing efficiency in the entire procurement process. However, despite the reality that the system requires the use of e-payment, the system cannot be safe with regards to cyber security related challenges.

E-contract management service in TANePS was used at a low rate in this study. While the system has been deployed to work and manage all procurement activities, the sampled entities used e-procurement for contract management at a low rate. This implied that, even though the system had been deployed, not all of its functionalities were used. The findings were in line with those of Shatta et al (2020a), who clearly state that a reasonable number of procuring entities have not been using the system fully. and some have not deployed the system at all. This gave them a chance to use the old-fashioned system of procurement. On the same note, Callist (2020) affirmed that the exactness and proficiency of procedures were fundamental, yet organizations frequently overlook some aspects of the systems they need to improve to meet targets. On factors enabling adoption of TANEPS, the software design had a positive impact on the IT readiness (b=0.696, p=0.042). Hence, the quality of software design in terms of user friendliness, security and compatibility enabled the employees' IT readiness to effectively learn and embrace the e-procurement.

Management policies negatively affected internal resistance (b= -0.517, p=0.002). Gunasekaran *et al.*, (2008) reports that resistance to change is an impediment to the successful implementation of a new idea because end-users believe that the change will harm their interests. When the management has a concrete plan, however, the amount of resistance decreases. This finding suggests that management initiatives, aimed at exposing employees to new technology, and dispelling their fears of adoption, would enhance adoption rates. Thus, management policies need to be restructured to promote the benefits of using TANePS among employees to change their mindset towards using the e-procurement.

The study found that internal resistance negatively affected adoption of TANePS (b= -0.506, p=0.002). Where there is internal resistance in the organization, it is impossible to deploy a system (e-procurement) because people will not use it Similar to other studies (Shatta at al 2020b; Padhi and Mohapatra, 2010), this finding indicates that

ISBN: 978-99949-0-888-2

the organizations need to motivate their staff to cooperate and work together to adopt the new system. Further, there is a need to promote the benefits of using the new system to change their mindset. IT-readiness (b= 474, p=0.002)) had a positive effect on adoption of TANePS. Indications are that since individuals were prepared for an IT-related computer program, they would effectively embrace it. Agreeing to Dangmei (2019), the utilization of IT comes about in expanded openness to benefit suppliers, successful work allotment, and higher handling productivity.

At the same time, management policies (b= 0.649, p=0.002) had a positive effect on adoption of TANePS. Such findings are in line with other studies that top management policies and directives have a greater association with the deployment of e-procurement systems (Shata et al., 2020). This finding suggests that top management's leadership and smart policy design play a vital role in implementation of TANePS. Consequently, the adoption of TANePS had a positive effect on the effective procurement (b=0.674, p=0.007). This result highlights that TANePS has the potential to accelerate the achievement of higher process efficiencies, such as: reduced staff, reduced costs, reduced time, and increased process efficiency. This result is consistent with that of Afolabi et al., (2019) who reported that, in most cases, organizations adopt e-procurement in the hope of achieving the perceived results of the system. These results include improved effective procurement activities and reduced procurement shortfalls across the organization.

Further, adoption of TANePS had a positive effect on the reduction of imperfections (b=0.721, p=0.001). The results were consistent with those of Croom, Simon. (2006) who observed that the use of e-procurement facilitates access to many bidders, and that increased competition among bidders leads to a reduction in shortcomings in the procurement process. This means that TANePS makes it easier to attract a many suppliers, increases competition among bidders, and reduces errors and imperfections in the procurement cycle.

On the influence of TANePS on employee's performance, the study found that the use of TANePS led to better performance, increased accuracy of production capacity, and shortened process cycle times. The use of TANePS has led to tremendous improvement in workers' performance than the manual system that was previously used. It is also interesting to note that the system had reduced the amount of time that the procurement processes took to complete the cycle. Shatta et al (2020b) noted that the increasing use of the internet and information technology has modified and encouraged businesses to a transition from a traditional procurement and supply chain philosophy to a virtual e-procurement and automated supply chain philosophy. Hence, the e-procurement system has added speed and value to all the avenues and activities of the business, and the employee's performance in the surveyed institutions.**6.**

6. Conclusions and Recommendations

Based on the findings of the study, we draw the following conclusions. Automation of procurement is one of the important advancements that are targeting to improve the operations of procurement in the public institutions. However, in this context, the intention of TANePS will not be achieved if some of the functionalities are not utilized to the fullest capacity, such as user registration and e-contract management services. For effective adoption of an e-procurement system, the institutions need to ensure that there is an adequate and user-friendly software design, IT readiness for employees to learn how to use the system, and supportive management policies. Moreover, policies and directives will help minimize both internal and external resistance that, if not suppressed, would let down the system for their personal gains. In this study, the use of TANePS has had great improvement and efficiency in the procurement cycle, better worker's performance, increased accuracy of production capacity, and shortened process cycle times. Thus, for continuous enjoyment of such benefits nation-wide there is a need to ensure the following:

i. To minimize internal and external resistance to the system, the government procurement authorities should carry out a periodic system review and maintenance in which difficult, ambiguous, and contested segments can be revised.
ii. The government procurement authorities and public institutions should carry continuous training programmes so that all people across the country who need to use the system are aware of how to use it. Such training may be carried out by a team of PPRA technicians in every region.

iii. The government procurement authorities and public institutions should provide technical assistance to vendors when they face problems. A well-established call centre that works 24/7 with an active IT technician should be strengthened to enable IT readiness among users. It has been found that, in most cases, when vendors call for assistance, the lines are blocked or not answered. In this situation, bidders normally get discouraged and decide not to participate in the competition anymore. Thus, with unlimited technical support for system operations, the number of vendors will increase, thereby making competition stiff.

iv. The government procurement authorities and public institutions should continuously monitor, evaluate, and review management policies of e-procurement system to ensure the desired objectives are achieved. There should be continuous learning and reporting in TANePS. Systems need to be put in place to aid monitoring, evaluation, learning and reporting at every step of public procurement. Reports from this activity should be utilized in adjusting and improving the system for efficiency and effectiveness.

v. The government procurement authorities and public institutions should regularly strengthen the security, and stability of networks to ensure effective use of the nation-wide procurement system.

vi. While the theory of technology diffusion has mentioned issues of management policy, IT readiness, and quality of software design, among other aspects, it has failed to include an aspect of employee participation, right from planning to deployment of the system. Bringing a new system to employees who were not involved right from the beginning is likely to bring about internal resistance. Thus, an aspect of user participation during planning and design of the system should essentially be considered.

vii. Based on the outcomes of this study, additional research should be conducted to examine the impact of other TANePS modules such as E-auction and E-catalogue on employee performance. These two modules were not included in this study since they are not currently in use. The system will be completely functioning once all the modules are in place, providing for a more complete picture of how it promotes employee performance.

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ISBN: 978-99949-0-888-2

Appendix A: Results from Reliability and validity tests

Constructs and constituent factors	Mean	SD	Factor from CFA loading	Factor loading from EFA	Cronbach's coefficient alpha
1. *Reduction of imperfections*	–	–	–	*0.867*	–
Use of TANePS has increased number of bid participants	3.2	0.6	0.854	0.8716	0.892*
Use of TANePS has reduction in tender fixing activities	3.2	0.6	0.827	0.804	0.832*
Use of TANePS has reduction in unethical practice by government staff	3.2	0.6	0.871	0.802	0.853*
2. *Procurement effectiveness*	–	–	–	*0.861*	–
Use of TANePS has centralized procurement	3.3	0.6	0.807	0.931	0.708*
Use of TANePS has Achievement of higher process efficiency (less staff, reduced cost and time)	3.3	0.6	0.813	0.818	0.718*
Use of TANePS has Ease in implementing variants of basic procurement process (such as splitting and packaging of tenders)	3.1	0.6	0.801	0.803	0.755*
Use of TANePS has Efficient work order and work contract preparation	3.3	0.6	0.812	0.955	0.692*
Use of TANePS has Easy in evaluating the procurement process to analyze contractor performance	3.3	0.6	0.973	0.845	0.638*
3. *Internal resistance*	–	–	–	*0.881*	–
Use of TANePS has increased non-cooperation of fellow officers due to changing power structure	2.6	0.6	0.834	0.969	0.715*
Use of TANePS has increased resistance from office staff to adopt new operational procedures	2.6	0.6	0.802	0.817	0.789*
Use of TANePS has increased resistance from contractors	2.6	0.7	0.864	0.901	0.815*
4. *Quality of software design*	–	–	–	*0.789*	
Use of TANePS has user-friendly design of e-procurement software	3.1	0.7	0.989	0.973	0.796*
Use of TANePS has incorporation of high-level software security	3.3	0.6	0.764	0.774	0.701*
Use of TANePS has compatibility of the software with the traditional procurement procedure	3.2	0.6	0.741	0.743	0.713*

ISBN: 978-99949-0-888-2

5. *IT-readiness*	–	–	–	*0.783*	–
Use of TANePS has effective training program to develop IT skill of employees	3.4	0.7	0.869	0.899	0.700*
Use of TANePS has availability of adequate software and hardware resources	3.3	0.7	0.988	0.932	0.774*
Use of TANePS has deployment of information system specialists	3.3	0.7	0.967	0.981	0.721*
Use of TANePS has availability of skilled personnel and financial support	3.4	0.6	0.849	0.866	0.712*
6. *Management policy effectiveness*	–	–	–	*0.809*	–
Use of TANePS has leadership and continued support of policy makers and top executives	3.3	0.6	0.871	0.817	0.707*
Use of TANePS has continuous monitoring and evaluation of the system	3.3	0.6	0.989	0.982	0.749*
Use of TANePS has advance plan to meet resistance to change	3.2	0.6	0.802	0.891	0.874*

Note: *Significant at $p< .01$.

Appendix B: ANOVA analysis for outcomes of TANePS on employees' performance.

Statements (OUTCOME)		**Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**
Performance is better when using TANEPS than that of my Previous performance (Before TANEPS)	Between Groups	9.944	2	4.972	26.737	0.045
	Within Groups	33.659	181	0.186		
	Total	43.603	183			
Performance when using TANEPS is similar to my Previous performance (Before TANEPS)	Between Groups	195.383	2	97.691	561.668	0.067
	Within Groups	31.481	181	0.174		
	Total	226.864	183			
Performance when using TANEPS is Poorly than my Previous performance (Before TANEPS)	Between Groups	11.388	2	5.694	32.737	0.186
	Within Groups	31.481	181	0.174		
	Total	42.870	183			
Cost was reduced due to use TANEPS	Between Groups	4.903	2	2.451	1.365	0.258
	Within Groups	325.075	181	1.796		
	Total	329.978	183			
Reduced administration costs due to use TANEPS	Between Groups	25.137	2	12.568	14.592	0.156
	Within Groups	155.901	181	0.861		
	Total	181.038	183			

ISBN: 978-99949-0-888-2

Enhanced decision making due to use TANEPS	Between Groups	44.968	2	22.484	29.089	0.075
	Within Groups	139.901	181	0.773		
	Total	184.870	183			
Increased accuracy of production capacity due to use TANEPS	Between Groups	4.545	2	2.272	3.190	0.043
	Within Groups	128.933	181	0.712		
	Total	133.478	183			
Negotiated unit cost reduction due to use TANEPS	Between Groups	5.746	2	2.873	1.546	0.216
	Within Groups	336.379	181	1.858		
	Total	342.125	183			
Reduced operations and inventory costs due to use TANEPS	Between Groups	2.688	2	1.344	1.053	0.351
	Within Groups	231.046	181	1.276		
	Total	233.734	183			
Improved visibility of supply chain capacity due to use TANEPS	Between Groups	28.677	2	14.338	14.960	0.134
	Within Groups	173.475	181	.958		
	Total	202.152	183			
Improved market intelligence due to use TANEPS	Between Groups	35.093	2	17.546	18.754	0.367
	Within Groups	169.342	181	.936		
	Total	204.435	183			
Enhanced inventory management due to use TANEPS	Between Groups	4.288	2	2.144	1.634	0.198
	Within Groups	237.446	181	1.312		
	Total	241.734	183			
Improved contract compliance due to use TANEPS	Between Groups	13.034	2	6.517	7.377	0.501
	Within Groups	159.901	181	.883		
	Total	172.935	183			
Shortened process cycle times due to use TANEPS	Between Groups	33.103	2	16.552	17.347	0.024
	Within Groups	172.701	181	.954		
	Total	205.804	183			

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A Real-Time Notification System for Traffic Congestion on South African National Routes

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Abstract
Transportation is an integral part of our daily life, and now with an ever increasing number of cars on the roads, traffic congestion is inevitable. Traffic congestion has a huge impact on service delivery and, in turn, on the economy of the country. Social network has revolutionized our lives, and commuters are now able to vent their frustrations and post live updates regarding these congestions. Social networks have enabled humans to become active live sensors participating in the network communication paradigm. This paper leverages Naïve Bayes classifier of Artificial Intelligence (AI) for data classification, .NET MAUI framework for application development, Social Network Scraping tool for collecting traffic congestion data from Twitter, and Sklearn library of Python to prepare, clean, and make meaning out of the Twitter data. The outcome of the notification system will assist commuters to plan their trips efficiently using alternative roads as suggested by the real-time traffic congestion notification system developed.

Keywords: Traffic congestion, .NET MAUI framework, Social network, Snscrape, Naïve Bayes.

1. Introduction

Road transportation is the widely used mode of transportation for goods and people daily (Department of Transport, 2017). According to Tsikai (2016), the transport department in South Africa contributes 12 per cent toward the Gross Domestic Product (GDP). Although transportation is a catalyst for economic development, it has also led to the emergence of road traffic accidents and road traffic congestions, which negatively impacts the economy. Road traffic congestions occur in almost any city, usually in certain areas of towns, and on national roads/freeways (SANRAL, 2020). Mechanisms to manage these traffic jams by altering traffic signals to stop and go, appointing officials to direct traffic flow accordingly, and adopting usage of hardware sensors and cameras have been adopted in South Africa. As seen in studies (Cherkaoui et al., 2019; Jayapal & Roy, 2016), an attempt to resolve traffic congestion using Vehicle Ad-hoc Network (VANET) was discussed wherein vehicles on the roads are wirelessly connected to each other through a vehicle-2-vehicle communication topology to send out information to other vehicles in the same locale. The VANET approach requires installation of nodes on known road points to process vehicular information. Unfortunately, not all vehicles are designed to participate in the VANET network due to lack of technology in vehicles. Additionally, installation of nodes is costly.

Social networks have become a vital component for daily usage, and its platforms have seen greater improvements since the introduction of Web 2.0 technology that enabled the ability to share rich information through posts and tweets (Abyre & Elhissi, 2021; Bessedik et al., 2012; Hsieh et al., 2008). Platforms such as Facebook, Instagram, WhatsApp, and Twitter have benefitted from this technology which, in turn, benefits the research community to propose solutions using this geotagged data (Soto et al., 2016). Kemp (2022) reported that there are more than 4.3 billion active users, equating to 59 per cent of the world's population, demonstrating how humans are active live sensors. Therefore, researchers view social media as a gold mine of data that can be used to develop data-driven solutions in various fields and areas. For instance, Netflix collects data from users about shows and movies they watch, how they navigate around the application, and the times they usually interact with the application, to better recommend right shows at convenient times

ISBN: 978-99949-0-888-2

(Kamarudin et al., 2022). Disaster monitoring analysis by Sufi and Khalil (2022) suggested usage of Twitter live-feed data to constantly find out possible disastrous situations globally using sentiment analysis and AI-based location intelligence. Immanuel et al. (2022) used social media data to detect users' depression polarity scores using AI. Skiba (2008) explored social media data to attain misinformation on vaccines by users. Their study used deep learning network that reacts on visual and text data to block out anti-vaccine messages. Many of these models suggest the importance of using social media data to achieve various solutions. This study uses Twitter data due to its instant availability through scraping.

Twitter is an open-source social media platform that enables users to share thoughts using live-feeds in real-time (Yousaf & Gillani, 2014). These thoughts are known as *tweets*, which were limited to only 280 characters and may include links, and visual data such as short videos, pictures, and animations. According to Kemp (2022), Twitter is one of top 10 social networks with millions of users. Tweets are posted in plain human languages; however, in different languages due to the diversity of users.

To address traffic congestion, South Africa deploys the following mechanisms to alleviate traffic congestion issues resulting from failure of traffic lights or occurred road accidents:
Traffic officers/points-men are deployed to improve the traffic flow; however, the traffic congestion would not lessen unless more commuters are informed in real-time about the occurrence of the congestion, shown in figure 1.1.

Figure 1: Traffic Points men traffic flow control

Commuters make use of Google Maps, which contains a feature that shows traffic congestion on the map with red patterns. Google Maps is a popular location-based navigation application that provides information about coordinates, suggests routes to commuters, and estimates on the times of arrival depending on the mode of transportation. This application gives alerts when one has set up a journey, and it still makes use of live data from other commuters to pinpoint where there is traffic congestion. Its biggest advantage is it suggests rerouting of journey as it provides alternative routes and their differences in time. Below is a representation of a Google Maps application indicating traffic congestion.

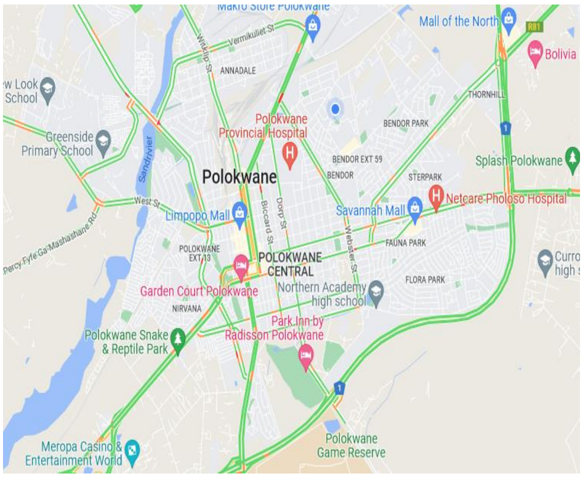

Figure 2 - Google Maps showing live traffic

At times it is useful to indicate the causes of traffic congestion, which would then give an estimate of how long the traffic congestion would last. However, having knowledge of traffic congestion estimates is not effective enough as commuters still need to get to their destinations, thus, it is crucial to provide detours to ensure time is not lost on the roads. As seen in figure 1.3 below, due to closure of the N3 route, a two-lane road was converted to a single lane road to swiftly manage traffic flow and allow commuters to use this detour lane to progress with their journey.

Figure 3 - One lane closed due to construction and traffic flow is managed.

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Broadcast communications also assist in relaying traffic congestion information to commuters through radio stations and televised news programmes. This information is limited, however, to main roads of metropolitans and is relayed on time schedules and may only benefit commuters travelling within the time schedules of broadcast communications (Yousaf & Gillani, 2014). Recently, broadcast companies are adopting the use of social media to disseminate the latest information they acquire in real-time. A downside of this is that it is limited to major cities. SANRAL (2020) wants to explore the use of machine learning (ML) techniques and algorithms to make effective use of the field devices acquired from detection systems and cameras, and traffic data from Global Positioning Systems (GPS) and cellular network providers. The Sanral Technology Innovation Hub (TIH) mechatronics engineer concurred that the use of this data can lead to automated incident-detection and incident-prediction models. The South African road infrastructure is considered ineffective (RTMC, 2021), when compared to other middle-income countries. The use of field devices would either be costly to install, or be limited to national roads, thus, leaving a gap on other rural/urban roads where traffic congestion would still be a problem. Table 1 below provides a summary of all the mechanisms deployed in South Africa to notify commuters about traffic congestion and other traffic related concerns.

Table 1 - Summary of mechanisms deployed in South Africa to address traffic related challenges

Traffic Related Mechanisms	**Challenges**
Traffic officers/points-men	These are only deployed in certain areas of the city, and provide no timely traffic-related information to incoming commuters in real-time
Google Maps Application	Only provides live traffic upon request and requires journey to be planned prior to receiving traffic updates.
Broadcasting Communications	Information is only available in fixed time schedules, and it only pertains to metropolitan cities.
SANRAL Adoption of ML	Field devices would be costly to install or, in contrast, be limited to national roads, therefore, only addressing traffic-related problems on major national roads.

Deriving social media data to make traffic congestion notifications would require deployment of machine learning and artificial intelligence techniques to understand and make meaning out of social media data. The paper employs Sentiment Analysis (SA), which is a machine learning technique to analyze emotions or opinions from textual data (Mejova, 2009). Social media data is sentiment-oriented, as people speculate and opinionate in discussions. SA will analyze the sentiment-oriented social media data to measure polarity, which is divided into positive or negative, and sometimes neutral. Document level analysis is applied on social media data as review on a traffic congestion is considered. For document level analysis, supervised and unsupervised learning methods can be used. This study uses Naïve Bayes algorithm, for classification purposes. Its advantage is its effectiveness and accuracy with little test data (Nasteski, 2017). The Naïve Bayes approach interprets a tweet as positive and negative, based on a helpful word level feature.

There is a need to propose a real-time traffic congestion notification system that makes use of sentiment analysis on Twitter data concerned with traffic congestion on national roads and classify the data using Naïve Bayes classifier. The data is then saved to a cloud database, Firebase Real-time database that allows callbacks of when data is inserted or removed. The proposed system is advantageous as it is less costly and should be effective compared to mechanisms listed in Table 1. Social media’s successful adoption is based on the success of smartphone and internet adoption by users worldwide, as reported by (GSMA, 2021), and the amount of data generated by users through social media is vital for research, where tools and techniques are available to harness data for better solutions in urban cities and rural communities.

In the next section, the related works pertaining to social media data and traffic congestion, and machine learning techniques and algorithms, are discussed. Section 3 describes the methodology followed to develop the proposed traffic congestion notification system. Section 4

ISBN: 978-99949-0-888-2

describes the implementation aspects of the proposed system regarding the tools utilized. Section 5 discusses the outcomes and makes evaluations of these outcomes and, lastly, section 6 concludes the paper with recommendations for improving the proposed system.

2. Related Works

This section discusses sentimental analysis in different areas and how it can be applied to social media data for predictive, recommender, and intelligent systems. The Web contains a large pool of available data generated through various streams, social media being one of them. Social media is a technology that enables sharing of ideas, opinions, and content on the Web, or through applications (Lenhart et al., 2009). Below, we examine previous studies on the usage of sentiment analysis on social media data, and the areas they employed this technique.

Elsafoury (2013) implemented a prototype utilizing traffic information tweets from Twitter for real time analysis in London. To extract tweets, parts of speech (POS) customized tagging method is used. Additionally, in conjunction with Google Geo-Coding API, tweets can be geo-located and analyzed. The geo-located tweets are used to draw routes on Google Maps, illustrating congested routes to commuters. Similarly, the proposed system makes use of Twitter data. However, in contrast, the proposed system retrieves any live tweet related to South African national routes. Not many users have their location turned on and may result in less data being mined.

Kumar et al. (2014) detected hazardous roads by accumulating hazard-related Twitter data posted by users. This paper's focal point is detection of hazardous road conditions using Twitter data through Twitter API. Data is then illustrated through map overlays, to alert commuters of road conditions on their current route. Twitter API is limited to the number of tweets to extract and requires one to have a Twitter account. This may cause a selected classification model to not produce desired results due to insufficient data. In the proposed system, Snscrape tool is used and can mine tweets dating back to a decade without account requirements.

Wang et al. (2017)'s model determined "talking points" of commuters in traffic congestion to assist relevant authorities for response and management of real-time traffic congestion. Natural Language Processing (NLP) and data mining techniques to extract traffic related tweets were applied. In contrast, Social Network Scraping API is used to mine data, then apply Naïve Bayes classifier algorithm to classify the data.

Lin and Li (2020) made use of crowd sourcing data from road accidents in the years 2016-2017 to predict complex patterns of traffic movement post a road accident occurrence through different methods. Traffic congestion conditions were divided into different levels, by embedding three ML algorithms, namely Random Forests, Support Vector Machine, and Neural Network. Their study focused on testing which of the three algorithms performs well with the crowd sourced data. In the proposed paper, social media data is used, which is relevant and current. Additionally, Naïve Bayes algorithm is used for classification purposes.

Staniek (2021) analyzed the effectiveness of a road condition tool (RCT) on crowd sourced data derived from mobile phones of commuters. The researcher assesses road defects by analyzing vehicle motion dynamics in road networks. Binary classifiers are used to confirm potential RCT. This paper focuses on traffic congestion caused by poor road infrastructure, assesses it, then notifies the municipality. The proposed system focuses on the existence of traffic congestions on South African national routes.

Putri (2021) provided a systematic review of intelligent transportation systems using NLP. Data used in this review is acquired from Scopus, and they utilized R programming language. To filter the data, they used the keyword "intelligent transport system", and the data was published from 1974 to 2020. They worked with structured data. In contrast to the proposed system, data from social media is recent and unstructured. The proposed paper uses Python programming language due to the availability of algorithms to process textual data.

Nguyen et al. (2022) proposed a solution that examines an automated data collection function that collects voice reports from commuters, uses deep learning approaches to analyze the voice data, and then provides the community with traffic updates in the form of awareness. They used Conformer model which is intended for classification tasks to mine speech recognition

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output for useful information. In contrast to the proposed system, textual information from social media is mined instead of commuters' voice reports.

This section reviewed previous literature related to traffic congestion and transportation systems that assist in predicting and detecting traffic jams due to various causes. Studies revealed similar methods and techniques to those of the proposed system. Several gaps were discussed for each related work; however, the standing out gap is that social media data, as raw as it is, is rich in information, and significant to intelligent and recommender systems. Moreover, it is important to mention the textual and unstructured data difference. Social media data supports research and automated applications and is significantly utilized due to its advantages over crowd sourcing and other datasets found on the Internet.

3. Methodology

Machine learning makes use of algorithms that could learn from historical data (Mitchell et al., 1990; Mitchell, 1999). Historical data refers to past experiences represented in the form of datasets, which are crucial for machine learning systems. This study uses social media data that is unstructured and will need to follow processes of extraction, cleaning, analysis, and make meaning that can provide sufficient information to researchers and users. Below are these data processes outlined in detail, and the tools and algorithms applied.

3.1 Data Mining

To retrieve tweets from Twitter, Social Network Scraping tool (*snsscrape)* is utilized. *Snscrape* is considered an API to scrape basic social media information from any social network without requiring authentication (Mancosu & Vegetti, 2020), unlike other APIs such as Twitter (Tweepy) API for Twitter, and Facebook Graph for Facebook. Additionally, this tool can extract more than 3200 tweets that span over a decade, compared to mentioned APIs. This tool will be used as a Python wrapper to mine for data on Twitter. The biggest advantage to using this tool is that there is minimal need to apply classification as it is able to filter out tweets based on the query provided. For this study, data was extracted from 6000 tweets related to traffic congestion on South African national routes, namely the N1 through to N18. Furthermore, tweets retrieved, spanned from 2018 to 2022. However, only tweets in English were filtered out using the attribute *lang:en*, standing for language. This shortens the preprocessing and classification that will be done on the data. As shown in figure 4, *Snscrape* has done most of the filtering task. However, data still needs to be preprocessed to ensure consistency and reliability.

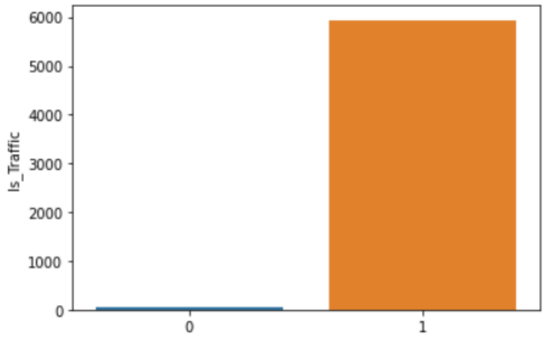

Figure 4: Tweets related to traffic congestion on SA national routes against tweets only related to traffic congestion acquired via Snscrape tool

3.2 Dictionary Creation

Data preprocessed in the previous phase was used to create dictionaries using Term Frequency-Inverse Document Frequency (TF-IDF), which calculates word importance in each document (Mishra & Vishwakarma, 2015). Traffic related congestions were obtained from the tweets using this technique to create two dictionaries, namely, traffic-congestion-route related dictionary and non-route-traffic-congestion dictionary, where sentiment analysis is then used to verify the tweets in the dictionary, and sklearn library for vectorization. These dictionaries are vital for the creation of the classification and topic modelling. Figure 5 and table 2 shows traffic-congestion related tweets and words respectively that are to be added to a dictionary.

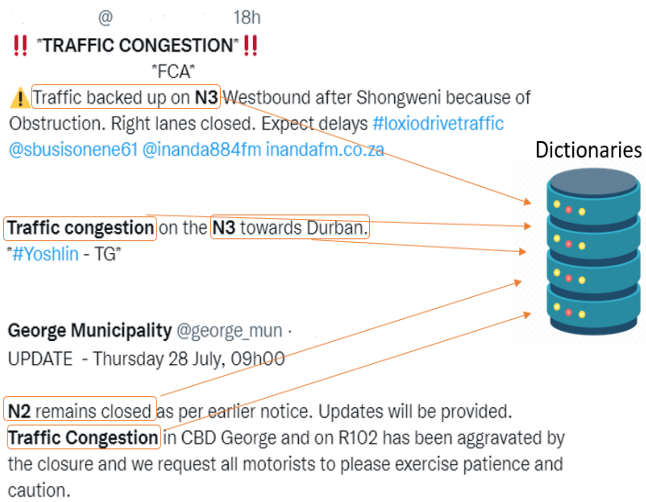

Figure 5: Dictionary creation illustration

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Table 2 showing some of the words that make up the traffic-congestion related dictionary

Traffic Congestion Keywords		
Traffic Congestion	Traffic Jam	National route 1, 2, 3
National route 4, 5, 6	National route 7, 8, 9	National route 10, 11, 12
National route 13, 14, 15	National route 16, 17, 18	Heavy traffic Rush hour

The tweets are filtered based on the keyword "traffic" appearing in a message; reason being that not all messages having the words "traffic" are related to road traffic congestion on South African national routes. For example, figure 3.3 illustrates some of the non-route-traffic-congestion incident tweets in the dictionary that are filtered out.

Figure 6: Non-route-traffic congestion tweets

For a tweet to be classified as a traffic-congestion-route, it needs to contain both the phrases "traffic congestion" and the name of the South African national route, e.g., "N1". Therefore, a machine learning classification model to classify any message as either traffic-congestion-route related or non-route-traffic-congestion is selected and trained. The two dictionaries are used in labelling the messages, by mapping the words in these dictionaries. For example, the following tweet in figure 7 would be labelled as traffic-congestion-route related, as it contains both phrases "traffic congestion" and "N3" which is one of the national South African route.

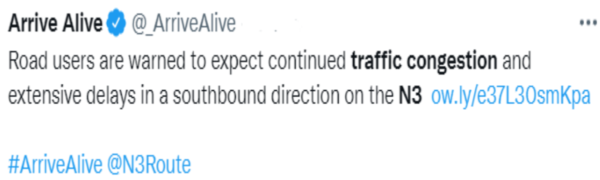

Figure 7: Tweet that would be an example of a traffic-congestion-route.

3.3 Data Preprocessing

Preprocessing is the process of cleaning data by eliminating special characters out of vocabulary words, emoticons, URLs, and social media features such as hashtags to list a few. For this phase, the data splitting processes were applied to ensure data is prepared.

3.3.1 Data Splitting

Using the train-test split mechanism provided by the Sklearn Python model library, the dataset was divided into 20 per cent testing and 80 per cent training data. The primary goal of a distinct train-test split is to ensure that class tests for train and test datasets are protected to the same extent as for the first class. To develop and analyze the model relying on the train information, the training data was also segmented into 5 folds' cross validation.

In data splitting these techniques were applied.

a) Cleaning

This technique involves the removal of punctuations and symbols (special characters) from the mined data (dataset). Using Regular Expression (RegEx) method, tweets that contain punctuations and emoticons are cleaned.

b) Tokenization

This technique involves the breaking down of sentences into words. This is crucial as an individual meaning entity to work upon is required. Therefore, due to first step of cleaning, tokenization can now occur on individual words. To achieve this task, nltk library was used in Python Programming.

c) Removal of Stop-words

Stop words are regarded as words in the dataset (tweets) that hold no meaning. Examples of such words are "I", "and", "or", "a", "have", etc. These words are removed as they were used solely to construct a sentence. This task was also achieved using *nltk* and *gensim* libraries.

d) Lemmatization

Instead of stemming, lemmatization technique was used as this is efficiently better. This technique is stemming, although, with a calculated process instead of guessing (Balakrishnan & Lloyd-Yemoh, 2014). It involves resolving the tokens to their dictionary form, that is, in full form. To use this technique, we made use of the nltk stem library. However, some stop words may persist from the dataset, and we improved this technique by identifying those stop

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words, appending them together, then having them removed.

3.4 Feature Extraction

Documents are transformed into document representations to allow for clustering. Document representation technique used in this study is TF-IDF, using the two equations below. For example, *tfidf* for the word "traffic" is ["traffic", "congestion", "heavy"], ["there", "bad", "taxi", "accident"] for tweet number 1 is:

$$tfidf\,(t = \text{"}traffic\text{"}, d = 1, D) = tf(\text{"}traffic\text{"}, d = 1) \times idf(\text{"}traffic\text{"}, D)) \quad \textbf{(1)}$$

$$tfidf(t = \text{"}traffic\text{"}, d = 1, D) = 1 \times log\,2\,|1| \approx 0.3010 = 0.3010 \quad \textbf{(2)}$$

From equations 1 and 2, the term document matrix after *tf-idf* is applied to the real-time tweets mined. The term traffic represents any of the keywords identified in table 2. Figure 8 indicates the document term matrix applied to extracted tweets.

```
(0, 31)      0.28048963048831294
(0, 59)      0.28048963048831294
(0, 50)      0.28048963048831294
(0, 63)      0.28048963048831294
(0, 2)       0.28048963048831294
(0, 71)      0.18546782437602974
(0, 28)      0.28048963048831294
(0, 47)      0.28048963048831294
(0, 19)      0.28048963048831294
(0, 67)      0.28048963048831294
```

Figure 8 : document term matrix

3.5 Classification Model

The state-of-the-art technique for classification purposes is presented below to distinguish between non-traffic-congestion and traffic-congestion related messages.

Naïve Bayes Classification Model

Naïve Bayes classifier was used to classify Twitter data in this study. Its performance was evaluated using accuracy, recall, and precision. Precision, measures number of traffic-related texts correctly predicted as belonging to a created dictionary. Recall determines the number of tweet text classified correctly. Finally, accuracy measures the number of texts, belonging and not belonging to a correct dictionary, that were correctly predicted. These metrics will help us understand how the Multinomial Naïve Bayes classifier performed on the twitter dataset. To verify these, polarity scores from performing sentiment analysis on the texts in dictionaries is performed. Traffic-congestion related tweets are assigned a positive sentiment, whilst non-route-traffic-congestion tweets are assigned a negative sentiment.

Using .NET MAUI, which is a framework for developing cross-platform applications, an application showing alerts of traffic congestion from live tweets was developed. The app's purpose is to relay the information to users when a tweet's sentiment is positive, i.e., related to traffic congestion. After this classification and polarity determination, the data is exported to a JSON file, which is a JavaScript Object Notation file that stores data in an organized manner. Using Firebase SDK, a link is created to service Python. From the dictionaries created in Python, they are sent to Firebase through a Firebase client library. Firebase provides a Realtime database to store data as a tree hierarchy, formally known as JSON tree. Figure 9 below is representation of this hierarchy.

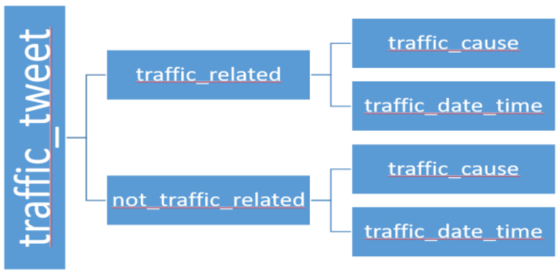

Figure 9: Hierarchy of JSON data.

Realtime Firebase Database offers live data monitoring. This means that whenever the Python library feeds the database with a live tweet, a tweet is saved, then invokes listener methods to perform a task with new data. The action is the same even when data is deleted from the database.

4. Experiments, Results, and Evaluation

Twitter data is of key importance to this study. In the first phase, data was collected using an efficient Python tool named *Snscrape*, as opposed to studies by (Nguyen et al., 2022; Staniek, 2021) where data was collected through voice reports and was crowd sourced respectively. The ability to use Twitter data to solve traffic congestion related problems has attracted a lot of research work, noting the work of Zulfikar (2019), where Support Vector Machine (SVM) classifier was utilized. The objectives were to use the real-time

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tweets about traffic congestion on South African National Routes to inform the masses through a mobile application. Advantages of using mobile phones are that this study can be utilized by countless commuters due to high adoption and usage of smartphones, as reported by (ICASA, 2022). However, smartphones have limitations that may affect the proposed system. It is important to note that the proposed system will only work if Internet access is available. Additionally, battery life may be a concern due to constant listening of tweets posted in real-time.
As new tweets arrive, they are classified as "traffic congestion route" related or, as "non-route traffic congestion" related, as opposed to a study by (Al-qaness et al., 2019) where they measured traffic congestion severity.

These tweets are subsequently subjected to sentiment analysis, to verify the results in the sense that traffic congestion route related tweets are given a positive sentiment, and non-traffic congestion tweets are assigned a negative sentiment. The sentiment and the topic extracted from the tweet are exported to a JSON file. Through the Firebase SDK Python library, the JSON file's data is uploaded to Firebase Realtime Database. However, extensive care is given to data prior to saving it. The data is preprocessed first using Regular Expression method and Natural Language Processing techniques. Figure 10 below is a representation of raw tweet that undergoes data preprocessing.

```
Raw data
                                               Tweet
0  Traffic congestion be what? E check like all d...
1  Traffic congestion on the TRAC N4 highway, tra...
2  The traffic in N1😳 I have never seen such a lo...
3  Authorities have advised motorists to avoid th...
4  BRAAMFONTEIN: M1 Southbound, ROADWORKS - traff...
5  Can someone help explain the cause of the traf...
6  N3 Toll Concession Operations Manager, Thania ...
7  Traffic remains affected on the N3 at Van Reen...
8  Traffic congestion on the N1 North, after 14th...
9  Congestion; N3 to DBN from Pavilion (St James ...
PS C:\Users\LangaRM>
```

Figure 10: Raw data extracted using *Snscrape*.

After preprocessing the data, punctuations, URLs, stop words, and emoticons were discarded, and results were as follows.

```
CLEANED DATA
                                               Tweet
0  Traffic congestion check like 29 million car ...
1  Traffic congestion TRAC N4 highway traffic he...
2  The traffic N1 long vehicular traffic congest...
3  Authorities advised motorist avoid N1 north G...
4  BRAAMFONTEIN M1 Southbound ROADWORKS traffic ...
5  Can help explain cause traffic congestion N2 ...
6  N3 Toll Concession Operations Manager Thania ...
7  Traffic remains affected N3 Van Reenens Pass ...
8  Traffic congestion N1 North 14th Avenue offra...
9  Congestion N3 DBN Pavilion St James Ave EB Cl...
PS C:\Users\LangaRM>
```

Figure 11: Processed Twitter data.

This data was then used to create dictionaries that are categorized as traffic-congestion-related and non-traffic-congestion-related. Tweets were divided into 80:20 ratios for training and testing of the model.

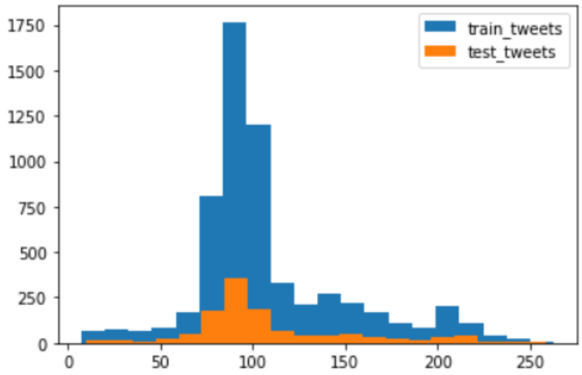

Figure 12: Train tweets vs Test tweets.

Figure 12 shows train tweets set against test tweets set to assist the model make better classification of traffic-congestion-route tweets and non-route-traffic-congestion tweets. From the 6000 harvested tweets, 2100 tweets were traffic-congestion-route related. From the set, 20 per cent (1200 samples) of the data was used as test data, as observed in figure 13.
Naïve Bayes classifier was then tested for accuracy, F-score, precision, and recall. The output of Naïve Bayes classification model is depicted in Figure 12.

```
              precision    recall  f1-score   support

           0       1.00      0.78      0.88         9
           1       1.00      1.00      1.00      1191

    accuracy                           1.00      1200
   macro avg       1.00      0.89      0.94      1200
weighted avg       1.00      1.00      1.00      1200

Confusion Matrix: [[   7    2]
 [   0 1191]]
AUC: 0.9990670771527195
```

Figure 13: Naïve Bayes confusion report.

ISBN: 978-99949-0-888-2

Based on these deductions, the Naïve Bayes classifier is suitable for classifying tweets into established dictionaries, as concurred by (Varghese & Jayasree, 2013). Figure 14 shows that the model can accurately predict between two categories of data, based on the count and frequency scores. The results obtained using Naïve Bayes are in line with results obtained by Meilani et al. (2021) on Twitter data.

```
NaiveBayes Tfidf Score:  0.9983333333333333
NaiveBayes Count Score:  0.9925
```

Figure 14: Accuracy prediction and count test data to achieve predictions.

Finally, features extracted were then exported to the Firebase Realtime database in JSON format. For a smartphone system, a background service attached to the Firebase Realtime database was implemented to be launched when a new tweet formatted as a JSON object enters the database.

From successful modelling, a mobile application was developed to relay traffic congestion on South African national routes to other users. Below is a representation of the mobile application user interface (UI) to show all the classified tweets on national South African routes.

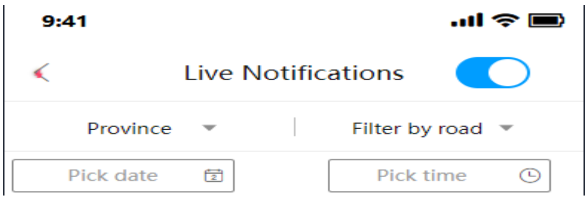

Figure 15: UI of the mobile application to relay extracted tweets related to traffic congestion.

Figure 15 illustrates live tweets filtering options when a tweet is tweeted in real-time. The application updates its user interface (UI) based on the data saved in the Realtime Firebase database. From the live notifications coming in, commuters can filter the alerts by province, national road, date of congestion, or time of congestion. To avoid interrupting notifications from the background service, the application has an option to toggle off and only receive notifications when within the application. This allows the commuter to receive notifications when and if needed.

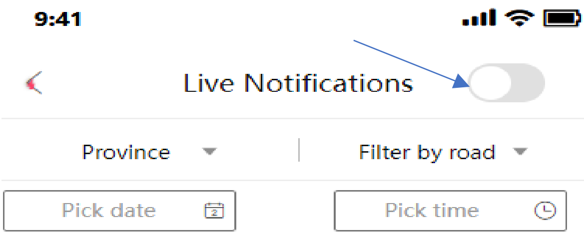

Figure 16: Turning off live notifications to avoid receiving notifications even when not commuting.

Most previous works (Kilaru & Ghosh, 2021; Xu et al., 2019) only focus on selecting the appropriate model for classifying tweets, whilst this study makes further use of the classified tweets to develop the said mobile application.

Using Firebase client in Python, figure 17 assumes that a live tweet related to traffic congestion was tweeted, preprocessed for extracting features, then submitted to the Firebase Realtime database via the client. When the database registers this tweet as a JSON object, a live notification appears in the application or, as a notification in the notification area.

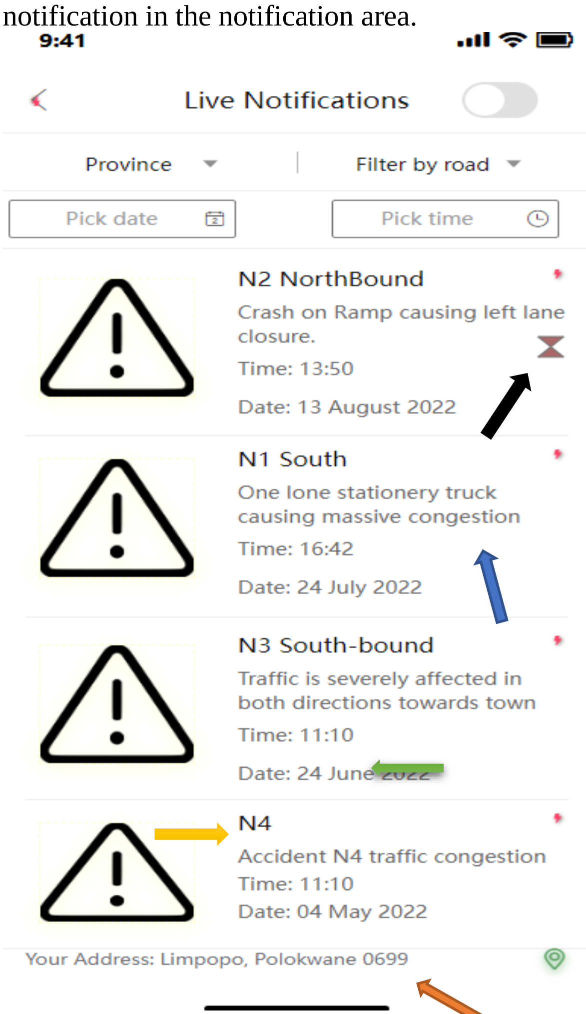

Figure 17: Tweets related to traffic congestion transformed to notifications on the mobile app.

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From figure 17, the following discussions are made from the assumption that a real-time traffic related tweet is tweeted and saved to the database.

a) Orange arrow:

The orange arrow at the bottom of the UI points to the information pertaining to the province where the commuter is situated. The location auto updates depending on the commuter's location.

b) Gold arrow:

The gold arrow points to the name of the national route in South Africa, which is one of the features extracted from an assumed real time tweet.

c) Green arrow:

The green arrow points at locale information which is the date and time when the tweet was tweeted. This is useful for when the commuter may want to know previously sent notifications.

d) Blue arrow:

The blue arrow points to the description of the traffic congestion notification. The description, when available, describes the causes or reasons behind the traffic congestion.

e) Black arrow:

The black arrow points to an icon that represents a recent notification.

The advantage of having a mobile application for visually representing this information is to assist commuters in planning road journeys. In the next section, we provide further discussion how advantageous the system will be to the commuters and the body of knowledge in addition to what was presented in this section. However, the system has limitations and these limitations are outlined. Comparison of this study's results against some of those in the related work is done in detail in section 5.

5. Discussion

The use of social network data to support model creation and testing, and intelligent systems, proved to be equally efficient, more so than data collection methods used in related work such as crowd sourcing (Staniek, 2021), speech reports (Nguyen et al., 2022), field and vehicular sensors (Lin et al., 2022). Compared to Elsafoury (2013)'s work, the proposed system establishes traffic-congested-route related tweets and further verifies classified tweets by applying sentiment analysis, to notify other commuters with locale of traffic congestions on the national route. Kumar et al. (2014) used Twitter API to mine for tweets, which is limited to only 3500 tweets. This study used *Snscrape* tool which has no limits to the number of tweets to mine, hence, the usage of 6000 tweets. All tweets, written in simple English relating to the phrases "traffic congestion, N1, N2… through to N18", are listed in table 2. These tweets were then used in implementing the Naïve Bayes algorithm, as it has been determined to give more accurate output on large data.

Wang et al. (2017) relied on "talking points" from blogs which are limited. There are few studies which make use of machine learning modelling results within a smartphone application, thus, this study makes a significant contribution.

However, there is a limitation to take note of, and that is this system is only suitable in the context of South African national routes. Additionally, the system relies on Internet access to retrieve data from Twitter, and to save the dictionary tweets in the Realtime Firebase database which is a cloud database. Mobile applications' drawbacks were also discussed, and it is important to mention in addition that the proposed system will only be utilized by commuters owning a smartphone.

The developed system was able to address the main objective of this study, which was to develop a real-time traffic congestion notification system that uses Twitter data about traffic congestion on South African national routes for the betterment of road users. The paper used natural language processing techniques to derive meaning out of data, and apply Naïve Bayes algorithm to classify tweets as traffic-congested-route and non-route-traffic-congestion, and to further develop a mobile application for notification purposes

6. Conclusion

The ever increasing vehicle population on South African roads has introduced major road challenges such as road accidents and traffic congestions. These challenges negatively affect service delivery which, in turn, hinders the economy. The results confirm the efficiency of the proposed system, that is, it can retrieve a tweet, segment it to find meaning that is then used to notify commuters of a possible road traffic congestion. This can improve road safety and flow of traffic. For future work, the paper recommends that the system additionally informs commuters about the duration of these traffic congestions.

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Investigating the Barriers of ICT use in Teaching and Learning at Public Schools in South Africa

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Abstract
Information and Communication Technology (ICT) has reshaped the field of pedagogy in many different ways. The increasing use of ICT tools in teaching and learning cannot be overlooked. Learners who are abreast with technology are independent and relieve overreliance on educators regardless of the geographical distance. ICT is important within the education sector as a means of enhancing the process of teaching and learning in a classroom. Despite the value of effective use of ICT tools, the South African government, having designed the curriculum to support effective ICT use in teaching and learning, and to some extent having provided ICT tools in public schools, there are still challenges in the effective adoption of ICT tools in teaching and learning.
The purpose of this study is to investigate the barriers of ICT tools use in teaching and learning and propose guidelines in teaching and learning at public schools. The study used a mixed-method and data was collected from public school teachers through a questionnaire composed of both qualitative and quantitative variables. To gain further insight, educationalists were also interviewed. It was discovered that there are multiple challenges that hinder the adoption of ICT in public schools. Key challenges identified in the study include a lack of ICT relevant skills, lack of ICT infrastructure, poor IT support, lack of efficacy from the level of teachers, and attitude were amongst many other influencers to non-compliance. The study recommends that the government adopt an ICT framework that will advocate for unison in ICT policy from all walks of government (district, provincial, and national) and also mandate and incentivize use of ICT by teachers in teaching and learning.

Keywords: ICT tools, Framework, South Africa, Public schools.

1. Introduction

There is an increased use of Information and Communication Technology (ICT), more so in the era of the fourth industrial revolution. As a result, (Mireku, 2016); Penprase (2018) suggests that with the advent of the Fourth Industrial Revolution, (ICT) becomes a sine qua non in the field of teaching and learning. Hence, training learners to adapt to the changes influenced by the fourth industrial revolution will play a vital role in driving effective use of ICT in teaching and learning (Gleason, 2018). ICT tools promote high-level communication despite space and time, and despite more cost-effective methods; ICT also increases productivity (Hernández-Bravo et al., 2016).

Furthermore, Sang et al. (2010)indicate that ICT tools promote improved and adequate learning settings to nurture flexible information construction in complex learning fields, and to provide for special individual differences. Moreover, Das (2019) alludes that ICT has the potential to have a significant impact on economies and communities by lowering information and transaction costs, creating new collaboration models to increase worker efficiency, encouraging innovation, facilitating access to essential services, and enhancing education. ICT use in classroom setting has been the subject of extensive research in recent years Arkorful et al. (2021); (Suleiman et al., 2020) (Dei, 2018); (Ojo & Adu, 2018). Dei (2020) suggests that implementing a well-designed ICT infrastructure in the education system can transform both teaching and learning practices. Arkorful, Barfil and Aboagye (2021) state that ICT enables more interaction between students and teachers, develops critical thinking skills, and enables students to better understand the material they are learning in class. Das (2019) further

ISBN: 978-99949-0-888-2

suggests that the advancement of ICT influences quality education by increasing learner motivation and improving basic learning skills.

In addition, ICT tools support the process of teaching and learning; however, there are challenges associated with the effective use of ICT in the teaching and learning process (Jamil et al., 2016) . According to Meyer and Gent (2016), ICT is important within the education sector as a means of enhancing the process of teaching and learning in a classroom. They further argue that while strategy and policy on information and communication technology exists in schools, implementation is slow, and capacity is limited. In a similar vein, the adoption objectives lack clarity and, as such, the strategy is poorly integrated. In support of this, Mireku (2016) argues that rural public schools face different challenges that do not occur in urban schools, such as a lack of teaching and learning software, ICT hardware devices, a paucity of infrastructure, etc. Furthermore, after the closure of educational institutions due to COVID-19, ICT was incorporated as a recovery plan in educational institutions, assisting them in transitioning from traditional learning techniques to e-learning, ensuring that learners continue their studies at home. (Maatuk et al., 2022), suggest the that most South African public schools, especially in townships and rural areas, were negatively impacted by the school shutdown, as they were unable to integrate ICT in their teaching and learning, due to the unavailability of necessary ICT resources. These militate against the introduction of computer courses and incorporating ICT in the teaching and learning, which will lead to producing non-competitive youth in the fourth industrial revolution.

1.2 BACKGROUND AND CONTEXT

It is evident that initiatives, such as digital, mobile and online learning, are all supported by ICT tools. Providing public schools in South Africa with high-quality education is the Department of Education's responsibility, but it is not the only one; other stakeholders also have a role, such as non-governmental organizations (NGOs), academic institutions, and other educational activists. In South Africa, there is a growing use of ICT in education, according to (Meyer & Gent, 2016). A major role is being played by ICT in driving education, and this role should be well planned. The authors add that the measurement of progression must be explicit in the planning of the process, and that there is a need to develop the skills and confidence of teachers to effectively use ICT, and to integrate ICT teaching and learning within the education system. Furthermore, the authors speak of increased focus on pedagogy in ICT to ensure strategic alignment for effective ICT use at all levels in the education system. The authors identify several role players in ICT use in education that include district, provincial and national levels. These role players are illustrated in the diagram below.

Three spheres of governance and role players for ICT in education

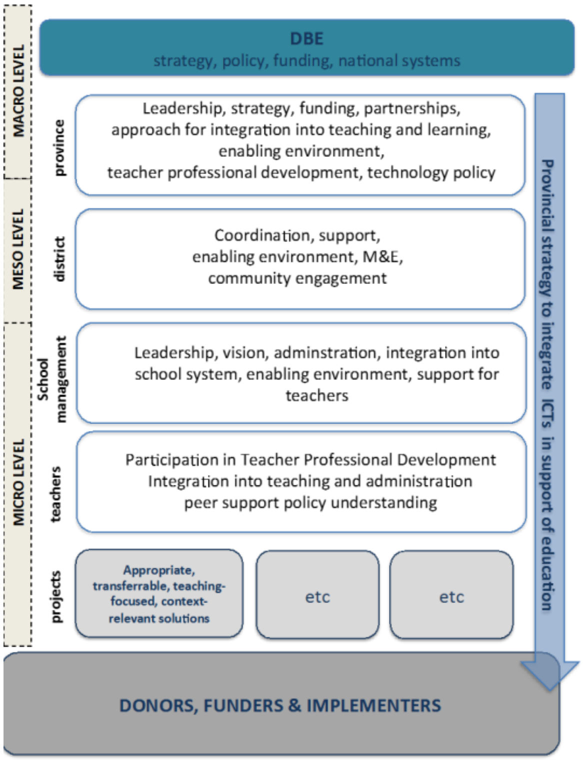

Figure 1. Three spheres of governance & role players for ICT in education (Meyer & Gent, 2016a)

These role players can influence the availability and effective use of ICT in education and it is suggested, therefore, that they be aligned from top to bottom at all levels. The authors touched on four key areas of effective use of ICT in teaching and learning that cover assessment, progression, participation and curriculum content. Elaboration of their importance was done, and these areas are vital to the effective use of ICT in education. In addition, the study identifies critical factors that should be incorporated across all levels of governance. These critical factors are illustrated in the diagram below, and include factors at macro, meso, and micro levels, as well as factors that would support alignment across all the levels.

ISBN: 978-99949-0-888-2

MACRO	***National and provincial*** *Provide leadership and facilitate integration* Leadership, vision, clear objectives, accountability, a strategy for ICT integration in support of pedagogy, a strategy for integrated teacher development, policy to ensure technology and content choices that are relevant to the context, enablement of other levels
MESO	***Province and district*** *Create an enabling environment* Capacity for support and enablement (teachers, technology, operations); community engagement; facilitate communities of practice
MICRO	***School management, teachers, projects*** *Create an enabling environment, learn and apply, integrate with the context* Create an enabling environment (systems, practices, scope for training); participate in appropriate professional development; learn from each other; develop and integrate context-specific, transferrable and affordable solutions; engage the community.
ACROSS	***All levels of the educational system*** *Ensure alignment* Ensure alignment from strategy through implementation. Align external stakeholders and ensure integration with the system before transfer of projects or programs. Also, recognise that different activities need to happen at different levels. Ensure that the right things are happening at the right places, in line with where the skills, scope and decision–making authority reside. For example, policies need to be developed and implemented to ensure that solutions are cognisant of the local realities; this needs to happen at the provincial rather than the national level. Furthermore, policies to ensure consistent standards need to be developed at national level, not provincial level.

Figure 2. Spheres of governance & their roles)

Conceptual Framework

The availability of ICT tools in schools does not automatically translate to their effective and efficient use in teaching, learning, administration and management. It is from an assessment of the current state of the effective use of ICT in teaching and learning, based on a framework that would support assessment, that guidelines may be proposed. Thus, stemming from the literature, six key elements for assessment are identified. These include government support, available ICT tools, security measures provided for the ICT tools, teacher efficacy, state of ICT tools, curriculum practices and use of ICT tools. Each of these elements is briefly discussed.

Government: The government's role in this framework is three-pronged: Formulation of ICT policies, provision of ICT tools and monitoring and control. Through the Department of Education (DoE), the government draws up ICT policies from the national government to be adapted and implemented by schools, which is in line with the mission and vision statement of the school. This will ensure uniformity across the Area Office (AO), provincial and national levels. Meyer and Gent (2016) observe that, currently in South Africa, a high misalignment of ICT policy exists. Furthermore, the role of ICT tools procurement should be a responsibility of the government (Bingimlas, 2009). It should not only provide financial relief, the government should

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also see that the tools are delivered on time to schools, that they are supported adequately, and it should also ensure that each school has more than one qualified educator who can impart ICT knowledge to support the subjects' content delivery. In addition, the policies drawn should also include targets in which performances, output and outcomes can be measured through proper monitoring and control.

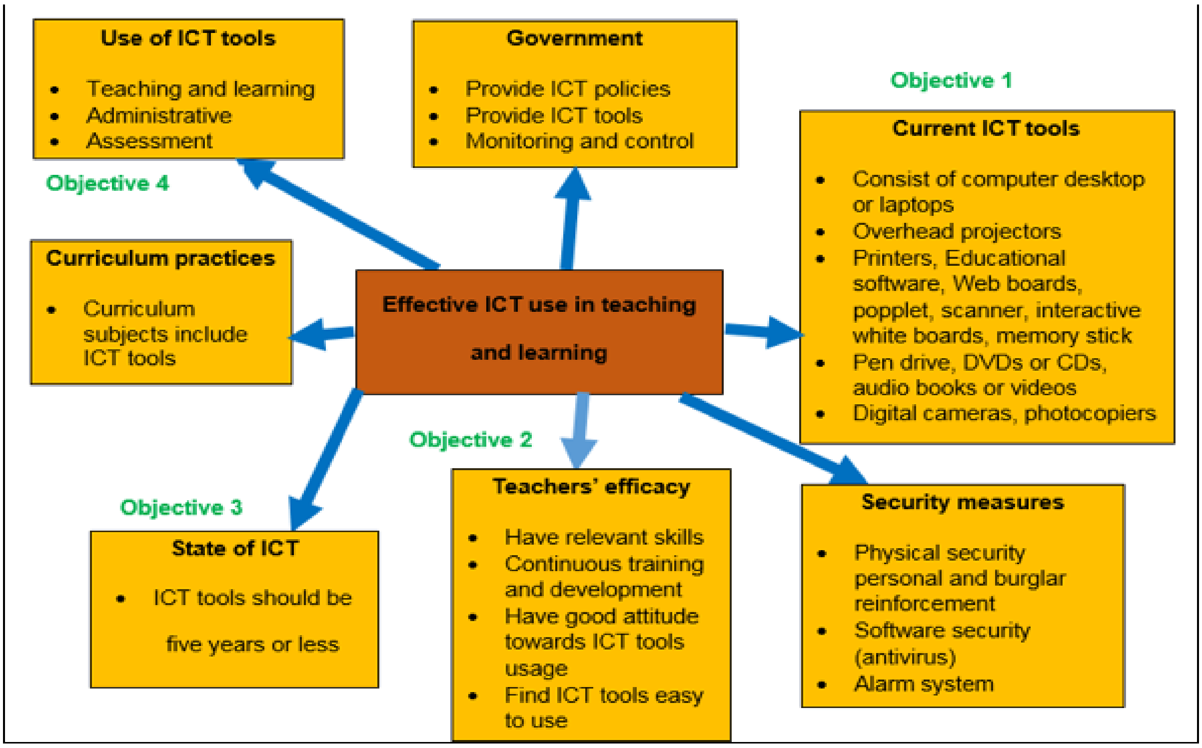

Figure 3. Hypothetical Model

Current and relevant ICT tools: There is a need to identify the ICT tools to be used in the school environment. This would be useful in terms of standardizing ICT tools in teaching and learning without being oblivious to the situation and locations of the respective schools. This will help the Department of Education to break barriers of a divide amongst learners; as such, learners from both urban and rural schools will be equally ICT savvy (Gillwald et al., 2018); (Mwapwele et al., 2019; Salam et al., 2018). Security measures: As a sequel to the provision of ICT tools, it is imperative to equally provide for adequate security to safeguard the equipment. This implies that the measures of ICT tools protection should not only cover the software, there should also be the presence of physical security such as burglary proof, closed-circuit television cameras, alarm systems, biometrics methods, etc., to protect the electronic devices. The importance of these measures cannot be overemphasized; it protects data and safeguards systems against infections and malware, which enables programs to run faster and smoother. In a similar vein, it also ensures that physical infrastructure is protected.

Teacher efficacy and use of ICT tools: One of the most important aspects in the framework is the teachers' skills and efficacy. The teachers will not teach what they do not know. Therefore, the Department of Education must ensure that the educators in the classrooms are knowledgeable on the usage of ICT tools; this would make it easier for its integration into teaching, learning, and evaluation. Furthermore, the status of skills and efficacy, as well as the relationship the two have would greatly impact the attitude of an educator towards their mindset about ICT tools and their usage in teaching and learning. If teachers have positive perceptions about ICT tools and are willing to use them, it would become the culture of teaching and learning in the school. This should be facilitated by the training arrangement for teachers, which should not be a once-off, but on a continuous basis as the ICT world is a rapidly evolving and is an emerging field.

State of ICT tools: The state or model of schools' ICT tools is of great concern. It is observed above that technologies are still emerging; therefore, government policies on ICT should accommodate the timely disposal and replacements of ICT tools that have become obsolete and outdated. This

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would accommodate the dynamism in teaching and learning, irrespective of time and space.

Curriculum practices: The contents of the curriculum in the 21st century should include ICT tools. Currently, not all subjects integrate ICT tools in their curriculum. All subjects should incorporate ICT tools in teaching and learning to avoid creating a divide amongst learners. This will prepare learners towards the opportunities and challenges of the 4th industrial revolution.

Use of ICT tools: It has been emphasized how ICT tools can be multi-purposeful in educational activities. Aside from facilitating and enhancing teaching and learning, ICT tools are also integrated into learners' evaluation as well as schools' administration and management. Learners' assessments and grading are done online without recourse to time and space. In a similar way, teachers' and other staffs' punctuality to school and classes could be monitored through electronic devices; meetings are conducted through video conference, and presentation done through Skype, etc. The synergy of components of this framework, when harnessed properly, would enhance the effectiveness of ICT tools in teaching and learning at public schools. However, when any of the components of the framework are not taken into consideration in the formulation and implementation of ICT policies for the school, the chances of posing challenges are high, because they are inter-related and interconnected.

2. Related Works

The potential benefits for the effective use of ICT tools in teaching and learning are of interest to research. Byrom and Bingham (2001) highlights that the rise of technologies has complicated effective use of ICT tools and poses challenges for teachers. Moreover, Byrom and Bingham (2001) suggest for effective use of technology, it requires changes in teaching; in turn, the adoption of a new teaching strategy could be a catalyst for technology integration. However, Tondeur et al. (2017)found that there was a mismatch between the educational change and the meanings attached to that change by those involved in the instructional process. Previous research into the effective use of ICT tools in teaching and learning has examined related subjects such as barriers to successful ICT integration in teaching and learning and ways to overcome those barriers (Bingimlas 2009).Assessment of teachers' skill and ICT integration in schools (Ramadan et al., 2018). The study found that teachers' adoption of ICT tools for teaching and learning is significantly influenced by age. When compared to their older colleagues, the younger teachers were more technologically savvy.

Furthermore, Erişti et al. (2012) examined teachers' views about the effective use of technology. This included processes, problems experienced and suggestions for the effective integration of ICT tools in teaching and learning. The relationship between teachers' pedagogical beliefs and their technology practices is critical (Ertmer, 2005). Teachers need to perceive the use of ICT tools in teaching is important for them to effectively use the tools(Ghavifekr et al., 2016).

Additional studies on the effective use of ICT tools in teaching and learning have explored the relationships among preservice teachers' conceptions of teaching using mobile devices and the quality of technology integration in lesson plans (Tsai & Tsai, 2019). Leadership stakeholders have an influential role in terms of the influence learning leaders have in the effective use of technology in the learning environment, and the types of professional development that best support learning for these leaders was described by Christensen et al., (2018). Regarding the assessment of ICT tools effectiveness, Kayisire and Wei (2016) assessed effectiveness through a case study approach using 40 African countries. Furthermore, Padayachee (2017), snapshot survey of ICT integration in South African schools found that teachers are uncertain with respect to the enforcement of effective use of ICT tools. This is confounded by poor infrastructure and a lack of skills, and it was recommended that future studies need to focus on implementation guidelines for use of ICT in class for both teachers and learners. Furthermore, it is no use in only identifying the barriers and recommending solutions without contextualizing the solution to the type of schools. Mireku (2016) stated that South African public schools do not have the same challenges as private schools when implementing ICT in teaching and learning; hence, this study examined the challenges that public schools encounter when implementing ICT in teaching and learning. This would make it easier to direct pertinent solutions toward the South African public schools' lack of effective ICT implementation.

3. Methodology

This study uses a mixed method to undergo the research process. The mixed method uses both qualitative and quantitative data to undergo a research study. The sampling method used for this study is purposive sampling; purposive sampling selects respondents based on their experience, role and knowledge (Etikan et al., 2016). Purposive sampling was used in this study to select the respondents, from 26 public schools, mostly villages and farm schools.

A sample size calculator was used to determine the sample of the study using Krejcie and Morgan’s (1970) suggestion that an N of 130 is sampled to 97 respondents, and for this study, only 59 participants responded by means of a questionnaire. Furthermore, five education specialists were interviewed from the Mafikeng North-west Department of Education. Confirmatory factor analysis was used for the quantitative data, and coding was used for the qualitative data. Ethics clearance was obtained. Participants gave written consent to participate in the study, for the dissemination of findings in the form of thesis, conference presentations and manuscripts. All ethics requirements were adhered to.

4. Data Analysis and Results

This chapter presents the discussion of the findings from the data analysis. To achieve the objectives of the study, the results were analyzed and presented as they appear in the different sections of the questionnaire and from the interviews.

The Cronbach Alpha measures the internal consistence in the data where we have Likert scale variables as in the present study. In this study the Cronbach's alpha is 0.948, which indicates a high level of internal consistency for our scale as shown in Table 4.1 below. Nunnally (1978) states that instruments used in basic research should have reliability greater than or equal to 0.70.

Table 1. Reliability Coefficient Alpha

Reliability Statistics	
Cronbach's Alpha	N of Items
0.948	56

Table 2. Validity Analysis - KMO and Bartlett’s Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.727
Bartlett's Test of Sphericity	Approx. Chi-Square	3938.197
	Df	990
	Sig.	.000

The table above displays the KMO and Bartlett’s test which measure the validity of the Likert scale instrument used in this study. The KMO in the study is 0.727 and means the data is factorable. Exploratory factor analysis can be conducted.

The analysis began by analyzing the demographic information of the respondents. Regarding the distribution of age almost half (49%) of the respondents were between the ages of 41 and 50 years, 31 to 41 years (28%), less than 30 years (9%) and over 50 years was 15 per cent. More than half (62%) of the respondents were female and only (38%) were male. The majority of the respondents (96%) were black educators. Only a few principals took part in the study (16%). Most respondents (68%) spoke the Setswana language and only a few respondents spoke other languages. Regarding lab facilitation, almost 87 per cent of respondents indicated that there were no educators responsible for lab facilitation. However, 71 per cent of respondents indicated that they had computers for administrative purposes and printers at their schools (61%), and 94 per cent indicated that they did not have computers for their subjects. Regarding overhead projectors, 52 per cent of the respondents disagree with their availability. Meanwhile, 49 per cent of the respondents agree that there are computer laboratories in their schools.

Confirmatory factor analysis

The confirmatory factor analysis (CFA) begins by testing for instrument validity and reliably using KMO and Bartlett’s test and the Chronbach alpha respectively. The KMO in the study is 0.727 and means the data is factorable, while the Cronbach's alpha is 0.948, which indicates a high level of internal consistency. Instruments used in basic research should have reliability greater than, or equal to, 0.70 (Singh, 2017). The CFA seeks to confirm the factors that contribute to the effective

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use of ICT tools in teaching and learning in public schools. The CFA starts with an unmodified measurement model, highlighting the four indices of interest namely, the Chi-square, Root mean square error of approximation (RMSEA), Comparative fit index (CFI) and Goodness of Fit Statistics (GFI) (Abrahim et al., (2019). Figure 4.1 displays the best model using the SPSS Amos software version 25. The best model complies with one index. The cmin/df is between 1 and 3. Although the model does not comply with the rest of the fit indices, it can be used to identify the factors that influence ICT integration as ,Schermelleh-Engel et al. (2003) states that even though a model has a good fit it, does not mean it is the correct model. Table 1 displays the fit indices. The model identifies six factors, namely: use of ICT tool (UICTT), security measures (SEC), Teacher Efficacy (TE), Governance (GOV), Learner Efficacy (LEFF) and State of ICT (SICTT) as factors that drive ICT Integration in public schools.

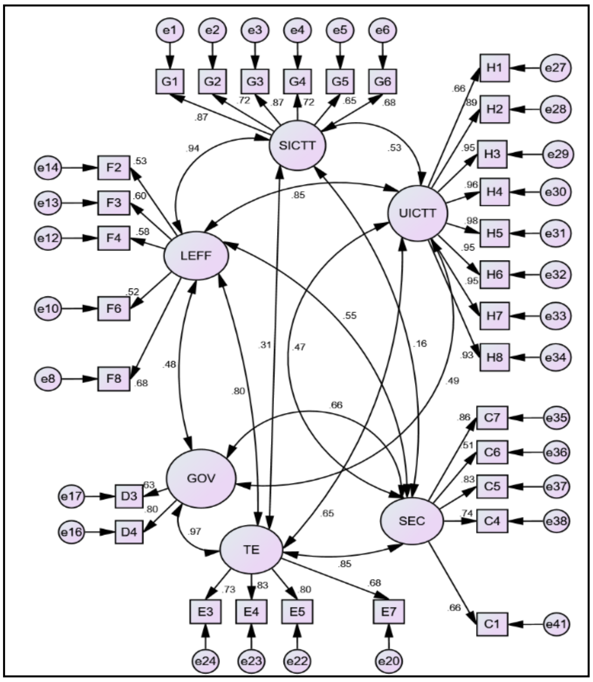

Figure 4. Best Measurement Model for ICT Integration

Table 3. Model Fit Indices

Metric	Observed Value	Recommended Value
cmin/df	2.616	Between 1 and 3
CFI	0.718	> 0.950
RMSEA	0.154	<0.060
PCLOSE	0.00	>0.050
GFI	0.551	>0.9

The best model complies with one index. The cmin/df is between 1 and 3. Although the model does not comply with the rest of the fit indices, it can be used to identify the factors that influence ICT integration. Schermelleh-Engel et al., (2003), state that even though a model has a good fit, it does not mean it is the correct model. A good fit model is regarded as plausible. This model is then used to identify factors that drive ICT Integration. The six factors are, namely: use of ICT tool (UICTT), Security measures (SEC), Teacher Efficacy (TE), Governance (GOV), Learner Efficacy (LEFF) and State of ICT (SICTT). All the mentioned variables are key in implementing a successful ICT tools integration in schools.

Qualitative data analysis

For the qualitative data analysis ATLAS. ti version 8 was used for coding the open-ended questions from the questionnaire. Two themes were identified from the qualitative data, namely Challenges of ICT Integration and Solutions for overcoming challenges. Table 4.4 displays the identified codes.

Table 4. Model Fit Indices

Challenges Effective ICT Use	Solutions for Overcoming Challenges
Administrative support	Computers and computer labs
Attitude of teachers	Electricity
Computers	Government support and monitoring
Electricity	ICT policies
Government support	ICT resources
ICT resources	Security
Limited data	Train educators in ICT Skills
Low maintenance	WIFI network connectivity
Low salaries	
Motivation	

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network connectivity	
Policy	
Poor infrastructure	
Provide resources	
Qualified and skilled teachers	
Security	
WIFI	

Respondents identified the availability of ICT resources as being the biggest challenge for effective ICT use in the schools followed by the availability of qualified and skilled teachers, the shortage of electricity, the shortage of computers in the labs, network connectivity and Wi-Fi connection. Low morale from teachers, lack of support from school administrators regarding the use of ICT resources, lack of Government support and poor government policies were also regarded as not being supportive of the effective use of ICT in schools.

Regarding solutions for overcoming the challenges of training educators in ICT technologies, they would be the provision of ICT resources to schools, an adequate supply of electricity, security in most schools, the provision of computer labs and computers, improving Wi-Fi connectivity, government support, the development of effective ICT policies, the training of educators in ICT technologies, and the provision of ICT resources. These would all help in improving ICT integration in the schools. Figure 4.2 displays a sematic diagram for the ICT integration for this study. A successful ICT integration is possible if there are strong and meaningful relations between “government support” and the “teachers” in using ICT Infrastructure.

Respondents from both the questionnaire and interviews indicated the same challenges regarding non-effective use of digital tools in teaching and learning in public schools.

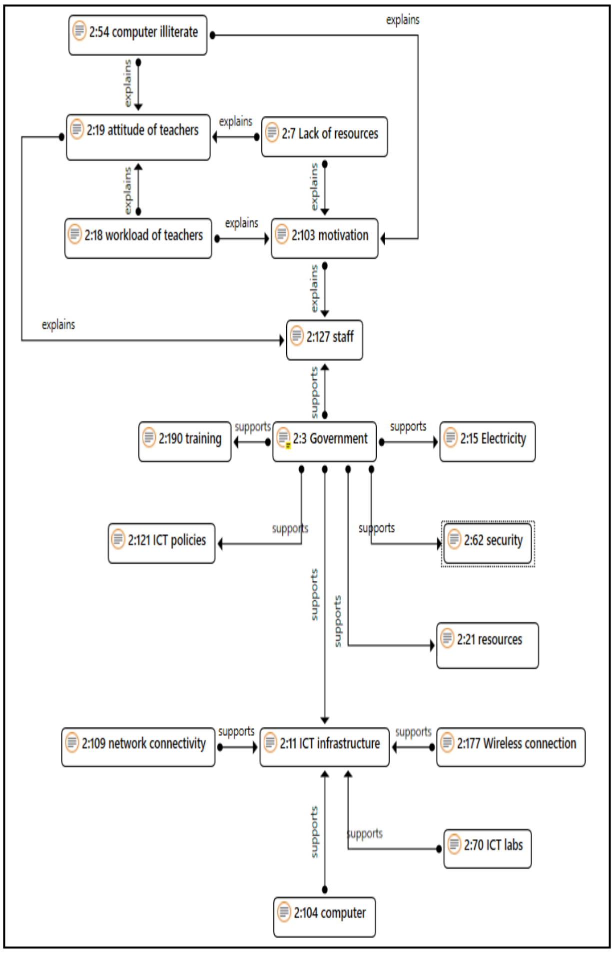

Figure 5. Semantic Analysis for ICT Integration

5. Evaluation and discussion

In this study, six factors were identified as being key in effective use of digital tools in teaching and learning. Government support, available ICT tools, security measures provided for the ICT tools, teacher efficacy, state of ICT tools, curriculum practices and use of ICT tools are the six factors that will promote the successful use of digital tools in teaching and learning once there is unison, understanding and collaboration. Meanwhile, there are challenges to the successful use of ICT tools in the classroom such as lack of resources, connectivity, electricity, and lack of support amongst many other reasons behind non-use by teachers. The DoE, as part of the government in public schools in the South Africa should mandate the use of ICT tools in teaching and learning of all subjects. ICT tools should not only be used for administrative purposes of the school but should also be part of a bigger practice. This move has shown rewards in developed nations. This move of integrating ICT in teaching and learning can only be made possible if there is a mandating policy from all levels of government; the national, provincial, and school levels.

ISBN: 978-99949-0-888-2

Teachers will only integrate ICT tools into teaching and learning if they are guided by policy. Successful integration of ICT tools in teaching and learning will require the voice of teachers, educationalists, policy-makers, national government representatives and information technology scientists to sit in the planning of ICT policy to voice and address all the possible challenges and concerns. From this meeting, there must be a coherent policy and framework that can be used in public schools.

This framework must also be accompanied by a performance standard for teachers as this will add an aspect of motivation to educators. This can also help meet objectives and add a point of compliance from the level of teachers and those that will be doing monitoring and support in schools. The government must assign a task team, especially for reasons of monitoring and support, and this task team must consist of pedagogical and technology experts. The task team must provide technical support and quality assurance to teachers to achieve the successful implementation of ICT in the classroom. Within the policy issues, such as teacher training, disposal of ICT tools and replacement and security strategies, must also be addressed within the policy.

This would help all schools to have equal chances of teacher training; it should be outlined that in any school, more than one teacher be trained to avoid disappointments should the trained educator leave the school. Otherwise, schools should also organize in-house training to empower all teachers in the school, and appoint a designated teacher who will oversee all ICT tools within the school. The selected educator will need to be inducted from the level of the district on the ICT tools policy, developed together with school's management about the ICT policy for the school.

The ICT policy must address issues of security. South Africa has high crime rates in schools, as was the case of Western Cape and Gauteng provinces when they were the first to run with ICT integration in schools. From the evidence gathered, it indicated that most dilapidated laboratories were a result of theft; therefore, security should be ensured at schools. Full-time security and alarm system controls would be ideal as it would benefit the holistic safety of the school. Burglar doors, window and cameras would also help if thieves already had access to the school's premises. Regarding empowering all schools equally, a development plan at the level of the province must be developed and adhered to. Another issue is one of electricity. Electricity in schools is important as the ICT tools need electricity to operate. Independent networks of the school's electricity must be revised to avoid possible disturbances from the community. Another issue of concern was connectivity; the government needs to invest in efficient connection tools for schools.

All the recommendations can be made, but there will be no growth without the financial injections from government. Therefore, it is the duty of government to ensure that financial muscle is being put in a school for the success of ICT tools integration. In addition, the most important resolution on ICT tool integration in teaching and learning is resource availability and teacher training; educators are the core implementers of ICT tools in teaching and learning and, if they are skilled, they will gain confidence and integration of ICT tools will, therefore, be a success. The South African development plans have the objective of developing ICT knowledgeable learners who can participate in the global economy. The success of this objective will depend on use in all provinces, and a coherent policy framework adoption.

6. Conclusion

The goal of this study was to look into the challenges associated with using ICT technologies for teaching and learning in public schools. It was found that there are several obstacles to ICT adoption in public schools, and until all of these obstacles are addressed, ICT tool integration in public schools would not be successful. The study proposes that many areas can be studied with regard to effective use of ICT tools in teaching and learning at public schools. For example, future studies could explore barriers to effective use of ICT in public schools using longitudinal studies. Furthermore, studies may examine assessing the effectiveness of ICT policies in public schools as the pressure from the fourth industrial revolution increases. Future research may investigate relevant ICT facilities that should be made available for teaching and learning in public schools, and a comparison may also be made with how private or independent schools effectively use ICT tools in teaching and learning.

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Evaluation of Mauritian IPv4 address space within Internet Background Radiation data

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Abstract

This paper explores the contribution made by IPv4 address space attributable to Mauritian organisations to the Internet Background Radiation (IBR). Data spanning a duration of 19 months starting in January 2021, from six discrete network telescopes is used as the basis for the analysis. A decomposition of the traffic is presented considering top origins by both ASN and netblock. An analysis is presented on the top 10 targeted TCP ports across the data. Alongside this an exploration is done into some of the more unusual probing for known vulnerable services that was observed. A determination of the reflected traffic and consideration of identified anomalies concludes the analysis. Mauritian IP address space is found to be relatively well regulated, and not have a large population of contributors to IBR either via active scanning or via reflected traffic.

Keywords: Network Scanning, IBR, Internet background Radiation

1. Introduction

The Internet has become a critical tool for the facilitation and distribution of commerce, education and entertainment. The necessity for reliable internet connectivity was further demonstrated during the recent global pandemic. While the vast majority of traffic traversing global networks is ’productive’ and non malicious, there has been a consistent gradual uptick in the degree of malicious, or at least questionable traffic observed targeting hosts. One of the challenges around being able to analyse this traffic is separating it from the traffic that should, or is intended to be there. A technique proposed by Moore (2002, 2003) was to monitor unallocated IPv4 addresses (or address blocks). Since these addresses were unallocated, unused and hosting no legitimate services there should, in an ideal world, be no traffic. Unsurprisingly there is a fair amount of traffic that is observable - generally produced though a combination of mis-configuration, active scanning and reflected denial of service activity. This traffic was termed by Pang et al. (2004) as *Internet Background Radiation* (IBR). IBR provides a valuable proxy by which to gauge the degree of unsolicited traffic traversing the internet, and from which other activities can be inferred.

This research considers the contribution of IPv4 addresses physically located in, or attributable to Mauritius. The country has a high degree of Internet usage with subscription rate of 143.3/100 inhabitants as reported by government statistics (Statistics Mauritius, 2021). Similarly, there has been a steady increase in the national aggregate Internet connectivity reported to be 211,312 Mbits/s, a 46% increase over the year prior, which was in itself a 42% annual increase (Statistics Mauritius, 2020). While a small country by all relative measures (population, economic, IPv4 allocation), it serves an important role within the African internet community with AFRINIC being hosted there, as well as a number of submarine cables interconnecting.

The results presented provide insight into the current state of affairs of network operation within the nation. A the rapid growth in both international connectivity, and usage by the population, it is not unexpected that more potentially malicious traffic may be observed (even though remaining a very small fraction of the total).

The remainder of the work is structured as follows. Section 2 introduces core concepts and related work. Sections 3 and 4 comprise the bulk of the work, respectively discussing the data collection and processing, and the interpretation of the results. Conclusions are presented in Section 5 along with some proposals of how the work, and findings could be applied in the future.

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2. Related work

While IBR is unsolicited traffic being recorded, it is important to keep in mind that it does not directly correlate with malicious activity. While scanning makes up the majority of observed activity, reflected traffic is also worth noting. Reflected traffic can be generated through two types of activity. The first of these is where spoofing has been used as part of network scanning to increase the difficulty of defenders in identifying sources. This is especially so with the use of TCP-SYN scans where only a single response packet is needed to determine hosts being alive or services present. Related to this is where spoofed address space has been used as part of a denial of service attack. In both these cases attackers have shown a preference for using 'dead' or non-responsive IP space for the spoofing. The use of this IP space ensures that there are no responses from systems receiving unanticipated connections - and in the case of TCP responding with TCP-RST packets. The differences in the observed IBR data are broken down further in Section 4., with a specific analysis of reflected traffic in section 4.3.

Little work directly referencing Mauritian Address space or network security in general was found for a direct review. Two notable sources relating to Internet Security within Mauritius are Maistry et al. (2015) and the later Abrahams and Mbanaso (2017). Both point out the need for and importance of security - something that is of increasing importance as countries transition towards digital and information economies. In order to achieve the latter, fast, reliable, and most importantly security information communication paths must be available. Today this is provisioned via the global Internet. In terms of prior research looking at the prevalence of Mauritian IP addresses appearing as part of larger scale surveys, works by Padmanabhan et al. (2016) and Griffioen and Doerr (2020) have a stronger relationship with the work described here. Padmanabhan et al. (2016) highlight Mauritius Telecom as one of the top 20 network operators that periodically reassign IP address space. Griffioen and Doerr (2020) ranked Mauritius Telecom (AS23889) as 14th in their ranking of telecom operators by IP address churn, using network telescope data focused on traffic relating to the Marai botnet. This ranking is likely closely linked to and influenced by the findings in Padmanabhan et al. (2016).

This paper provides a suggested step towards being able to quantify, and ultimately enhance the security of a national network using passive intelligence gathering techniques, the output of which can be used for more proactive identification, mitigation and remediation of issues.

3. Methodology

This research considers Internet Background Radiation (IBR) data collected during the nineteen month period spanning January 2021 until the end of July 2022. The discussion below addresses the process followed in terms of the data collection and selection for this research and the subsequent processing and preliminary interpretation of this data.

3.1 Data Collection

The data was collected using six network telescopes. Each telescope comprised a /24 IPv4 netblock within the allocation of IPv4 address space under the purview of AFRINIC. The data collection systems were located at a core datacenter of an African NREN. Sensors are names primarily by the most significant octet of their address space (equivalent to the /8 in which they reside). In the case where there are multiple blocks being monitored within a /8, the initial naming is followed by an alphabetical value based on the date of commissioning. Sensors 146 and 196D did not span the entire period as indicated in Table 1. They have however been included as they show noted similarity to the other four and have an overlap in operation. The sensors are suitably distributed numerically, as well as topologically in that unintentional sequential scanning is unlikely to run across all netblocks. These collection systems are part of a much longer-term project dating back to 2007. It was felt that given the concerns around the geolocation data as discussed in Section 3.2, that while a longer temporal baseline of data was available, it made sense to constrain this data from the start of 2021.

Traditionally major contributors to IBR have been in the East, China, Korea, Russia and in the west the USA, Canada and Brazil. The degree of contribution is largely linked to costs of internet connectivity, internet adoption, and most significantly the number of IP addresses in use (Irwin, 2013; Pang et al., 2004; Wustrow et al., 2010). These factors together with national legislation around Internet Security, all correlate with the general volume of scanning, and potentially malicious traffic emanating from an IP range (and ultimately country).

The data was collected using tcpdump to record all incoming traffic for the monitored netblock received via a dedicated network interface. The netblocks being monitored by the IBR sensors were routed to collector systems from edge routers on the NREN network. No upstream filtering was applied to this traffic. The collector systems in turn discard all

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received datagrams at the receiving interface and have explicit firewall rules in place to prevent any response being generated. The resulting capture files (using the widely adopted *libpcap* format) are periodically rotated, compressed and moved to other systems for processing. All timestamps are GMT/UTC+2.

Table 1: Sensor Capture Duration

Sensor	Start	End
146	1/1/2021	23/11/2021
155	1/1/2021	31/7/2022
196A	1/1/2021	31/7/2022
196B	1/1/2021	31/7/2022
196C	1/1/2021	31/7/2022
196D	1/6/2021	31/7/2022

Table 2: Sensor Events (millions)

	Year		
Sensor	**2021**	**2022**	**Total**
146	400	-	400
155	411	352	763
196A	452	401	853
196B	416	351	767
196C	420	363	783
196D	150	421	571
Total	2 249	1 888	4 137

Sensor 146 ceased operation in 11/2021

3.2 Data Processing

One of the first challenges in processing the data was the identification of appropriate netblocks to include in the scope of constraining the evaluation to Mauritian IPv4 Address space. An initial filter was done using the Maxmind GeoLite2 Country database This was then subsequently validated using the service from Team Cymru[1]. The one deviation between these is noted in the discussion around results. From this process, 862 netblocks were identified, comprising a total of 4.6 million IP addresses (approximately 0.12% of the usable IPv4 address space). Considering the population size this is 3.75 addresses/inhabitant. While there is some question over the absolute accuracy of Geo-location services as noted by Poese et al. (2011), this is less of a concern when looking at country rather than absolute co-ordinates or city level. As such, and given the exploratory nature of the work, the use of two independent resources, and the lack of a list of address blocks from an authority such as CERT-MU the approach taken was felt to be reasonable.

The address lists were used with `tcpdump` to apply selective filtering of all TCP, UDP and ICMP traffic originating from these blocks found within the IBR datasets. The resulting files were processed using a combination of tools such as `libtrace` (Alcock et al., 2012), `tshark`, `editcap` and `capinfos` in conjunction with a number of shell scripts for data manipulation and integration. An overview of the makeup of the approximately 4 billion IBR events collected and processed is shown in Table 2.

The initial extraction and filtering processes resulted in a substantially smaller dataset of just over 1 million events. An overview of the results can be seen in Table 3. This data was used as the basis for the remaining analysis presented in this paper. The examination of this data was guided by prior work such as Benson et al. (2015), Iglesias and Zseby (2019), Irwin (2013), Pang et al. (2004), and Wustrow et al. (2010). The results of this are discussed in the section following. The resulting data and scripts used for undertaking this research are available via GitHub (Irwin, 2022). To preserve the privacy of endpoints (including any potential compromise or vulnerability), the final octet has been masked when individual addresses are noted.

4. Results

Following the analysis undertaken in the previous section, 13 054 individual IP sources were identified. Of these, 12 895 (98.7%) were attributable to active ASNs at the time of writing. These originated from 338 netblocks, which in turn were contained in 73 ASNs. AS23889 contained the majority of addresses. This is not unexpected given the large proportion of IP allocations within this AS. The remaining 160 addresses are discussed in Section 4.4 as part of the anomalies identified in the research. Figure 1 provides an overview of the hosts observed during the period of study. Plotting the number of unique hosts seen each hour is a better measure of the diversity of the activity as opposed to packets where a few noisy hosts can obscure the picture. From this plot two areas of increased activity are present - in mid-December 2021 (16-19th), and mid-June 2022 (11-15th).

In both cases these spikes are linked to a burst of traffic from multiple sources. December's burst of traffic is attributable hosts within 45.195.x.0 /24 probing on ports 1434/udp, 6881/udp, 8000/udp, 8082/udp. Each host in this group only sent a few probe packets. This bears similarity to the use of decoy scanning. June's spike peaked on the 12th,

[1]https://team-cymru.com/community-services/ip-asn-mapping/

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Table 3: IBR attributable to .MU addresses

Sensor	Year 2021	Year 2022	Packets Total	% TCP	% UDP	% ICMP	% Other
146	38 883	0	38 883	91,86	7,30	0,52	0,32
155	66 686	86 584	153 270	59,66	3,90	36,36	0,09
196A	126 944	124 544	251 488	52,14	15,50	32,31	0,05
196B	92 528	123 429	215 957	60,47	2,89	36,58	0,05
196C	89 352	117 789	207 141	59,89	2,77	37,28	0,05
196D	57 583	124 551	182 134	42,59	2,31	55,04	0,06
Total	471 976	576 897	1 048 873				

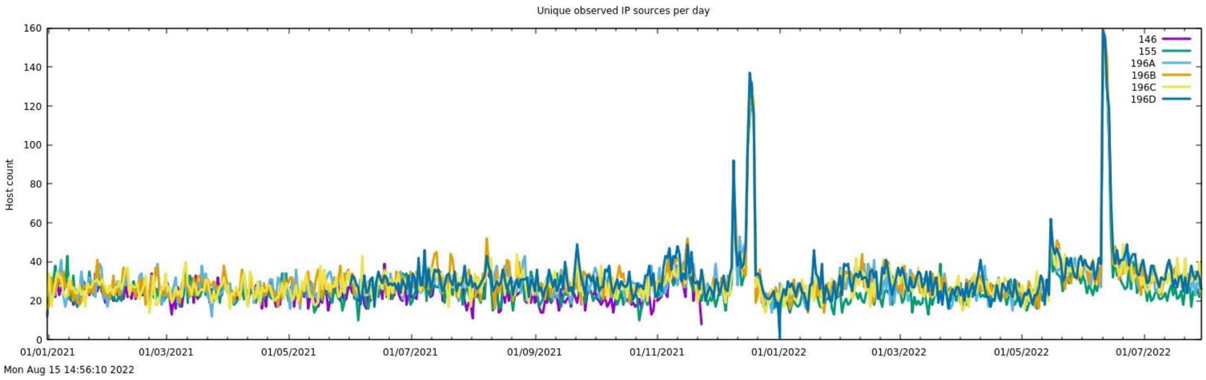

Figure 1: Timeseries for IBR sensors

and exhibits very different behaviour, with a spike in hosts traffic from across 124 /24 blocks, but with an appreciable contribution of nearly half the hosts identified from a /24 in 41.164.0.0/16. The IBR emissions seem to have been quite widespread, given the alignment visually as in Figure 1 and in the raw data. What is of interest is that when considering the rate at which packets were received, which remains fairly consistent as in Figure 2, The log scaling of the y-axis of the latter is due to a massive spike recorded by Sensor 196A on the 16th March 2021 of 32 000 packets. This appears to have been a co-ordinated scan, or even attack against a single host of 196.AAA.AAA.212, which originated from five hosts in two consecutive /24's within 45.204.0.0/16. This traffic was a flood of amplification attempts using the NTP monlist exploitation (Rudman & Irwin, 2016). With this considered, along with the volume, this was more than likely an attempted amplification attack against these hosts. The netblock in question appears to have been sub allocated to a cloud services firm in Hong Kong.

Table 3 presents a summary of the resulting observed traffic across the network telescopes (IBR sensors). This is broken down by year and in the cases of all sensors, more traffic has been observed in the first seven months of 2022 than in 2021. The one exception to this is seen in 196A. The volume of traffic across those sensors in 196/8 is fairly consistent, with 146 and 155 having lower observation counts. This is similar to that observed by Irwin (2013) showing that 'older' netblock allocations appear to receive less IBR.

Considering the traffic composition of the IBR as shown on the right of Table 3, almost all traffic was spread among the three 'classic' protocols of TCP, UDP and ICMP. More detailed composition of TCP and UDP is presented in Section 4.2. ICMP traffic is interesting in that traffic of this type presents at a much higher proportion than seen in other studies. The majority of this looks to be active probing via ICMP type 8 (ping) messages (Postel, 1981).

In the case of 196D-2022 all but 38 ICMP packets fall into this classification, 44 610 (60%) of which target 196.*DDD*.*DDD*.1 - a pattern of behaviour indicative of checking if a target network is 'alive' as .1 is typically used for gateways. ICMP datagrams of types 3 (unreachable) and 11 (TTL exceeded) (Postel, 1981) are present but in minimal amounts. This is indicative that the IBR sensor ranges have not been spoofed for use or used in DDoS attacks against .MU addresses. Overall 'ping' packets account for over 99% of the ICMP data as expected for scanning or 'liveness' probes. The handful of packets not falling within the three primary Internet transport protocols were all IP type 17 (GRE) packets (Farinacci et al., 2000). These unencrypted, isolated datagrams are mostly attributable to a Microsoft VPN adapter sending to hosts globally. How these packets ended up at the IBR sensors is unclear. The following sections explore the received traffic in more detail.

4.1 Top Sources

Considering the sources of traffic received, of the IP addresses attributable to an active ASN, 96.5% are contained within the top 10 ASNs. This is shown in Tables 4 and 5. With nearly 70% of the total identified sources AS23889 operated by Mauritius Telecom is a significant contributor. This ASN appears to have the largest range of netblocks within the .MU ranges, and as such its appearance is unsurprising.

Table 4: Top 10 Identified ASN Sources

Rank	ASN	IPv4 Src	%
1	23889	8 862	68,72
2	30844	1 832	14,21
3	36937	691	5,36
4	30999	341	2,64
5	37100	294	2,28
6	40065	184	1,43
7	327693	77	0,60
8	137443	73	0,57
9	133847	57	0,44
10	133199	43	0,33
Total		12 454	96,58

Considering the top 10 most active netblocks, based on the number of unique hosts observed, traffic attributable to these constitutes 56% of the total hosts observed. It is no surprise that nine of these fall within AS23889. It should be noted however that only 1.5% to 3% of the hosts in these blocks are being observed, indicating that the majority are likely *not* involved in Internet wise scanning or other activities detectable.

Much of the identified activity is scanning on well known exploited services such as 23/tcp (telnet), 445/tcp (ms-rpc) and 2323/tcp (telnet-alternate). The first and latter, being commonly associated with exploitation of IoT or embedded deices by the *Mirai* family of malware (Neshenko et al., 2019; Sinanovic´ & Mrdovic, 2017). These show clear signs of repeated scans for vulnerable services against hosts well outside the operating organisation's control. Specific network ports targeted by the IBR traffic in general is discussed in the section following.

4.2 Targeted Services

A large part of IBR analysis is the evaluation of the services being targeted by the inbound unsolicited traffic. This is especially so in the case of 'active' traffic such as network scanning. The results of this allows researchers and cyberdefense professionals to infer as to the rate and volume of scanning (Bou-Harb et al., 2014; Harder et al., 2006). The majority of the activity of interest occurs on the TCP protocol. The results for the dataset under study for TCP are shown in Table 6.

Three ports of interest, especially so since these were heavily targeted by the top sources as identified in Section 4.1 are:

- 5555/tcp used by the Android Debug bridge (NIST, 2019)
- 9530/tcp an exploit in Chinese DVR equipment (Nichols, 2020)
- 37215/tcp (CVE-2017-17215) is a remote exploit in Huawei routers (NIST, 2017a; SonicWall, 2019)

These were by no means the only sources of traffic targeting these, and they were observed across all sensors and from a range of addresses, albeit at a less persistent rate. The traffic patterns observed are indicative of active scanning and probing for exploitable services.

Considering Table 6, a significant portion of traffic recorded during 2021, for Sensor 146 was seen to be targeting 6379/tcp. This is the default port used by the REDIS database. The prevalence is due to repeated regular weekly scanning from a host within 154.66.240.0/24 from mid-August 2021, through to November 2021. Given the timing, this is likely linked to the remote code execution vulnerability detailed in CVE-2021-32761 (NIST, 2017b) released in August 2021, and serves as a suitable example of how IBR analysis can detect emerging scanning trends.

Common TCP services targeted across all six sensors are 22/tcp (SSH), 23/tp (telnet), 80/tcp (http), 445/tcp (Microsoft RPC), 1433/tcp (Microsoft SQL Server), 3389/tcp (Microsoft RDP) and 8080/tcp (http/proxy). The prevalence of 23/tcp scanning is very much attributable to a combination of active scanning by IoT botnets such as Marai and Hajime (Neshenko et al., 2019; Sinanovic´ & Mrdovic, 2017).

The remainder of the top 10 targeted services are:

ISBN: 978-99949-0-888-2

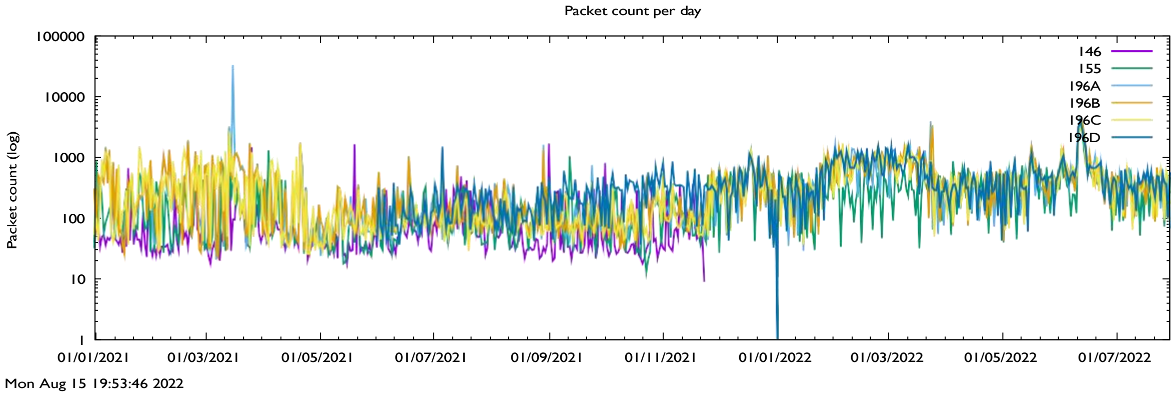

Figure 2: Timeseries: Packets per day

Table 5: Top 10 Source Netblocks

Rank	**Netblock**	**ASN**	**ASN Owner**	**IPv4 Src**	**%**
1	102.116.0.0/17	23889	Mauritius Telecom	980	7,60
2	102.119.176.0/20	23889	Mauritius Telecom	899	6,97
3	102.115.224.0/20	23889	Mauritius Telecom	882	6,84
4	102.114.0.0/17	23889	Mauritius Telecom	795	6,17
5	102.112.0.0/17	23889	Mauritius Telecom	793	6,15
6	102.118.0.0/17	23889	Mauritius Telecom	724	5,61
7	102.115.240.0/20	23889	Mauritius Telecom	670	5,20
8	102.112.128.0/17	23889	Mauritius Telecom	563	4,37
9	102.114.128.0/17	23889	Mauritius Telecom	497	3,85
10	196.216.92.0/23	30844	LIQUID-AS	452	3,51
Total				7 255	56,26

Table 6: Top 10 TCP destination ports

	146		**155**		**196A**		**196B**		**196C**		**196D**	
Rank	**%**	**Port**	**%**	**Port**	**%**	**Port**	**%**	**Port**	**%**	**Port**	**%**	**Port**
1	15,58	6379	23,99	23	17,64	23	17,64	23	16,32	23	29,58	23
2	14,37	445	5,19	445	6,26	37215	6,29	37215	6,75	37215	10,74	445
3	10,55	23	3,58	1433	5,59	445	6,14	445	6,73	445	10,63	37215
4	7,66	80	1,46	22	1,47	1433	2,28	1433	2,11	1433	3,33	1433
5	7,06	22	0,89	8080	1,17	80	1,18	80	0,81	80	1,26	22
6	5,52	8728	0,73	2375	0,95	22	0,91	22	0,76	22	1,18	80
7	5,43	8291	0,72	80	0,41	25	0,43	8080	0,45	8080	0,83	8080
8	3,90	8080	0,70	2376	0,41	21	0,41	25	0,43	25	0,68	25
9	2,91	3389	0,57	25	0,41	8080	0,40	21	0,40	2375	0,67	5555
10	2,26	9530	0,49	2323	0,39	4899	0,39	4899	0,39	2376	0,62	2375
Total	75,24		38,33		34,70		36,06		35,15		59,52	
n	35 718		91 437		131 123		130 591		124 054		77 566	

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- 2375/tcp and 2376/tcp are both default ports used by the Docker service
- 4899/tcp is a port used by Radmin, a remote administration tool.
- 8291/tcp is a port commonly targeted by the Hajime botnet on Mikrotek Routers. This scanning emerged in early 2018 (Herwig et al., 2019)
- 8728/tcp is the default API service offered on the RouterOS platform by Mikrotik

The above covers the top 10 tcp services targeted across the six sensors. These top 10 ports accounted for around 35% of all traffic in most cases. The two exceptions being 146 where they accounted for 75%, largely due to the heavy influence of the repeated scanning for 6379/tcp (and the likely reduced dilution of an additional years traffic). 196D also deviated from the rest, with the top 10 services accounting for nearly 60% of traffic on this sensor, with 23/tcp accounting for nearly half of this.

4.3 Reflected traffic

An important but much smaller component of traffic that needs to be considered is that which is likely 'passive' in the sense that the packet have likely been generated as the result of a response to a spoofed packet claiming to have originated from an IPv4 address forming part of one of the monitored IBR ranges. Reflected traffic was isolated looking for both the TCP-SYN and TCP-ACK flags being set. This is indicative of a response from an incoming TCP-SYN packet as step two of the 3-way handshake. This was done using tcpdump with the following BPF filter:

```
"tcp and (tcp[tcpflags] &
(tcp-syn|tcp-ack)==tcp-syn|tcp-ack)"
```

Relatively little traffic was detected as being potentially reflected with just over 1 000 packets being detected across the six sensors. This is a healthy result and likely indicated a low occurrence of denial of service targeting the .MU ranges. The only two ports with any significant traffic volumes were 80/tcp and 443/tcp - both providing web services. Reflected traffic such as this is common with web servers where syn-flooding attacks can be used, or alternately decoy scanning.

4.4 Anomalies detected

The final component to reflect on is anomalous traffic - in essence that which should not be there or exhibits unexplained behaviour. Two areas already highlighted are the GRE traffic in Section 4., as well as the 160 IP addresses belonging to Mauritian attributable IPv4 space, but not linked to any active ASN. The latter implies that no return traffic would reach these addresses due to there being no entries in the global BGP routing infrastructure. These could have been announced at the time, and the route withdrawn. Historical global BGP records would be able to address this question. A final element to consider is the actual attribution of Mauritian IP space and the accuracy thereof.

The first of these to be addressed is those IP addresses attributed to Mauritian IP space, but not having any active records in global routing tables. This is typically an indicator of an IP block that has been allocated but is not yet in use. The 160 'stray' IP addresses spanned 15 netblocks. The top three, comprised 68%, with the highest netblock having 60 sources. What can be taken from this is that these were either in test use, or were more likely spoofed (for the same reason IBR ranges often are). The majority of traffic originating from these addresses was either ping requests, or targeted 23/tcp and 2323/tcp. These are clear indicators of scanning behaviour.

The last anomaly worth mentioning is that of the discrepancy between the netblock lists derived from Maxmind, and the country based geolocation produced by the Team Cymru service. Fourteen IP addresses across three netblocks were reported by the Team Cymru resolver to belong to AS37705 in Tunisia. Another single IP address was attributed to be located in the USA (AS3223), although this is contained as a /32 route (single host) in Maxmind and could thus be part of route peering.

5. Conclusion

This paper presented an analysis of a dataset with a duration of nineteen months. The data was gathered from existing Network Telescopes. The dataset was filtered, and traffic attributable to Mauritian IPv4 address space was isolated. This then formed the dataset on which the remaining analysis in the paper was undertaken. The result of this was that there is a relatively low emission rate of IBR from Mauritian IP space. What there is, is largely confined to a small cluster of netblocks, with 70% emanating from within a single ASN. Even so hosts count (even among the most active netblocks) only constitutes 1-3% of the hosts within them.

The scanning activity that is observed is in line with other analysis and current trends outside of .MU address space. A significant proportion of traffic is found to be targeting well known exploitable services. This could be due to a number of reasons, but the two most likely are machines that have been

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compromised, and are looking to further propagate infection, or are being used to scan for vulnerable systems to compromise. The detailed analysis of the likely case is outside the scope of this work but can be achieved with appropriate TCP fingerprinting.

5.1 Future Work

While the IP address space understudy is shown to to represent an extremely small proportion of the IBR data collected, it nevertheless illustrates what has been observed with other address blocks with country level attribution. A relatively small proportion is responsible for the majority of malicious/misconfigured traffic that constitutes IBR. Future work could be applied at a national level though organisations such as CERT-MU in the early detection and remediation of known bad actors within the monitored address space.

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Development of an Unmanned Aerial Vehicle incorporating a Convolutional Neural Network for Weed Detection

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Abstract
This paper introduces the development of an Unmanned Aerial Vehicle (UAV) as an efficient asset that incorporates a high-performing pre-trained architecture for weed classification and detection in real-time. The UAV includes a modular sprayer and embedded systems. Weeds provide a continuous threat to the cultivation of agricultural plants and reduce yield, as well as increase waste. To address the issue, an autonomous system and intelligent sprayer are described to spot weeds or undesirable plants and spray herbicides on desired places. The effectiveness of five various pre-trained architectures (AlexNet, GoogleNet, VGG19, DenseNet201, and ResNet50) for image classification and prediction are investigated, and the top performing model was determined. The best-performing trained model, ResNet 50, achieved a training accuracy of 98.57 percent and a validation accuracy of 100 percent at 25 epochs.

Keywords: Deep Learning, Convolutional Neural Network, Transfer Learning, Computer Vision, Raspberry pi, Unmanned Aerial Vehicle

1. Introduction

The human population has increased dramatically and will reach about 10 billion by 2050; this will increase the need for intensive agriculture (Chen, et al., 2019). Global, overall production of soybean crops has immensely developed at a 4.68 percent Compound Annual Growth Rate, beginning around 1961, whereas African agricultural yield echelons are enormously increasing at 48percent quicker, at a rate of 6.84 percent each year. Africa's production, with the world inclusive development is generally a result of an expansion in soybean sections of land cultivation, regardless of quality. The three main soybean-producing countries in Africa are South Africa, Nigeria, and Zambia (Cornelius & Goldsmith, 2019).

The agricultural sector is the major foundation and driving engine of economic growth in Africa. South Africa, as such relies on agriculture. Multiple pathways, such as, agricultural crop production, can potentially stimulate market-related businesses. As such, it is imperative to eradicate weeds in agriculture as they provide a continuous threat to the cultivation of agricultural plants, reducing yield and increasing waste. This will ensure that crop yield is nurtured to give rise to greater economic growth that is beneficial to South Africa (Partel, et al., 2019).

United States (US) farmers sprayed around 113.36 million kg of pesticides around their crop field to combat weeds. According to the global herbicide market, farmers sprayed 746.58 million kg of herbicides. This tremendous, consuming number of herbicides is generally high because of the manual spraying procedure whereby herbicides are sprayed consistently in the farm fields. Since weeds, for the most part occur in patches, a manual, ordinary spraying procedure is inadequate in terms of margin (cost) and strategy or technique. Similarly, aimless spraying causes ecological issues (for example soil and water tainting) and agrochemical build-ups on food items. Consequently, innovation and development of smart drones, or UAVs incorporating herbicide sprayers, is expected to mitigate these adverse consequences.

UAVs are well equipped with cameras; and sensors, and are a prospect for a variety of commercial uses such as aerial photography, surveillance, etc. To massively deploy UAVs (drones) and further reduce their costs, it’s necessary to power them with deep learning architectures, which is an advent of computer

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vision. Deep learning, as the subset of machine learning in object identification and detection is essential for feature extraction of images collected for the sole purpose of preprocessing data and data analysis. The implementation of UAVs incorporating embedded systems, sprayer modules and advanced technological algorithms, such as Convolutional Neural Network (CNN), Artificial Neural Network (ANN), and Deep Neural Network (DNN) enhances agricultural production with greater quality, and less scrap (waste). The identification and detection processes incorporated in UAVs are important for the security measures of military zones, personal private zones, human life, and privacy. UAVs are classified as either fixed-winged unmanned aerial vehicles (FW-UAV) or rotating-wing unmanned aerial vehicles (RW-UAV). FW-UAVs are both harder to pilot and more costly than RW-UAVs. Furthermore, FW-UAVs require a runway for landing and departure, whereas RW-UAVs can take off and land on an area of 1 m^2.

This paper proceeds in this outlined manner: Section 2 describes related work. The methodology adopted in this study is consolidated in section 3. Section 4 outlined the results that are evaluated and discussed in section 5.

2. Related Works

2.1 Machine Learning Structure and Computer Vision Technology

Weed detection has become an important area of research in the agricultural sector given that weeds frequently take different nutrients from crops themselves. As a result, various weed identification techniques have emerged inside the vision-based system (Razfar, et al., 2022).

Machine Learning (ML) architecture is a subset of Artificial Intelligence (AI) that permits accurate prediction of results by algorithmic software with a non-explicit input program. Architecture is a valuable rule which is similar to, or better than a human speciality. Computer vision (CV) is an artificial Intelligence technology that permits computers to comprehend and identify pictures (Ukaegbu, et al., 2022). The application of both ML and CV has increased enormously worldwide and includes areas such as the selection of A or B-grade tiles in tile manufacturing companies, box defects or non-defect boxes in box manufacturing companies, and transportation of material by Laser Guided Vehicles (LGVs) from Warehouse to collection areas. Due to the high production, quality performance and precision level of DL algorithms or techniques, the agricultural sector has adopted advanced drones with constructed trained networks.

Deep Learning (DL) is categorized under machine learning (ML), which constitutes a sophisticated or contemporary huge data analysis, and an image processing technique to yield satisfactory results, and large potential through the construction of different Neural Networks to imitate the way the brain functions. In practice, DL known as deep structured learning, or hierarchical learning, constitutes several components, such as convolution layers, sequential layers, pooling layers, batch normalization and activation functions etc. The advent of DL is image analysis and computer vision. Figure 1 depicts a typical deep learning architecture.

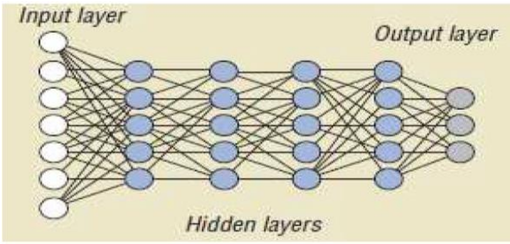

Figure 1: Deep learning architecture (Ukaegbu, et al., 2022)

2.2 Smart Agriculture-Deep Learning

Garcia-Garin et al. (2021) introduced a new deep learning approach incorporating CNN linked to a web-orientated application within the R programming language. An autonomous model was created in this study to detect and quantify floating marine debris in aerial photos. A total of 3723 aerial photos were used to train the deep learning model. The obtained accuracies of image classification and cross-validation were both above 80 percent (Garcia-Garin, et al., 2021).

Thanh Le et al., (2020) reviewed the effectiveness of the Local Binary Patterns (LBP) based algorithm to CNN models such as VGG-16, VGG-19, ResNet-50, and Inception V3 to detect crops and weeds with comparable morphologies. For the demonstration of classifying proof for images, a thorough investigation was conducted on CNN and LBP's performance. However, limitations with CNN models, inclusive of the requirement for a large dataset for the learning phase, synchronization, and overfitting concerns

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transpired. A further experiment was conducted where the model was trained with crop images at advanced stages and tested at early stages (Thanh Le, et al., 2020).

Kulkarni et al., (2019) proposed work on IOT-based weed detection utilizing CNN and image processing. In this study, a framework for weed detection is developed that first trains a CNN model using huge images of both weeds and crops. The integrated CNN model is installed on a first proposed system design (raspberry pi), which receives images from a second proposed system design (camera), where a raspberry pi starts to perform Image processing and image segmentation using ReLU and pooling layers. As a result of training, the system gave an average of 85 percent accuracy, 7 percent average false ratio and 2.6 percent false acceptance ratio (Kulkarni & Dr Angadi, 2019).

Chandy (2019) proposed a precision agricultural strategy using a camera-equipped drone and an NVIDIA Tegra System on Chip (SoC) to detect several pests in coconut plants. The expert technique incorporated a Deep Learning algorithm with data augmentation and feature extraction. An innovative Unmanned Aerial Vehicle that films coconut trees in a particular farm area has been constructed. A dataset of pests and diseases was utilized. (Chandy, 2019).

Partel et al., (2019) invented and modified an intelligent prototype utilizing machine vision and artificial intelligence-based Deep Learning for precision weed management. For target recognition and image processing, two distinct embedded graphics processing units (GPUs) were assessed: NVIDIA GTX 1070 Ti with the NVIDIA TX2 GPUs (Partel, et al., 2019).

Mohamed et al., (2018) examined a method for locating diseased grapevine areas using visible-domain UAV images. A deep learning approach has been presented for detecting vine diseases utilizing CNN and color data. Diagnosis of early signs of the disease symptoms is significant in maintaining a healthy vine. The aim of the proposed method of early detection of vine diseases in photos taken by UAV and RGB sensors at an altitude of 25 meters through CNN's approach, is to obtain a pertinent combination of the feature spaces that results in high accuracy of realizing symptoms at a stage where they begin to appear (Kerkech, et al., 2018). Figure 2 portrays the breakdown of numerous processing steps of the generated technique.

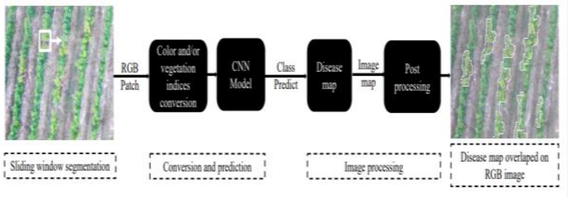

Figure 2: Different processing phases of the CNN model (Kerkech, et al., 2018)

2.3 Unmanned Aerial Vehicle in agriculture

Gayathri et al., (2020) briefly reviewed the deployment of UAVs for agricultural monitoring and pest management, as well as fertilizer spraying. Agricultural drones are driven by innovations in increasing agricultural production parameters by applying fertilizers and herbicides precisely where and when they are essential. The additional benefits of a quadcopter are swift maneuverability, increased payload, high lifting power and stability, and it is much easier to operate in comparison to other aircraft. The implemented quadcopter incorporates a global nozzle for spraying both pesticides and herbicides, the GPS to guide the quadcopter for remote control, the transmitter channel, and motors for controlling the quadcopter through payload by autopilot. The monitoring of crop health is assisted by a mounted UAV camera and the raspberry pi to identify the diseases on crops. This approach tends to improve the development of crop production and growth (Devi, et al., 2020).

Kurkute et al., (2018) studied drones for smart agriculture and discussed different architectures based on UAVs, and gave various technologies used to mitigate human efforts in terms of operations in agriculture, including spraying modules to quadcopter systems. Different algorithms were discussed to closely monitor and control the cultivation of crops using systems such as micro-controller 8051, Atmega 328, ATMEGA 644PA, Atmel 644PA and a GPS. The system design using Atmega 644PA was chosen to be the efficient implementation (Kurkute, et al., 2018).

Maski et al. (2017) developed an agricultural drone with a mounted sprayer for pesticide applications to crops. The development and evaluation of the drone incorporated six BLDC motors, two LiPo batteries (Lithium Polymer), landing gear, spraying components etc. The

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developed model, Hexacopter, Unmanned Aerial Vehicles (UAVs) integrated the mounted sprayer operation control with a transmitter at ground level for assistance, and an HD FPV camera to monitor live spraying operation. This adopted, innovative technology is tremendously helpful as it mitigates costs and overuse of pesticides and reduces pollution (Maski & Palled, 2017).

Aravind (2015) studied a sophisticated herbicide spraying robotic asset with automated weed detection. He used an algorithm that detects weeds mostly through erosion and dilatation, and he also incorporated a Raspberry pi for signal purposes (Aravind, et al., 2015).

This overview of previous works shows that researchers have utilized the latest technologies to construct a deep learning system for built drones. However, less data was utilized and overfitting, as well as execution time, were major hindrances. It is important to study deep learning architecture that incorporates a huge dataset for training the algorithm and preventing overfitting while, minimizing execution time using a GPU hardware accelerator. The CNN algorithm could be optimized using the quantization method for efficiency maximization.

3. Methodology

The paper consolidated two methods: design considerations and neural network modeling. The first method outlined the design considerations of the drone, such as the drone’s stability, its efficiency, and the performance of flight maneuverability. The second method dealt with the construction of the Convolutional Neural Network using Deep Learning on Google Collaboratory to train the neural network model from scratch and, using Transfer Learning for image analysis. Additionally, for the identification and classification of various weeds, where the sole of the study/research lies, the performance of five different CNN architectures (Alex Net, Google Net, VGG Net, Dense Net, and Res Net) are investigated and utilized in training the model, and the best performing network is selected as the backbone for the CNN model. Moreover, the paper incorporates a module sprayer. The embedded systems are incorporated to assist the UAV asset in navigating into and achieving its desired goal.

3.1 Design considerations

Some important design considerations are incorporated in this section along with details, pointing out the performance of the model's flight maneuverability and the drone's stability. The only prerequisite for the designed model is that it must accommodate a large payload and be portable. Equation 1 displays the chosen payload using assumptions.

Quadcopter calculations:

1. *Selected Payload*
   = 400g (1)

2. *Mass of the drone without herbicide liquid*
   = 5800g (2)

3. *Required motor thrust:*
   =2/4 (5800g) = 2490g (3)

4. *Motor Thrust Equation:*

$$T = [(eta \times P)^2 \times 2 \times P_i \times r^2 \times Air\ density]^{\frac{1}{3}} \quad (4)$$

$eta = 0.7 - 0.8$

$T = [(0.7 \times 701.964)^2 \times 2 \times \pi \times (0.3)^2 1.22]^{\frac{1}{3}}$ = 52.56 N

Thrust calculation = 52.86 x 0.101 x 1000 = 5338.90 N

Therefore, the motor selected produces enough thrust.

Figure 3: Designed drone model on CAD Inventor

5. *Lift force*

$$F_L = C_L \times \frac{1}{2}\rho V^2 A \quad (5)$$

$$= 1.5 \times \frac{1}{2}\rho 1.2 \times 8^2 \times 6.2$$

$$= 364.56\ N\ each\ motor$$

Where C_L is an airfoil characteristic, ρ is the density of air, V is the airspeed and A is the area.

Table 1 summarizes the results obtained from an online calculator to describe the flight performance.

Table 1: Flight performance indicators using an Online calculator

Altitude	121.92 m
Coverage Area	7.5g/m^2
ESC	20% - 50%
Flight maximum time:	18– 40 min

The results reported in Table 1 were considered to improve the drone stability, efficiency, and performance of flight maneuverability (Ukaegbu, Mathipa, Malapane, Tartibu, & Olayode, 2022).

Figure 4: Top view of a designed quadcopter model on CAD Inventor

3.2 Experimental Approach

Data acquisition

The method developed in the study comprises two stages: i) training and ii) testing/validation. Implementation of the proposed method using the Deep Learning algorithm requires a dataset which we acquired from the Kaggle platform, a data scientist and machine learning expert online forum. The acquired images have been grouped into four classes, weed, soybean crops, soil, and grass. The noise and lighting variations have been considered over the dataset to improve the size and quality of training datasets and prevent overfitting.

The integrated dataset was made of 15336 images. This incorporates 9641 pictures utilized to train the CNN architecture, and 5695 images utilized to validate the trained CNN architecture. The dataset has been partitioned into 63 percent and 37 percent for training and validation, respectively.

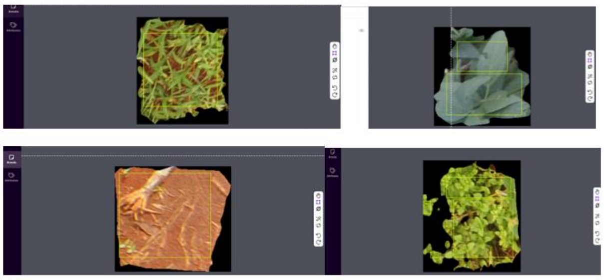

Figure 5: Annotation of image dataset from four different classes

Operating System of Raspberry Pi 3B programming

Raspberry Pi is a minimal expense, being a collection of single-board computers (SBCs) that plug into a computer or television and makes use of a normal game console mouse. Raspberry Pi enables people to examine the registration and figure out how to program in peculiar dialects such as Scratch and Python (Suriansyah, et al., 2016). It can do everything a personal computer can do, such as accessing the web and watching high-definition videos, producing math sheets, word editing, and playing games.

Figure 6: Raspberry Pi 3B Model

Training CNN model and deployment on a Raspberry Pi

A TensorFlow Lite model was incorporated as a structure for running lightweight AI models. It is ideally suited for low-power gadgets such as the Raspberry Pi. First, the raspberry pi is set and updated accordingly. A pi camera is utilized, and the camera interface is enabled. For this

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deployment, pretrained data is used. The data is pretrained on a computer, copied and pasted onto a python script in raspberry pi where results are stored. In this manner, TensorFlow is used to cross-check the image, and when the pretrained results are stored in the correct location it is observed that the Raspberry Pi could recall the data and cross-check with a simple image (Irfan, 2019).

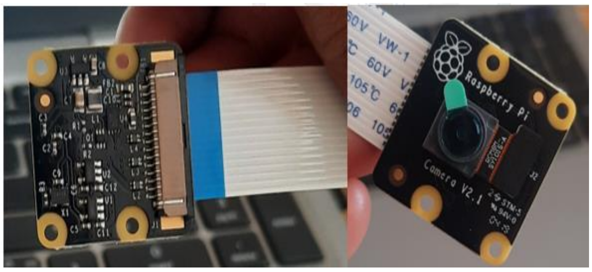

Figure 7: Pi NoIR Camera V2

4. Experiments and Results

4.1 AlexNet

AlexNet is a CNN which consists of eight (8) layers deep (learned layers). There are five (5) convolutional layers, several of which are followed by max-pooling layers and three (3) fully connected layers. Figure 8 depicts the architecture, which explicitly shows the communication of the GPU at certain layers. The variant of the model type was entered in the ImageNet Large-Scale Visual Recognition Challenge 2012 (ILSVRC12) competition and won with a top-5 test error rate of 15.3 percent, compared to 26.2 percent for the second-best application (Sudha & Sujatha, 2019). As observed in figure 8, the last completely linked layer's output is routed to a 1000-way SoftMax producing more than 1000 class labels. The result shows a fully connected layer with 4096 neurons. In the event of training the Alex Net model, the data and dropout were incorporated as primary ways to combat overfitting.

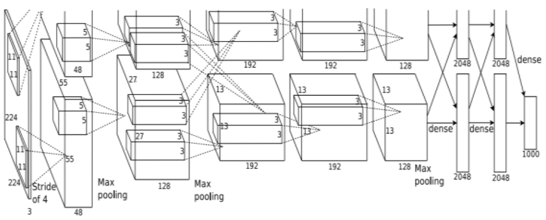

Figure 8: AlexNet Architecture

4.2 GoogleNet – Or Inception V1 is 22 layers deep

Inception architecture is used in GoogleNet, which has a total of 22 layers (or 27 layers if we count pooling) when counting only layers with parameters (Sudha & Sujatha, 2019). In the 2014 ImageNet Large-Scale Visual Recognition Challenge, the deep CNN reached the new state-of-the-art for classification and detection (ILSVRC14). The primary distinguishing features of the architecture include increased network depth and network breadth, which result in a decrease in the number of parameters and an error rate of 6.656 percent. Figure 9 depicts the Inception V1 model structure.

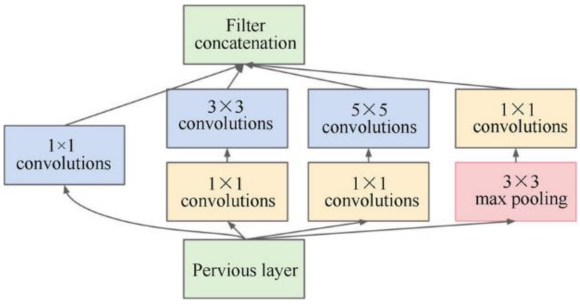

Figure 9: GoogleNet Architecture

4.3 VGGNet

Google DeepMind and the Oxford University Computer Vision Group have jointly proposed the deep convolutional network known as VGGNet. It demonstrates how important network depth is in determining performance. Thirteen convolutional layers are present, followed by three fully linked layers (FC6, FC7 and FC8) (Usman, et al., 2019). The organization has great speculation execution, simple to relocate to other image acknowledgement projects, and can download the parameters that VGGNet has prepared to accomplish a decent initial weight activity. Numerous convolutional neural networks depend on VGGNet, such as FCN (Fully Convolutional Networks), UNet, SegNet, and so forth. There are numerous versions of VGGNet, VGG16 and VGG19 are normally utilized. Figure 10 depicts the VGG19 model structure.

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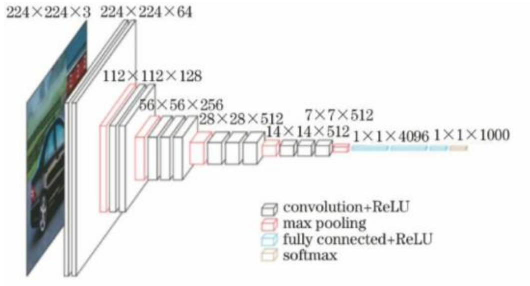

Figure 10: GoogleNet Architecture

4.4 DenseNet

The DenseNet network was proposed by Huang et al. (2017). This architecture is ideal as it offers network-wide shortcut connections, which results in explicit deep supervision. Dense blocks and transition layers are the primary building pieces of the DenseNet network. The transition layer is the area between two neighbouring dense blocks, while the dense block is a highway module with many connections. Dense blocks define the input and output connection methods, and the transition layer is used to determine the number of channels. The size of the internal feature map of the dense block must be consistent. The dense connection of highways alleviates the gradient disappearance problem of deep networks, the features are reused, the model parameters are greatly reduced, and even the over-fitting on small sample data is reduced. The disadvantage is that as the depth of the dense block deepens, the dimension of the deep input feature map and the final output dimension is very large. Figure 11 depicts the DenseNet architecture.

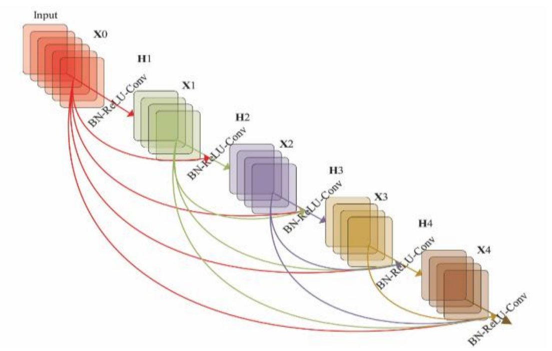

Figure 11: DenseNet Architecture

4.5 ResNet50

ResNet-50 is a 50-layer deep CNN. In 2015, the model won the ImageNet competition. The model has over 25 million parameters and is famous for its greater training accuracy. Figure 12 depicts the model architecture of ResNet50. This algorithm proved that the deeper the trained network, the greater accuracy lies.

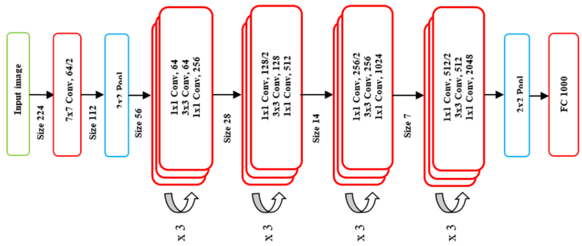

Figure 12: ResNet 50 Architecture

Table 2 summarizes the network architectures with the specified network and year the network was developed, the parameters and achieved accuracy of each incorporated network.

Table 2: Network architectures with layer-depth

#	Network	Year	Parameters	Accuracy (%)
1	AlexNet	2012	62 000 000	91.84
2	GoogleNet	2014	4 000 000	81.67
3	VGG-19	2014	138 000 000	93.57
4	DenseNet-201		20000000	86.43
5	ResNet50	2015	25 000 000	98.57

Table 3 summarizes the architectures with parameter input sizes, depth, and the network developer.

Table 3: CNN architectures with parameter numbers

#	Network	Depth	Input Size	Created by
1	AlexNet	8	227-by-227	Alex K. et al
2	GoogleNet	22	224-by-224	Google
3	VGG-19	19	224-by-224	Siminyan,
4	DenseNet-201	201	224-by-224	He et al
5	ResNet50	50	224-by-224	Kaiming He

4. Evaluation and discussion

5.1. Experimental Results

This section shows images of the collected data (desired and undesired plants) that were used in training the CNN model for image classification and detection.

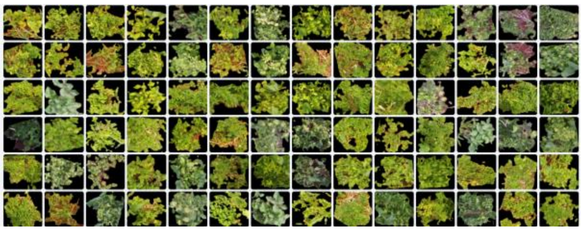

Figure 13: Dataset used for training and validation

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The learning rate has a fundamental impact on how deep learning networks are learned and validated.

5.2 Training of a Convolution Neural Network Model using Transfer Learning on Google Collaboratory

Before training a Neural Network with collected images, the images were first tweaked so that they were in a uniform size of 224 and 224 (height and weight) with channels of 3 and a float array of 32.

Figure 14 depicts the graph presentation of the training and validation accuracy. It also displays the training and validation loss. Additionally, figure 15 displays the intermediate presentation of the results to obtain the feel of how the dataset is in the training platform.

Figure 14: Graph representation of Training and Validation accuracy and loss of ResNet50 model

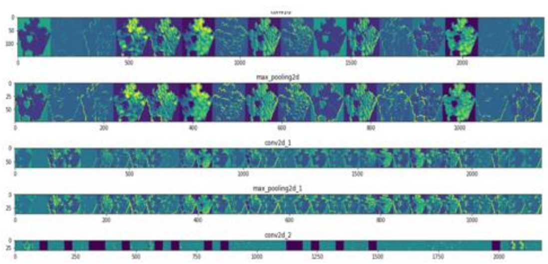

Figure 14: Intermediate presentation of results from Google Collaboratory

5.3 Theoretical Results

A quadcopter design was modelled on AutoCAD Inventor whereby the relevant standards and calculations were visited and performed to ensure that the model design's components are compatible with each other and are capable of carrying out the required operation. These components include DC Brushless motors, ESC, Flight Controller, Propellers, Drone frame, Sprayer module, tank, pump, nozzles, camera, Raspberry pi etc. Additionally, from the off-shelf, the lightweight components were integrated to build a prototype (Figure 16). Given that smart farming aims to reduce the amount of traditional inputs while optimizing crop production and profit yield (land, water, fertilizers, herbicides, and pesticides) required to grow crops, some additional factors and requirements had to be considered for the best choice. The programming paradigm has been carried out and the incorporated CNN has been built using ResNet50, trained successfully and produced accuracy results of 98.57 percent training and 100 percent validation.

Figure 15: Constructed Hexacopter

6. Conclusions

As stated earlier, the major aim of the research was to develop an efficient asset UAV incorporating CNN and a modular sprayer for weed eradication in real-time. Agriculture is a field that has been lacking the mass adoption of technology and its advancements. South African farmers need to be up to the mark with international techniques. Deep learning is a crucial element of machine learning, and an approach to comprehending the peculiarity, development, and faults of image processing

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techniques. It has established its immense powers over conventional algorithms of computer science and statistics. In this paper, deep learning state-of-the-art architectures are investigated, and it is concluded that the size of the data may enormously affect the accuracy, plus the number of epochs plays a major role too. Based on this article, a weed detection model system with accurate performance in real-time is implemented to eradicate weeds by applying herbicide on the side specific. The selected, trained, best model is ResNet 50 with a training accuracy of 98.57 percent and validation accuracy of 100 percent. It is anticipated that the model and prototype built will inspire future work that will investigate improving the accuracies, debug the errors, and that further work on the detection system will be deployed on a raspberry pi that will carry the specified task.

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Development of a Smart Tourism Information Chatbot for Mauritius

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Abstract

Due to the current COVID-19 situation worldwide, the tourism industry has been heavily impacted worldwide. Chatbots help to minimise the spread of the virus, by limiting physical interaction, whilst help to promote the industry and make available tourism information in an accessible familiar manner. This paper aims to analyse the various aspects of the tourism industry and identify the gaps that need to be addressed in order to improve the customer experiences in Mauritius. The aim was deploy a tourism information chatbot that will provide the necessary information and recommendations to tourists coming to Mauritius and attract potential tourists plan their next trip in a few steps, using off-the-shelf technologies. The main advantage of the developed Chatbot is that is built on off the shelf technologies (Rasa, Telegram, etc), but with the ability to be further extended with APIs. Thus the chatbot developed exhibits a number of innovations for a Tourism chatbot, such as Google search, weather acquisition based on location and COVID-19 statistics.

Keywords: Tourism, Chatbot, Telegram, Rasa, COVID-19

1 Introduction

Tourists have been visiting Mauritius for its 3s which are the sun, sea, and sand. The tourism sector is a major employer that contributes significantly to Mauritius total gross domestic product (GDP), it is also considered to be one of the main sources of revenue for Mauritius. As one of the major drivers of economic activities, tourism has been identified as one of the fastest growing sectors in Mauritius. It has been linked to the development of the country's economy and employment opportunities which has contributed around 24% GDP (Gounder, 2021). Due to the COVID-19 pandemic the tourism sector has been highly affected which has forced people to stay home, it has caused several negative impacts such as travel restriction and closed borders of many countries around the world, which it has led to a reduction of demand for leisure and work purpose travellers. In just a year Mauritius has lost around 10.8% of its GDP form the tourism industry (statista, 2022). Since January 2020, there has been a significant decrease in tourist arrival due to travel prohibitions, border restrictions, and quarantine measures. The suspension of economic activity drastically reduced government revenue, the tourism industry has taken a major hit, with border closures, mass flight cancellations, and hotel bookings as resorts and hotels closed, resulting in job losses and salary reduction. In October 2021, the Prime Minster of Mauritius has fully opened the border to international visitors, trying to rebuild its key tourism industry after long months of isolation from the rest of the world but COVID-19 still remains a risk in Mauritius, social distancing, wearing of face masks, using hand sanitiser are mandatory in public and mandatory temperature check done in businesses and mall. Due to the pandemic tourists want to avoid high risk and crowded tourism areas, they may decide not to go/visit their destination and would like to minimise human interaction (M. K. Rahman, Gazi, Bhuiyan, & Rahaman, 2021). In order to minimise human interaction tourists can use chatbot which are 24/7 available. A Tourism information chatbot can bring a new way of customer service agents, acting as a user's first point of contact and providing useful information or intelligent responses to questions asked. It can improve customer satisfaction in this area by providing quick, almost instantaneous responses, regardless of the time of day the customer contacts a tour operator service and can also improve in personalising marketing efforts to specific users by talking in the appropriate language and focusing on the appropriate

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items or services (Calvaresi et al., 2021). That is to say an AI chatbot can analyse data and request from the user better than humans to more precise answers and can reduce human interaction due to the COVID-19 pandemic. This paper covers the development of one such chatbot, specifically for tourism during COVID-19 and the implementation of automated features that enhances the tourism experience. This paper is outlined as follows;Section 2 covers the background, Section 3 discusses the methodology. Section 4 elaborates on the results and Section 5 concludes the paper.

2 Background

Mauritius is often considered as a must-visit destination by tourists for its various attractions such as its tropical climate, beaches, and ethnic diversity. In the last decade, the tourism industry in Mauritius has grown dramatically, it is the third pillar of the Mauritius's economy, the travel and tourism sector has always been affected by various factors which are economic factors, political conflicts, and technological advances which it had contributed to the way it is now. Tourism is considered one of the fastest-growing sectors in Mauritius, it is creating jobs and boosting the local economy. However, the tourism industry has contributed significantly to the Mauritius's economic growth and development. In 2020, with the COVID-19 pandemic in Mauritius, it has caused various negative impacts such as restricted travel accommodations and closed borders and the arrival of tourist in Mauritius. As shown in chart the figure 1 below due to the pandemic caused by the COVID-19 diseases has severely affected the tourism industry in April 2020, this has led to a reduction in the demand for work and leisure travellers and Mauritius has lost around 10% of its gross domestic product in a year (statista, 2022).

As travellers become more digital natives, they are also demanding more meaningful travel experiences. With the rapid emergence and evolution of technological advancements has greatly impacted the dynamics of the tourism and hospitality industry. The evolution of tourism has changed the way people book their vacations. Today, they do their research online before they go to a travel agent. With the rise of smartphones, travellers can now control all of their travel activities anywhere and can now access services like hotel reservations and airline tickets without having to go to a website. They no longer have to wait for the events to happen for them to control their experience anytime and anywhere. Through the use of the internet, travels can experiment with the various features and functionalities of the new channels and develop their own personal travel plans (Dickinson et al., 2014). On the other hand, it has made these services very useful to many tourists since their smartphone is their daily life. Some travel apps are useful for tourists, but they can be considered as bloatware. Most of the time, these apps are focused on a specific topic like real-time weather updates, managing flights and hotel bookings and place to visit, most of the time, these apps are useless once a tourist has used them once. However, chatbots can operate 24 hours a day, seven days a week, which is far beyond the typical work week of human employees, and they can serve multiple users simultaneously. Instead of creating apps that are cluttered with useless features, travel chatbots deliver a cleaner alternative by using existing instant messaging platforms that people already use that do not create bloatware on their device. They make it possible for tourists to receive updates and promotional offers without having to download separate apps for each service they'll be using (Pillai & Sivathanu, 2020). The Tourism industry is benefiting immensely from technological advancements, like Artificial Intelligence (AI), robotics, and chatbots. The emergence of these technologies has changed the way the tourism industry operates and address some of the challenges that the new generation of travelers faces ((Pillai & Sivathanu, 2020). Chatbots have become an integral part of the tourism industry in the last couple of years, as this technology have the ability to automate procedures, replace people, and even provide new services (Calvaresi et al., 2021). Various sectors of the tourism industry benefit from the use of chatbot technology such as hotels, car rental services, and travel agencies (Ukpabi, Aslam, & Karjaluoto, 2019). With the increasing popularity of instant messaging apps, the tourism industry uses this platform to deploy their chatbot to help streamline their sales process and provide a better customer experience to travelers.

Due to the rise of instant messaging, people are demanding more information and better solutions for their travel needs. Chatbots are becoming more prevalent as they provide a more natural and user-friendly interface to interact with various websites

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and smart devices (McTear, 2018). According to traveldailynews (2022),it was revealed that that 87 percent of users would be happy to interact with a travel chatbot to plan their trip or compare various options when it comes to booking a travel trip that could save them time and money. Despite the hype around chatbots, some travel chatbot are not as adept at guiding users through the various aspects of their trips. With so many choices when it comes to planning a vacation, many travellers are looking for an easier way to arrange their trips. According to McTear (2018), developers have created various chatbot-like apps with various functionalities for Facebook Messenger and Amazon Alexa. For the past few years, the use of chatbots in the hospitality and tourism industry has been increasing due to its popularity, it has started becoming an important part of the tourism industry. Many hotels and other tourism companies have their own bots on social media platforms (Doborjeh, Hemmington, Doborjeh, & Kasabov, 2021). In the tourism industry, AI chatbot technology is used for customer support, booking, tailored recommendations, marketing, and customer feedback which it provides personalised and relevant information to user's questions and requests. Using chatbots, it helps travel agencies to easily complete travel related tasks more accurate and efficiently that their human assistants (Pillai & Sivathanu, 2020). The technological advancements enabled travellers to make better decisions when it comes to their travel plans. Prior to the Internet era, people had to rely on the information provided by their travel agent for their travel plans. However, the information given by their travel agent can be inaccurate or outdated. Now with the help of internet, travellers can just go search on the web and plan their tips without the aid of a travel agent or to watch videos about their destination to obtain information regarding their trip. According to appsolutions (2022), the benefits of integrating a chatbot in the tourism industry are:

1. Increase engagement with tourist.
2. Reduce workload and operation costs.
3. Increase number of arrival and sales.
4. Build communities.
5. Attract all kind of tourists.

2.1 Existing Tourism Information chatbots

Chatbots on an instant messaging platform are more often just a different interface to an existing service like Expedia bot, Skyscanner chatbot, Cheapflights chat and Hello Hipmuk chatbot which use Facebook Messenger to plan your vacation. With the rapid growth of chatbot, instant messaging platform such as Facebook Messenger and Telegram are providing APIs to facilitate the deployment of chatbot (Grasselli & Zupancic, 2018). The tourism industry has gain interest of how a chatbot can be efficient. Moreover, users liked how the chatbot provided immediate feedback and their natural language was used to express their needs (Alotaibi, Ali, Alharthi, & Almehamdi, 2020). Some examples of tourism chatbots include :

1. The ski resort Zauchensee in Austria has created a chatbot on their website (https://www.zauchensee.at) named Zauchi that would allow guests to easily find the information they need to plan their trip and stay in the area. It has been noted that it eliminates the need for a customer representative to email or call them (appsolutions, 2022).

2. Saga, which was developed by Hopstay, is the most advanced chatbot that the Faroe Islands has launched. It is designed to answer the typical questions and provide dynamic information that tourists might have when they visit the islands. It will help visitors easily access all the information such as transport information, recommendations, and events, and available 24/7 on Facebook Messenger (appsolutions, 2022).

3. Sunny is the digital assistant of Serfaus-Fiss-Ladis region, with its various features, such as planning and organizing trips. Sunny is able to help people plan their vacations as smoothly as possible and also provide helpful information about their travel destinations and local weather conditions (appsolutions, 2022).

4. Claire a B2B travel bot and travel management solution. It is a virtual assistant that is powered by A.I., and it is designed to help small and medium sized businesses to

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manage, control and automate their corporate travel through the various options when it comes to traveling. The bot's side will help them book a trip that's compliant with their policy in just a couple of minutes. Claire also has the ability to negotiate private rates and customize travel according to their preferences. Users can text Claire to resolve any issue they might have while traveling. It can also be reached through various platforms, such as Facebook Messenger, Slack, and SMS. On the travel management side, Claire can provide detailed analytics and send expenses directly to a company's expense management system (*There is a bot for that*, n.d.).

5. Pana is a virtual travel agent that allows you to interact with a human travel agent through a messaging app. Unlike other chatbots, it does not advertise itself as a bot. Instead, it uses AI to get to know the user better and has an interface that is similar to other messaging apps. It begins with a a welcome call to the user by the travel agent that will learn about the user travel preferences. The user can submit any kind of request for a recent or upcoming trip using the mobile app, text message, or email while communicating with Pana, and according to their website, travel agent will respond within minutes. The user can easily book a trip that a travel agent suggests with just one tap. One of Pana's more intriguing capabilities is its ability to inform the users when they should get to the airport and what the weather will be like when they get there. When they finally arrive at the destination, Pana takes on the role of "concierge," provide "vetted recommendations for your meals and activities." However, it requires a paid subscription (*Pana*, 2016).

6. SnapTravel offers conversational commerce to provide affordable hotel rates via a chatbot. It attempts to use SMS, Facebook Messenger, or Slack to find you a hotel that fits your needs and price range. It claims to have "hidden offers" of its own and searches Expedia, Priceline, and more than 100 other websites for the best price using a combination of artificial and human intelligence. The bot will initially ask the user for their travel destination and dates, any hotel brand choices, budget, any preferred areas within the city and more. Based on the user request it will give a cost estimation for their request (*https://www.snaptravel.com/*, n.d.).

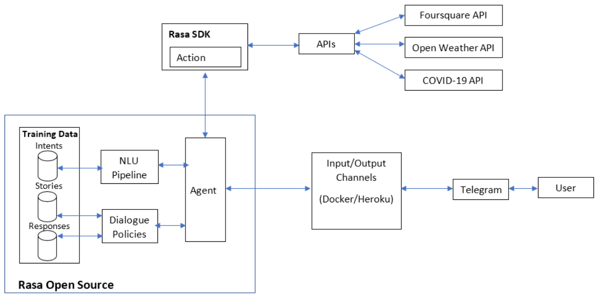

Figure 1: Chatbot Architecture

The main research gap being addressed is having a chatbot specific for Mauritius, with additional innovations that make use of off-the-shelf technologies with relevant APIs.

3 Methodology

The Rasa framework is used in order to build the backend of the chatbot, and Telegram is used for the front end of the chatbot. In order to use Rasa framework, the use of an IDE is needed to develop the chatbot. Visual studio code (VS code) is used to install Rasa and all its dependencies required. Python 3.8 is used to install Rasa and the dependencies. Figure 1 shows the complete architecture.

The TensorFlow software library is used for developing artificial intelligence and machine learning systems. It can be used across a variety of tasks, but it focuses on deep neural components. Python was used to create the scripts to interact with APIs such as Open Weather Map API and more. For the hosting and deployment of the chatbot, it is achieved by using a Docker container which contains all the necessary software components to run an application and Heroku to simplify cloud deployment.
The development of the chatbot is divided in three parts; the first part was to identify what question may a user ask a tour guide or tour operator; second part was to find the answers to the question, and lastly create stories/scenarios about the interaction of the user with the chatbot. A list of intents is very important for a bot to interact with end users efficiently and effectively. It should include many possible questions and statements, it

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is done by providing examples what a user might ask for.

3.1 Design

This chatbot has been designed to answer all the users' questions about traveling to Mauritius and things to do in Mauritius, whilst considering COVID-19 scenarios (Example shown in Figure 2). Using this chatbot has some advantages over simply visiting the tourism website, one of these is that it gives a direct answer to a question, instead of requiring users to go/navigate through a large list of questions. The main features that the chatbot will provide are:

3.2 Creation of chatbot

In order to connect Rasa to Telegram, a Telegram API is needed to connect the back end to the interface of Telegram. Telegram offers a bot that generate bot API for developers which is BotFather API. It is a special account that does not require a phone number to be established. It serves as an interface for the code running on your server, in addition it handles all the encryption and communication, and allowed users to communicated with the bots in two ways by send messages and requests directly into the chat. This can be accessed through an HTTPS-based interface.
Rasa provides a number of files to create an AI based chatbot with programmable features:

3.2.1 actions.py

This file is used to create custom actions that can be called from an external service such as to query a database, or from an external API using Python. For example, the API used to retrieve the weather information is from Open Weather Map, in this custom action it is set that the Open Weather Map API only return the weather location the user requested, the API will return the condition, temperature, humidity and wind speed of the weather location in a JSON format.

3.2.2 stories.yml

This file contains sample conversations story between a user and a bot. The term story is used here to describe the interaction between a user and a chatbot that's actually happening. While the user inputs are being converted into actions, the responses are being treated as actions that the bot should perform when it's needed. They are used to train the dialogue management models of the Rasa. There are two groups of interactions that need to be considered when developing stories, the happy and unhappy paths. The happy path is when the user is following the flow of the conversation and providing the necessary information. In the "stories.yml" file, several stories were added to cover a wide range of opening and closing conversations. By creating these stories, it will teach the chatbot how to respond to unexpected situations, such as when the user's input doesn't make sense, or the message is written in another language.

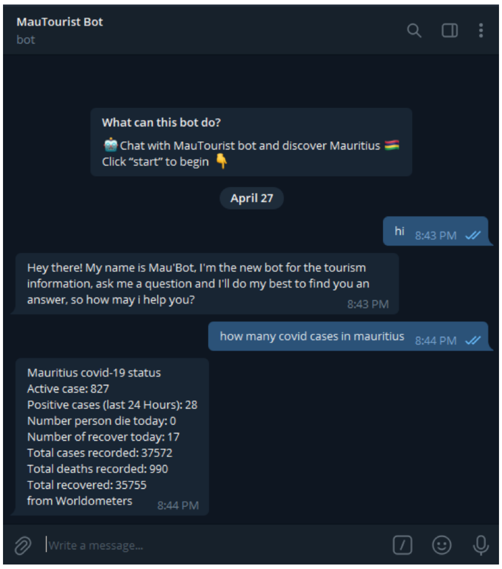

Figure 2: Live COVID-19 Statistics

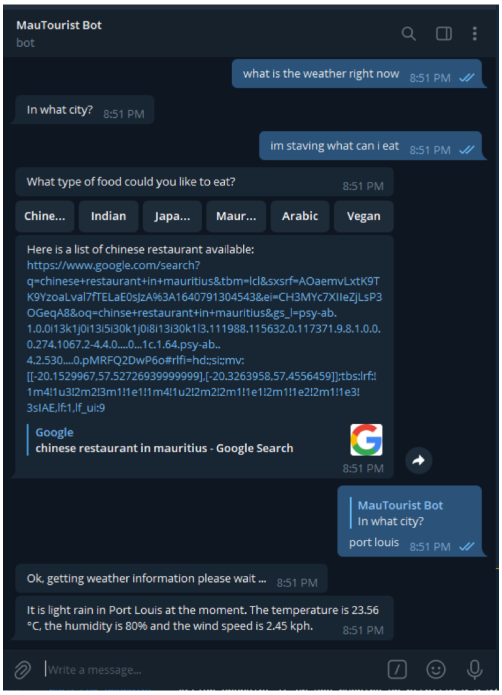

Figure 3: Chatbot restaurant selection

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The main component of the framework is the dialog management, it handles the various aspects of a conversation, and it decides on the next steps based on the conversations' details. It generates a probability model that predicts the actions that will be performed based on the previous actions. In some aspects, upon certain keywords, a selection button (in the example in Figure 3 - the keyword for food/cuisine allows further selection of a restaurant).

4 Results

This evaluation tests the natural language understanding (NLU) model separately with a train set and test set. By doing these test stories help to make sure how the bot will respond in specific circumstances. It will provide a confusion matrix table that shows the summary of prediction result on a model, if the bot is replying according to the story created it will give a proper value otherwise it will give a wrong value. The matrix helps identify classes that are commonly mislabelled. For instance, one class might be mistakenly labelled as another. The confusion matrix shows which intents are mistaken for others (true versus predicted labels). A histogram intent prediction confidence distribution will also be generated to visualise the confidence for all the predictions, with the correct and incorrect predictions. The intent confusion matrix (Figure 4) shows that the chatbot is correctly identifying all the intents. As it can be seen there are no outliers. The matrix shows the intent name, the highlighted diagonal indicated how many answers are there in the intent name and how many are correctly predicted.

A further test evaluates the trained dialogue model on a set of test stories. A test file is created with a sample of possible user request to evaluate the stories in the model. This will generate a yml file to show the result of the evaluation. Figure 5 shows the result of the evaluation whereby the overall result is correct (with no wrong intent). As it can be seen that the model is well trained to respond to the test stories created.

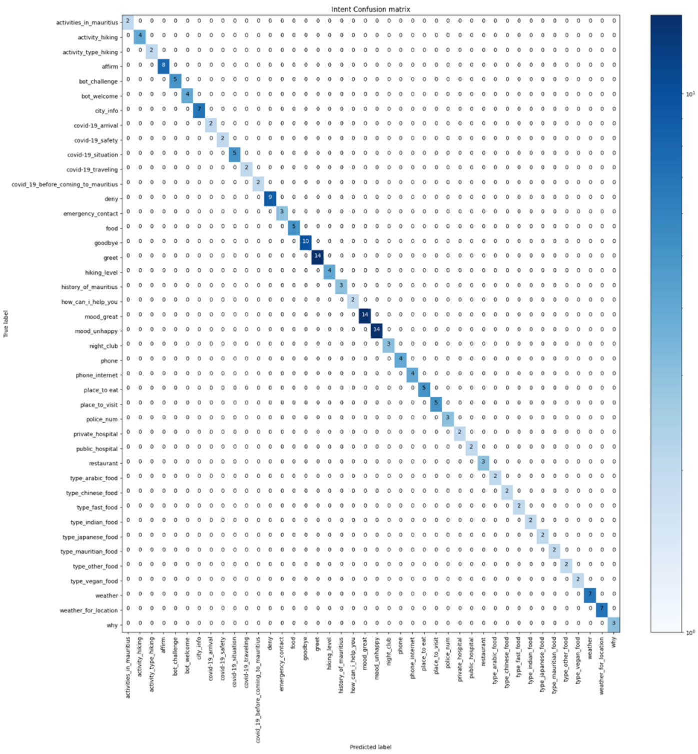

Figure 4: Intent confusion matrix

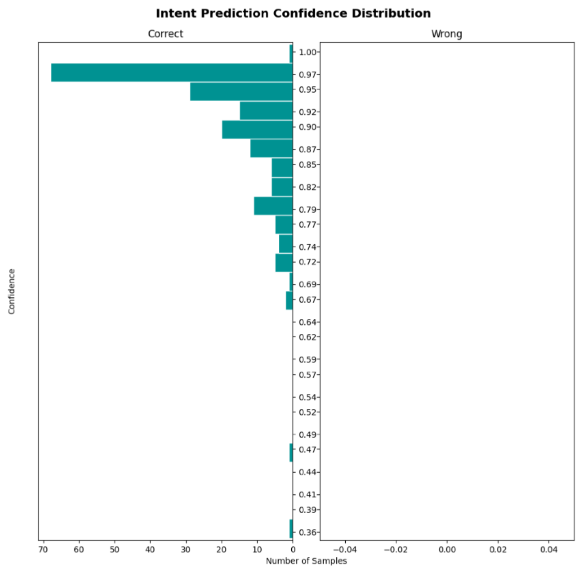

Figure 5: Evaluation

5 Conclusion

According to the latest research, chatbots are becoming very useful and effective tools for people with limited or no technical expertise. They can be used to enhance the user experience and provide better service. The goal of this paper was to demonstrate the development of a chatbot that will provide useful information about Mauritius as a travel destination so that they can make their experience in Mauritius more pleasant and enjoyable in a unique way through a conversation, whilst being able to promote the tourism industry in Mauritius post COVID-19. In this work we have created a

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chatbot using off-the-shelf technologies, and our results are encouraging. With these results, it can be seen that the Rasa open-source framework facilitates the creation of chatbot, and the evaluation that was conducted shows that the chatbot can have more features added to it as part of further work.

5.1 Further Work

This work can be extended by doing the following:

- More languages could be added and trained to support a wider range of users.

- Another feature that can be added to the chatbot is an action that can help the tourist to find the best deal for a hotel room of flight within their budget. For example, the chatbot will gather the data of the user either as from the input of the user or taken from the device of the user like GPS coordinates. In order to collect this information, the chatbot should complied with the General Data Protection Regulation and other laws which are applied, as there might be legal consequences for not follow the laws. Users should have the freedom to allow this or not.

- Initially, the chatbot is currently on Telegram which is one of the popular instant messaging platforms. Research also shows that Facebook Messenger is also a popular app used by many people. Aside from being on only a messaging platform the chatbot can also be used in other platforms to get more users and to promote Mauritius.

- Another action that can be added is a feedback feature that will allow users to provide suggestions to improve the chatbot and keep up with the needs of its users. This will allow the developers to keep up with the needs of its users.

- With the advancement of natural-language processing, chatbots can now understand and respond to ambiguous queries like “Family trip vacation” or “romantic trip”. This can be used to analyse their questions/request and provide a relevant personalise response and detect the emotional state of the tourists when they are using the chatbot. For instance, a chatbot can help a user find a great deal on hotel and flight. It can also provide a weather forecast during their visit and budget-friendly recommendations.

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Smart Walk: A Smart Stick for the Visually Impaired

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Abstract
It is estimated that globally, 285 million people in the world are visually impaired, while 39 million are completely blind. Visual impairment may cause difficulties for people to do their daily activities. There is a need for innovative, ambient, or active assisted living (IAAL) solution(s) to be designed, developed, and deployed for the visually impaired individuals. This paper presents a design of a smart stick for visually impaired individuals as an IAAL solution. The smart stick comprises ultrasonic sensors to detect objects and obstacles, a camera to capture the objects, a GPS module for location update and navigation, and a Raspberry Pi 3B+ which acts as a central unit for the whole system. The smart stick was tested in different environments and backgrounds. The image classification and object detection accuracy of the smart stick system was within the range of 59 per cent to 89 per cent (minimum and maximum range). The smart stick helped the visually impaired individuals to manage walking around their environment. The proposed system will improve the life of visually impaired people since it managed to accurately identify and detect objects with a 89 per cent accuracy level at a one-meter distance.

Keywords: Smart Stick,Walk, Ambient and Active Solutions, Assisted Living

1. Introduction

Ergonomics aims to reduce strain, fatigue, and injuries by improving product design with an overall goal of providing comfort in all environments. Ergonomics, for people who are visually impaired, is of vital importance. Visual impairment, also known as vision loss, is a decreased ability to see. To a degree, the latter, causes problems that are not fixable by usual means (i.e. prescribed spectacles). Visual impairment makes it difficult for visually impaired individuals to walk around their environment. The latter leads to visually impaired people being bed or chair-bound. This leads to the lack of activity and causes a dysfunctional standard of living. For example, the muscles of any human body will always lock themselves if one is not active. If visually impaired individuals do not partake in daily kinetic activities, their muscles tighten and they are bound to fall (E et al., (2020). Therefore, there is a need for an IAAL solution that helps visually impaired individuals manage daily activities.

This paper aims to use technology to improve the visually impaired individuals' quality of life. The technology helps to improve the movement of visually impaired t individuals and their day-to-day physical activity, and aid them in preventing accidents, and enhancing the safety of their environment. This smart stick technology is called Smart Walk.

The Smart Walk system uses Raspberry Pi as a central module, and is interconnected to ultrasonic sensors, a camera, buzzer, earphones and the Global Positioning System (GPS) module. The camera and the ultrasonic sensors serve as the input of the system to detect objects and convey the information to the Raspberry Pi for computation with the use of machine learning algorithms in TensorFlow and OpenCV. The latter detects and classifies objects, which are then translated from a text format to speech using Google Text-to-Speech (GTTS) and relayed to the user through earphones. Therefore, the smart stick enables visually impaired individuals to be aware of their surroundings. In this regard, a reduction of accidents and the free-to-move aspects of visually impaired individuals will be realized.

Section 2 of this paper discusses similar studies that were undertaken by different researchers to come up with solutions to help people with vision impairment. Section 3 presents the tools and

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materials used in designing the smart stick. Section 4 discusses the testing results and performance during the development of the smart stick system. Section 5 provides a conclusion and open research questions.

2. Similar Studies

An application that is installed on an Android device is used to recognize objects by names in the work by Aralikatti et al., (2020). This system uses face recognition, and its results are in real-time. The system uses a smartphone to record the video and divide it into multiple frames with OpenCV, and object detection is performed using YOLO. Once an object is detected, it gets inserted into a priority queue before being sent to a smartphone speaker for output to the user. The advantage of the system is that it has free download software that could be utilized by anyone who wants to improve it. The drawback of the system is that there are a lot of activities on the phone, and that may cause a lot of disturbance while the phone is trying to relay the message to the user (a visually impaired individual).

Various sensors and Light Dependent Resistors (LDR) are used by Patil et al., (2019) in a system to determine the lighting conditions and alert the user about them, while an ultrasonic sensor measures the distance between the system and the light emitting object. They used a moisture sensor for detecting wet surfaces. Their system included a radio frequency (RF) communication module, which is used to locate the system in an event when the user misplaces it. They used the Raspberry Pi 3 module to collect and process the images of objects placed at a distance from the system. The latter translates the results in an audio format through earphones to alert the user. Unfortunately, the system by Patil et al., (2019) could only see objects during daylight.

A voice assisted smart walking stick for blind people using GPS and Global System for Mobile Communications (GSM) techniques was proposed by Ambika and Raga (2018). It used Arduino Nano, Infra-Red (IR) proximity sensor for object detection, a moisture sensor for moisture discovery, and an APR33a3 voice playback module, which acts as a voice guide to alert the blind person. A similar system, known as the Arduino-based smart walking stick for the visually impaired, was contributed by Rangeetha, et al., (2016). It helped the visually impaired to identify the bus route. However, both systems by Rangeetha, et al (2016) and Ambika and Raga (2018), have similar disadvantages. In these systems, the user cannot differentiate between objects since they both lack object classification intelligence.

To improve the system disadvantages of Rangeetha, et al., (2016) and Ambika and Raga (2018), a virtual eye for visually blind people was introduced by Masal et al., (2019). This system uses a Raspberry Pi platform to connect advanced sensors through various ports for object detection. Furthermore, sensors for measuring the distance between the user and the object, the camera for image recognition, and a GPS module for navigation, were used. To improve the work of Rangeetha, et al., (2016); Ambika and Raga (2018); Masal et al., (2019); Khandewale et al., (2020) is adapted. The system by Khandewale et al., (2020) use Tensor Flow Lite, SSDLite-MobileNet-v2, Google text to speech (gTTS) technologies in Raspberry Pi to detect objects with 70 per cent accuracy during the day light. The latter system emulated in this paper and improved.

The system by Nahar et al., (2016) used the PIC16F690 platform with ultrasonic sensors to detect objects, a GPS with GSM modules to locate the person and assist with navigation, and a vibrator motor to alert the blind person if an object is detected. The advantage of the system was its affordability, compatibility and ease to carry around. However, this system does not classify the objects.

To improve the system introduced by Nahar et al., (2016), the work by D'souza, et al., (2019) used artificial intelligence technologies, such as OpenCV for image processing, and Tesseract OCR for text reading. These technologies aid the users in navigating better, especially in environments that they were not familiar with. Unfortunately, their accuracy level was at 50 per cent during daylight.

From the above, similar IAAL work, most of the components used to design a stick for helping the visually impaired individuals worked. The biggest challenge of this work was the low accuracy level during daylight, and almost no clear vision during the night. Secondly, few studies used AI tools for face recognition, object detection and object classification.

ISBN: 978-99949-0-888-2

The Smart Walk system proposed in this study uses Raspberry Pi with the TensorFlow Lite framework. The framework is preferred because it is a lightweight option for mobile, embedded devices, and the Internet-of-Things (IoTs).

3. Methods

Experimentation with a quantitative data approach was adopted as this study's research method. Figure 1 illustrates the block diagram of the proposed system.

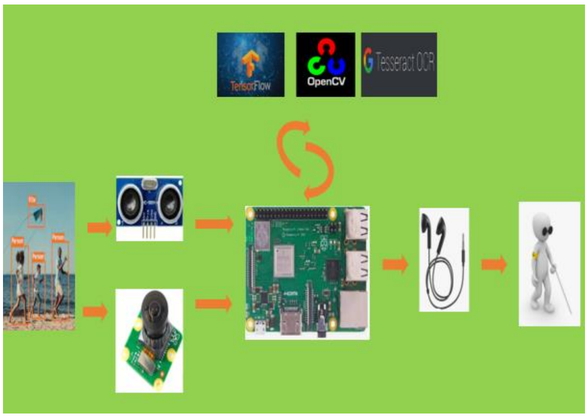

Figure 1. Smart Walk Block Diagram

The Smart Walk is a smart stick electronic guide system for the visually impaired. The system is made up of:

(i) An ultrasonic distance sensor (HC-SR04) to detect the objects along the pathway of the visually impaired individual, measure the distance of the target object by emitting ultrasonic sound waves, convert the reflective sound into an electrical signal, which is then sent to the buzzer and Raspberry Pi.

(ii) A Raspberry Pi 3B+ module computes the input signals from the sensors into meaningful instructions that are relayed to a user through headphones for notification in an event where there is an object ahead.

(iii) A Pi Camera is installed into the Raspberry Pi for object detection and character reading; the camera takes a picture from the surroundings, which are then recognized and classified using a pre-trained machine learning tool. The latter process is done with the help of Convolution Neural Network (CNN) through TensorFlow Lite API architecture, which compares the images from a pre-trained algorithm and converts the output to a text format. The output is further converted into speech using eSpeak. The audio output is then relayed to the person through earphones.

(iv) A Global Positioning System (GPS) is used as an additional feature to update the location of the user, which is projected in an APP.

The components discussed in (i) to (iv) to develop the Smart Walk system were integrated to work as follows: (i) a Pi camera captures an object and sends the information to the Raspberry Pi for processing. (ii) An ultrasonic distance sensor measures the distance of an object and reports the information to the Raspberry Pi. (iii) The captured image is detected and classified employing CNN (machine learning algorithm).

The captured image is compared with the pre-trained dataset and, if there is a match, the result is converted into text. (iv) Once the image is classified, the result is converted to audio for a text format using Google Text-to-Speech gTTS), which is a Python library. The audio version of the result is sent to the user through earphones to notify the visually impaired person of the object ahead. The distance of the object is also relayed via earphones and the position (front, back, left, right) of the object.

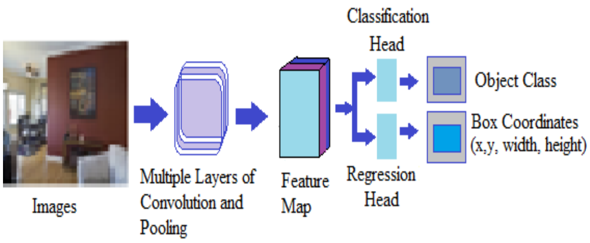

Figure 2. Adopted Convolution Neural Networks Architecture (CNN) (Aralikatti et al, 2020).

Figure 2 details the process and stages of image detection and classification employing CNN, which is specifically designed for image detection. The CNN breaks down an image into increasingly small squares, called convolutions or filters by using a process known as subsampling. The technique consists of an input layer, many hidden layers, and an output layer. The input layer receives the extracted image from the video, passes it to the hidden layer to be filtered and transformed into a specific pattern and then, lastly, passes it into the output layer for classification based on the input received from the hidden convolution layer.

The following pseudocode was used for the Object Detection:

ISBN: 978-99949-0-888-2

- *Start the object detection process*
- *Import OpenCV*
- *Import Coco names*
- *Pi camera initialization with OpenCV*
- *Real-time video recording on Pi camera/ OpenCV*
- *Split captured video into multiple frames*
- *Process one frame at a time*
- *Convert the frame into a grayscale image*
- *Convert image into NumPy array*
- *Start object detection with TensorFlow*
- *Display bounding box around the detected object with the label name of the object*
- *Insert the detected name into a queue*
- *Convert the text name of the object into audio format with gTTs.*

The components, adopted CNN and pseudocode, were integrated to produce the Smart Walk smart stick for visually impaired individuals illustrated in Figure 3.

Figure 3: The Smart Stick system

4. Results and Discussion

Smart Walk was tested in a different environment, i.e. during the day and at night, indoors and outdoors, and the results were recorded for three ultrasonic distance sensors used to check the object distances on the left, right and front.

Table 1. Smart Walk front distance performance

Object Distance (m)	Day Accuracy (%)	Night Accuracy (%)
0.12	99	69
0.23	97	68
0.3	95	67
0.55	92	64
0.6	92	64
1	90	63
1.15	90	63

Table 1 presents a Smart Walk front distance performance, and Table 2 presents right and left distance performance. For example, the Smart Walk was capable of clearly detecting if there was an object in front at shorter proximity, and the accuracy level decreased as the distance increased. In this regard, the system is more accurate if the object is nearby, but the accuracy will begin to be affected at distances of approximately three meters, especially at night. However, to combat this problem, a stronger sensor (or commercial) sensor should be used.

Table 2. Smart Walk left and right distance performance

Object Distance (m)	Day Accuracy (%)	Night Accuracy (%)
0.12	96	69
0.23	94	68
0.3	92	67
0.55	90	64
0.6	89	64
1	85	59.5
1.15	84	58.8

Table 3. Smart Walk type of object detected accuracy.

Object Distance (m)	Day Accuracy (%)	Night Accuracy (%)
Person	89	67
TV	81	61
Cough	78	59
Chair	76	57
Laptop	73	55
Bottle	71	53
Cup	69	52
Cellphone	64	48
Tennis Ball	59	44

Figure 4: Machine learning detection accuracy.

ISBN: 978-99949-0-888-2

Figure 4, presents the result achieved when testing the accuracy of the object detected using machine learning. In Figure 4, a person is identified at an accuracy level of 89 per cent at a one -meter distance. The rest of the results are captured in Table 3.

In testing object detection, a minimum of 59 per cent and a maximum of 89 per cent respectively was achieved if the object was placed at about one meter away. At closer proximity, about point one-two of a meter, the accuracy level rose by approximately 12 per cent during the day to be 99.7 per cent object detection, and 8 per cent during the night for the same object. The image presented in Figure 5 shows the results of text reading by the Smart Walk stick system using Google Tesseract OCR.

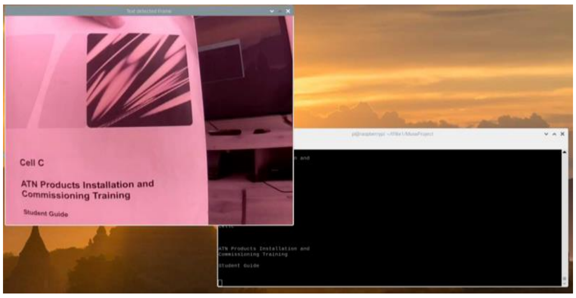

Figure 5: Text reading results using Tesseract OCR.

Figure 6: Smart Walk tracking APP

The App in Figure 6 shows the user's details, GPS position, some of the recently detected object positions, and access to the database. The system stores all the information in a cloud-based database (Firebase). All the real-time information stored in the database, including the location, can be viewed using the android App.

5. Conclusions

In this paper, a Raspberry Pi was used as the central component to compute all the intelligent tasks of the system. The ultrasonic sensors, together with the Pi camera, played a crucial part in collecting the information for the Raspberry Pi to process and output the results to the user in an audio format that the visually impaired will hear through the earphones. The Smart Walk system introduced OpenCV, NumPy array, TensorFlow, and Tesseract OCR to perform better than other systems. The other system achieved an accuracy of 70 per cent; the proposed "Smart Walk" smart system performs in the range of 59 per cent to 89 per cent. The Smart Walk has the potential of helping visually impaired individuals to manage walking around their environment. In future, the Smart Walk system should be tested in a dense vehicle traffic environment. It is envisaged that it will have good performance; however, its camera, detection and classification method should be improved to determine objects from distances greater than one meter. Secondly, the system should be tested with at least 20 visual impaired individuals to obtain more requirements for improvement.

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How Working from Home has Affected South African Industries? A Cybersecurity Culture Perspective

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Abstract
The notion of working from home is not a new concept. However, it has become a buzzword amidst the COVID19 pandemic. Some scholars were already engaging in the work-from-home (WFH) concept a few years before the pandemic. However, contextualization of this concept from a South African perspective only became compelling during COVID19 times, when various industries had to shift their focus and adjust rapidly. This paper aims to investigate through literature reviews, and to understand the cybersecurity challenges that emerged because of this adjustment. Moreover, to investigate South Africa's readiness and the lessons learned from this significant shift.

Keywords: cybersecurity, awareness, working from home, South Africa, cyber-attacks, Covid19

1. Introduction

When the coronavirus hit Wuhan, China in 2019, the world was not ready for the changes that were to follow. An upper-respiratory disease was identified in Wuhan in late December 2019 when dozens of people were reported to have mysterious pneumonia (World Health Organization, 2020). By the beginning of January 2020, the first death from the virus was reported. To date, millions of people around the globe have been affected and have died from COVID-19 (Statista, 2022). Some strange, but necessary, measures had to be put in place to protect the public from this invisible killer. Social distancing, keeping at least 2 meters between people in queues, hand sanitizing, wearing masks, limiting social gatherings and lockdowns, were just some of these measures taken worldwide (Mendoza-Jiménez et al., 2021; UNICEF, 2021). Organizations quickly made decisions to either lay off their employees, or get them to work from home (WFH) (Borkovich & Skovira, 2020; Posel et al., 2021). This came with a total shift in how people conducted their day-to-day work. A new challenge that came from remote working was employees finding themselves in a vulnerable position when it came to cybersecurity.

COVID-19 had unexpected technological implications that forced employees to quickly adapt to this new change, even though they were not fully equipped. The WFH culture meant that organizations had to make provision for their employees to access work systems outside of their work premises. Virtual Private Networks (VPNs) were used more frequently, and measures of authentication were improved to make sure only authorized users gained access to sensitive systems and data. Although this was the case, some employees still found themselves in breach of security measures by falling victim to attacks such as spam, phishing, giving out sensitive information via social engineering tricks, and so forth (Borkovich & Skovira, 2020).

South Africa, particularly, was faced with several challenges when the lockdown was initiated as a

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strategy to minimize the spread of COVID19. Outside of the cybersecurity risks mentioned above, there were social implications as well. People found it hard to follow the lockdown regulations passed by the South African government and supporting departments and, as a result, there was looting, breaking of curfew rules, and breaking the rules of not to go to places of entertainment such as nightclubs (Business Tech, 2021). It took time for people to get used to the new normal, and this led to the virus spreading like wildfire.

The lockdown was a necessary measure to prevent the COVID19 spread, and the benefits of working from home were experienced by both employees and employers. For employers, WFH meant less operational costs such as water and electricity usage, more productive employees, motivated employees, less time taken away from work (sick leave, etc.), and so forth (Rachmawati et al., 2021; Tusl et al., 2020). Employees had a more balanced work-life relationship, were more motivated to work, were spending less money commuting to and from work, and much more (Ipsen et al., 2021). Because there were few cars on the road, the environment also benefitted as there was less carbon emission (Rachmawati et al., 2021).

It was not long before hackers found an opportunity to disrupt organizations while their employees were exploring the notion of WFH. As mentioned earlier, businesses found new ways to conduct business and keep in contact with clients, stakeholders, and employees, and this included conducting meetings online. Zoom and Teams communication platforms were among the most used applications for both personal and business-related calls. In SA, there was a trend of Zoom calls being hacked. An incident is recorded where the SA parliament was holding a virtual meeting and hackers sent a flood of pornographic images to the meetings video call and hurled racially and sexually abusive insults as well (eNCA, 2020).

The sections to follow will report on the impact working-from-home has had on organizations when it comes to their cybersecurity culture. Section 2 presents a discussion on cybersecurity threats that emerged as a result of the WFH model. Although this paper acknowledges that these cybersecurity threats were not new to organizations, their rapid occurrence compromised several organizations beyond their response capabilities. Section 3 investigates South Africa's readiness to accept the notion of WFH and if it has built the capability to handle these cybersecurity threats that impact different organizations. Section 4 draws guidance from all these sections to provide a well-known perspective, yet not fully comprehended by several organizations that can be adopted as an initial effort to minimize the threats and impact. Section 5 provides a summary of the discussions presented in this paper.

2. Cybersecurity threats introduced by the WFH model

Human errors have predominantly contributed to global cybersecurity issues (Borkovich & Skovira, 2020). However, the WFH notion has exacerbated these issues as the cyber threat landscape was enlarged due to remote working. Cyber attackers have seen an opportunity to exploit security weaknesses as employees establish remote connections to various organizational networks and information systems (Georgiadou et al., 2022). The healthcare sector became a target during the pandemic and its network and systems that were compromised meant citizens' life and healthcare information were at high risk (Williams et al., 2020).

Common threats that have always been of great concern in many organizations and to various cybersecurity professionals, were accelerated beyond the cybersecurity professionals' ability to respond quickly. Khan et al. (2020) conducted a study on the common, but dangerous cyber threats, which worsened during the pandemic. Their discussions elaborated on the top ten threats and attacks that materialized, which compromised various organizations since the first hard level 5 lockdown, globally.

Malware and phishing techniques increased to become the most prevailing types of cyber-attacks during the pandemic. Phishing email subject lines and malware signatures had reference to COVID-19, which took advantage of the pandemic and social panic mode. Although phishing attacks are the most commonly known techniques used to harvest sensitive information from users and contribute to 61 per cent of cyber incidents, it remained the predominating technique during the pandemic (Naidoo, 2020).

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Fake websites and links were shared through social networking platforms to what was perceived to be informational platforms about the pandemic. Deceptive COVID-19 safety guidelines and vaccines have delivered malware into various organizational network infrastructures. In another study, Khan et al. (2020) assert that the World Health Organization (WHO), as a trusted health organization, had its website cloned and, allegedly, claimed to provide WHO-approved COVID-19 vaccine. As a result, numerous people unknowingly disclosed their credit card information to perpetrators while trying to purchase the vaccine kit via this fake cloned website (Khan et al., 2020).

Online video conferencing platforms enabled many organizations to continue their businesses during the early days of hard-level global lockdown. Zoom, Microsoft Teams, and Google Meet became the predominantly used video conferencing platforms (Gauthier & Husain, 2021; Khan et al., 2020). This significant increase in the use of these platforms was motivated by the variety of functions and features available to enable communication between organizations, clients, and employees (Singh & Awasthi, 2020). This meant that major and critical industries had to adopt those platforms to continue business operations, thus increasing the risk appetite (Khan et al., 2020).

As more organizations adopted these platforms, various vulnerabilities were discovered, which led to various countries banning the use of Zoom video conferencing due to insecure configurations which raised security concerns (Yadav, 2021). These concerns and the ban were a result of the security vulnerabilities that were exploited by cyber attackers (Singh & Awasthi, 2020). The exploitability of these vulnerabilities raised data privacy concerns, as these video conferencing platforms were penetrated by uninvited meeting attendees (Kagan et al., 2020).

3. South Africa’s readiness to adopt the WFH model and deal with cybersecurity threats

Various scholars in different academic disciplines have interrogated South Africa’s readiness to respond to cybersecurity challenges that emerged because of the significantly evolving Information and Communication Technology (ICT). These researchers’ focus and efforts are aimed to trigger extensive debates in the South African government and its agencies. Thus far, little is known about the cybersecurity readiness of the state (Veerasamy et al., 2019). Although the cybersecurity issues and readiness from a South African perspective have been an ongoing debate, and the readiness status remains unknown, the pandemic compelled the South African government and its agencies to rethink this readiness status and respond promptly. Furthermore, several South African government and locally based organizations failed to convey some level of adaptability, sustainability, and resilience in their cybersecurity units and structures.

In 2020, one of the largest private healthcare and hospitalization providers in South Africa had its admission and other business systems compromised. Although the organization claims that no systems hosting patient data were compromised, the fact remains that it had to operate with some of its affected systems being shut down to prevent the widespread effects of the attack. In 2021, the Department of Justice and Constitutional Development was hit with ransomware causing critical systems to be unavailable to internal and external stakeholders (Pieterse, 2021).

In addition to cyberattacks that affected various sectors, the education sector struggled to adjust to the changes that required ICT to be integrated into education systems to ensure continuous learning and the maintenance of good education standards. This is to illustrate that the current state of ICT is not well positioned to enable adaptability during stress; consequently, exposing a gap in the concept of security and the ability to respond to cyber threats.

Cyber-attacks have always been considered an IT problem, thus making other non-IT-related departments within the organization pay no attention to these issues, especially social-engineering attacks. From a South African context, the notion of working from home raises many security and privacy concerns which were not carefully considered during the hard levels of the lockdown. The WFH notion introduced unpredicted cyber risks to organizational sensitive data, hence the numerous attacks.

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Working from home only means a limited number of security settings and policies get to be applicable and functional, especially on users' machines. Apart from the security settings, home networks do not guarantee trusted and reliable connections, especially when users need to connect back to organizational networks. According to Chigada and Madzinga (2020), the threat landscape expands, even more, when users use their devices to connect to the organizational network and systems. This is because the majority of home network devices are poorly configured and fail to ensure secure and reliable connections (Abukari & Bankas, 2020).

Having an unmanaged personal device connecting through an untrusted and unreliable network can expose sensitive information and introduce network vulnerabilities (Abukari & Bankas, 2020). Although Abukari and Bankas (2020) recognize VPN as a technical measure that can be used to mitigate network connection security and related concern, it is not adequate to guarantee secure and reliable connections. This is because a VPN connection must be established by the user when they wish to access the organizational systems. However, the user can still perform other tasks without establishing the VPN connection. Nothing prevents the user from visiting malicious websites and responding to phishing attacks when they are not connected to the organizational network. Therefore, this study argues that mitigation techniques are beyond technical measures that can be deployed by an organization.

Although cyber-attacks and cybercrimes are global issues, South Africa's cybersecurity readiness is still unclear if not non-existent. Thus, these questions the capacity of various organizations within the South African borders to fully adopt and embrace the concept of working from home amid the cyber-attacks that have been emerging because of human errors and social engineering prevailing techniques.

4. Creating a Cybersecurity Culture through Awareness

Cybersecurity awareness training is not a new concept in the broader spectrum of cybersecurity. This concept has been a major focus in various research debates and business discussions that look to approach and minimize the cyberattacks and incidents resulting from human error and social engineering techniques. Pieterse (2021), Abukari and Bankas (2020) are of the view that cybersecurity awareness training and awareness programs are essential in organizations as an approach to minimizing cyber-related attacks, and shifting towards building a security-focused cyberculture.

South African organizations should put people at the center of their cybersecurity programs and strategies' discussions and planning. For many decades, anti-virus solutions have been accepted as the first line of defense in cyber-attack-related matters. However, the notion was changed when many organizations encountered threats and compromises as a result of human error and social engineering techniques. Thus, introducing the concept of cybersecurity awareness training and education.

This paper assumes that, as much as organizations are willing to invest money in their security tools, at least some greater effort must be dedicated to empowering users from a cybersecurity perspective. Security tools are as effective and efficient as the users. The South African Banking Risk Information Centre (SABRIC) has highlighted that the cyber-attacks that compromise South African organizations have caused them to lose at least 157 million dollars annually, which is close to three billion Rands (Kshetri, 2019). This means that organizations will need to assess their cybersecurity strategies and prioritize employee awareness and training. However, to ensure that these security awareness training initiatives are successful, the approaches should consider the relevance of the information being shared with employees, and also make sure that employees understand how they are to respond to cyber-attacks, especially social engineering attacks (Bada et al., 2014). Kritzinger and Von Solms (2010) recommend the consideration of practical aspects and challenges relating to the implementation of the WFH model from a security awareness perspective. Their recommendation outlines some important areas, which include the social impact on the employees that must be carefully considered and understood by organizations and, also by employees working from home. This area is mostly focused on the behavior of the employees changing and becoming more conscious of the threat (Abawajy, 2014). In addition, the understanding of cultural factors and how they influence intended behavior must be considered when designing and

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implementing security awareness training and content.

Various organizations have taken the initiative to integrate cybersecurity awareness into their technical security tools. These tools enable organizations to not only create cybersecurity awareness training and sharing of content but create a practical sphere of assessing the risk appetite from the users' perspective through phishing simulations. These simulations give the security teams within the organization an overall view of the awareness level of the users by how they respond to these simulations, which simulate real attacks. Moreover, these tools can automate training and phishing simulations to ensure that awareness training and sharing of content are done throughout the year and across various business units.

Although these security awareness and training platforms are beneficial to many organizations, they have not been easily adoptable in the South African context due to the default content embedded in these platforms. Some organizations have found it challenging to conduct security awareness programs using European content-generated platforms, as they do not apply in the South African context and culture; thus, rendering these platforms ineffective. However, these platforms have advanced to enable additions and modifications of security awareness content, which will allow South African content to be contextualized to fit the cultural setup and match the employee's cognitive characteristics (Bada et al., 2014).

The full realization of these security and awareness training platforms can enable South African organizations to create a cybersecurity culture even outside the borders of office premises. This study believes that the traditional methods of having cyber awareness posters and banners on office walls are no longer effective due to working from home. Therefore, these online platforms enable the organization to reach employees regardless of location. Also, these platforms enable the awareness level amongst employees to increase because the training and awareness strategies are becoming interactive (Abawajy, 2014).

Cybersecurity awareness training and programs can be successful if some effort and consideration are put into their development and implementation. For achieving successful security awareness training and programs in South Africa, this paper proposes taking guidance from Bada et al., (2014). The following considerations would benefit South African organizations when developing and implementing security awareness training and programs:

- Communication: Organizations need to understand how security awareness training and programs will be communicated to the employees.
- Context and relevance: Employees are likely to remember content that is relevant to their day-to-day functional duties. This is where the content must be specific and relevant to provide the employee with information on how the element of security relates to them, and how they can change their behavior while not affecting their performance.
- Humor: A sense of humor has a way of getting people to share information when they find something funny but informative.
- Language: different units within an organization use different business languages to communicate. Consequently, employees will easily remember a language they understand. Consideration of the language will enable the employees to be interactive and easily understand the message conveyed through the awareness training.

5. Conclusions

This study took a look at how COVID19 started and brought about a new way of working through the WFH model. Benefits were highlighted, ranging from those experienced by the employer, employee, and the environment at large. New cybersecurity threats were also introduced by the pandemic and SA was given a closer look in light of this. It is the assumption of this study that SA is not ready to fully adopt the WFH concept from a cybersecurity readiness perspective. However, adopting the security-focused cyberculture as discussed by Pieterse (2021) can enable various organizations to build towards being cyber resilient, while embracing the WFH model. Also, organizations should be prepared to put more effort into their cybersecurity awareness and training programs because this is a continuous process that keeps up to date with advancing social engineering and cyber-attack techniques.

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The Analysis of a GPT-based Sepedi Text Generation Model

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Abstract
Text generation is defined as a component of natural language processing that makes use of computational linguistics techniques to produce text that cannot be distinguished from human-written text. This study aims to develop and analyse a Generative Pre-Trained Transformer 2 (GPT-2) language model to generate Sepedi phrases. The under-resourced Sepedi language is regarded as a disjunctive language. The Sepedi language orthographic representation presents challenges and has limited resources. The GPT-2 transformer requires large datasets, as well as state-of-the-art computational resources. The unstructured National Centre for Human Language Technology (NCHLT) Sepedi text dataset was used. The text generation model developed with the small dataset managed to get the lowest loss value of 2.36. The output text generated using this model produces a text that is syntactically correct with instances of grammatical errors. The model performed better than previously developed Sepedi text generation models by using transformer-based technique.

Keywords: Sepedi, Text generation, GPT, Deep learning, Transformers, NCHLT

1. Introduction

Text generation is defined as a component of natural language processing (NLP) that makes use of computational linguistics techniques to produce text that cannot be distinguished from the human-written text (Touseef & Shaima, 2020). This process enables the use of computing machines to generate different text phrases and/or sentences for varying purposes such as those used in children storytelling. The text generation models face different problems such as the syntactic structure of the input data (Hajdik et al., 2019).

There are several factors that affect the performance of a text generation model. Factors such as meeting human understanding, readability, ambiguity, and semantic connections can degrade the performance of a text generation model (Stent et al., 2005). Different text generation models have been developed for many resourced languages (Islam et al., 2019). There are few models for most under-resourced languages such as Sepedi (Moila & Modipa, 2020). A model that generates text that cannot be differentiated from human-generated or machine-generated text would be useful for text corpus creation. Having a text generation model that has been developed for under-resourced languages will be one of the noble achievements towards implementation of the fourth industrial revolution (4IR) goals, providing end-users with options to choose from different languages.

The development of a text generation model requires a large text dataset. In general, data is the most important source of information for both

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corporate and academic research as it provides the organizations with insight concerning the day-to-day operation of the organization. The dataset firstly needs to be cleaned to remove any errors such as data duplicates (Sakthi, 2021). If the errors within the dataset are left unattended, the model may fail to produce text that is understandable to readers.

The process of developing text generation models has evolved with time. The current text generation research tasks focus on developing models using neural network (NN) techniques that use rule-based systems and probabilistic models (Welleck et al., 2019; Guo et al., 2019). Different techniques are used to generate text for different natural languages (Islam et al., 2019). These techniques include the use of Deep Neural Network (DNN) such as Recurrent Neural Network (RNN), Gated Recurrent Unit (GRU), and Long-Short Term Memory (LSTM), which are stable for sequence processing. Recent breakthroughs in the generation of dialogue responses, summarization, and other tasks requiring text generation and deep learning methods have proven to be highly successful (Ziang, 2018). At a high level, the technique has been to train end-to-end neural network models consisting of an encoder model to produce a hidden representation of the source text, followed by a decoder model to generate the target text.

While such language models have significantly fewer processing components than earlier language modelling systems, significant tuning is still required to achieve good performances (Ziang, 2018). These methods have low accuracy when using long sentences (Ravuri et al., 2016). With these techniques, the input is not processed in parallel, it is processed sequentially, leading to the problem of exploding and vanishing gradient (Bin et al., 2021). The transformer-based models can better process long-term dependency than RNN (Gillioz et al., 2020). The transformers make use of attention mechanisms to overcome RNNs problems. With transformer-based machine learning models, quite impressive results can be achieved since each word in the input data is treated separately, while the model processes the data simultaneously. A sentence is analysed to determine where each word falls within the sentence, and how far apart the words are. This paper aims to analyse a text generation model for the Sepedi language developed using the transformer-based deep learning technique.

This paper proceeds as follows. In the next section, the related work is covered (Section 2). Section 3 describes the methodology and Section 4 describes the implementation aspects. The results are presented and evaluated in Section 5. Section 6 concludes the paper.

2. Related Works

The background of different transformer-based language model techniques, and how they were used to develop different text generation applications, is briefly overviewed. Natural language processing uses computational linguistics techniques to produce text that cannot be distinguished from human-written words. Text generation involves how words combine to form a meaningful sentence. Many text generation applications frequently used include, question-answering, report writing, and vocabulary control (Woolley, 1969). For text categorization, the application uses data in the form of text and audio. It is necessary to consider the syntactic structure of the input data when generating text with generation models. Text generation faces a challenge in terms of how the output text will be generated. Hajdik et al. (2019) explains how semantic structure affects language context and content. This could result in the model producing ungrammatical sentences. The use of DNNs such as RNN, GRU, and LSTM has recently achieved great success for machine translation, dialogue response generation, summarization, and other forms of text generation. With these language modelling techniques, text is analysed sequentially, causing exploding and vanishing gradients.

Trying to overcome the problems of standard RNNs, Sutskever et al. (2011) suggest that training the RNN models on Hessian-Free Optimization called Multiplicative Recurrent Neural Networks (MRNNs) provide significant results better than when using traditional RNNs at character level text generation. While MRNN provides better results compared to RNNs, it doesn't fully address the problem of long-term dependencies.

Google AI introduced transformer models, an encoder-decoder language mode that makes use of an attention mechanism to process the text input using a parallelism approach (Vaswani et al., 2017). That is, the input data is processed all at once. Different transformer-based models are used

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in different natural language processing (NLP) tasks, including text generation tasks such as novel/story writing, customer services. These models produce state of the art performances based on their parameters (Topal et al., 2021). The transformers have a better way of dealing with RNN issues because they use an attention mechanism to eliminate the sequential processing of a text that RNN performs by focusing on the current word (Bin et al., 2021).

Transformers provide cutting-edge results in processing NLP tasks better than RNNs since they make use of parallelism, attention, embedded space, and position encoding. The important issue in text generation is to have a model that will make use of the training dataset and produce an output text that humans can easily understand (Vaswani et al., 2017). The need to have such a model that will generate meaningful sentences is essential since there are limited studies in automated text generation for Sepedi language. The transformers, such as the generation of Generative Pre-Trained Transformers (GPTs) such as GPT-1, GPT-2, and GPT-3 and Bidirectional Encoder Representations from Transformers (BERT), are transformer language models which have provided better performances in different tasks involving text generation (Schramowski et al., 2021). The results produced by these models were impressive in such a way that readers couldn’t distinguish if the text was generated by a human-being or the machine (Xia et al., 2020).

According to Keh & Cheng (2019), pretrained language models such as BERT, can predict the human personalities by using Myers-Briggs Type Indicator (MBTI). MBTI is a personality indicator that is used to predict the human personalities given a set of text. The model provided 47 percent accurate output using all four dichotomies, and 86 percent using any two of the indicators. Xu et al. (2021) describes how transformers can be used to extract text from video clips. The extraction is done by providing a few examples when pre-training the model. The model produced the best results compared to other supervised models.

According to Mager et al. (2020) pre-trained language models, such as GPT-2, produce readable and understandable text output if they are fine-tuned. This allows the model to not only produce flowing text, but also syntactically correct text. The study done by Du et al. (2021), with the aim of assisting communities with adapting to online systems was done using traditional RNN models and pre-trained language model, namely, GTP-2 to generate text for the tasks such as essays and summaries. The results provided by GPT-2 were impressive, as it shows that the community could easily read what was generated by the language model.

By using GPT-2 transformer techniques, we develop a text generation model for the Sepedi language - also known as Sesotho sa Leboa language (one of the eleven official languages spoken in South Africa). It is mostly spoken in the northern part of the country (Molepo, 2014). According to Gateway (2021), the Sepedi language is the 5th most spoken language in South Africa, with about 9.1 percent of the country's population, or roughly 13.8 million people. In South Africa, under-resourced languages are not as prioritized as the English language, so linguistic resource development for African indigenous languages is limited (Mkhize & Balfour, 2017). The difference between segregationist and assimilationist ideologies is still a major issue in the country as learners and students are primarily still being taught in the English language rather than their mother-tongue languages.

The language modelling literature shows that little research has been done using pre-trained language models on text generation for under-resourced languages. As such, this paper aims to develop and analyse a GPT-2 language model to be able to generate Sepedi phrases.

3. Methodology

3.1 Dataset

In this paper, the main goal is to analyse the unstructured National Centre for Human Language Technology (NCHLT) Sepedi dataset (Eiselen & Puttkammer, 2014), then apply the process of word tokenization. This will be followed by the generation of Bag–of-Words using the tokenized words. Finally, word embeddings are produced, that is a word-vector representation, wherein words with much the same meaning are characterized in the same way. The next task is to perform data visualization, the graphical representation of the dataset.

3.2 Text analysis

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Analysing the text data allows us to get the meaning behind the data. Before analysing the text data, it needs to be prepared to remove different features that can lead to poor results. The pre-processing task is performed to prepare the text data for analysis, which improves the performance of the model, that is, it has a significant impact on the outcome of the model. This includes the removal of any punctuations, as well as the removal of emails and websites names. Analysing the text data allows the process of determining the total number of unique words, word frequency.

The process of retrieving information from the text data is called text analysis (Jeffrey, 2008; Kalra & Agrawal, 2017). Text analysis provides an insight into the data. The process of text pre-processing allows the removal of all non-alphabetic strings from the corpus. This includes the removal of special characters, punctuations, and numbers. Failure to do so could result in representational inconsistencies in the output of the model.

3.3 Text Visualization

Dealing with an unstructured dataset requires one to fully understand the structure of the dataset. Having to understand the length of each word in the dataset will provide an idea of how the data is structured. This includes having to understand how each sentence is structured based on the number of words in each sentence. Words are made up of a few characters, while sentences consist of few words. Both words and sentences can be short or long in size. By doing so, it allows us to find out how word length and sentences affect the outcome of the language model. Different approaches have been used by different authors to analyse their effect in the corpus, and the influence they have towards the performance of the language model (Taylor, 2015).

3.3.1 Word length count

Figure 1 shows the words as a function of the length of the words. From the dataset, the shortest word is one character long, while the longest word is 70 characters long. However, the word with 70 characters long is a long sequence of characters that make up multiple sentences joined together. It remains something to be further investigated.

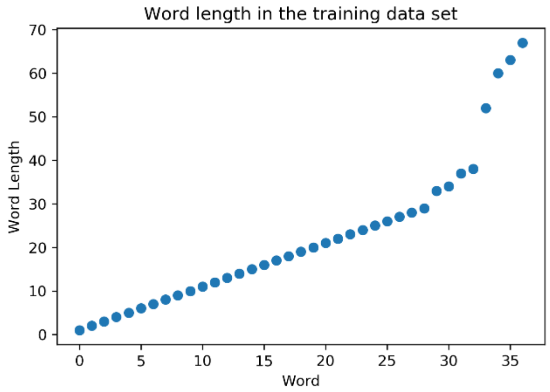

Figure 1. The word length of the words in the training set.

3.3.2 Word Length frequency

Figure 2 shows the frequencies of the word length, that is, the count of how many words there are of a specific length (in terms of character count). It can be observed that words of length between 20 and 70 are appearing once in the corpus. There is a high frequency of words with the length of 2 characters. Double-characters words appear most in the dataset.

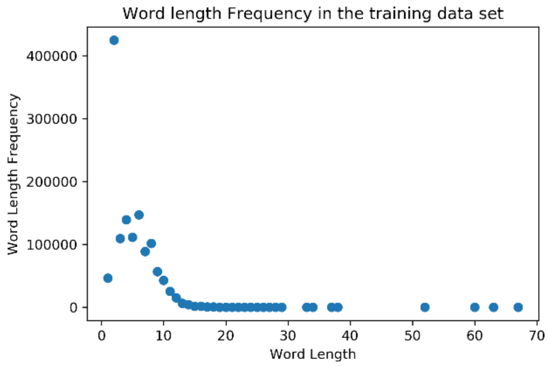

Figure 2. The word length frequency graph for training data

3.3.3 Word count frequency

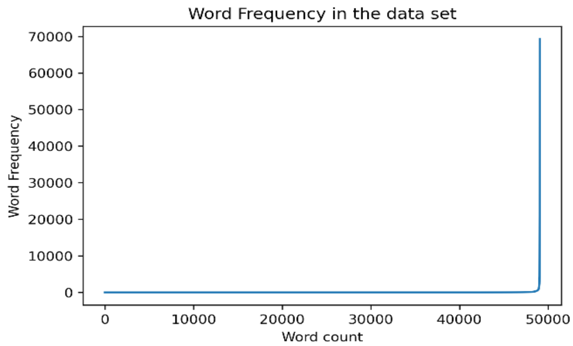

Figure 3. The word frequency graph for training dataset

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Figure 3 shows the word count frequency in the dataset. It can be seen from the graph that word number 0 to 4500 have a low frequency with a flat straight line, whereas the graph increases exponentially from word number 4500 with the highest frequency of at least 70000. The analysis was investigated with the aim of finding out the reasons behind the flat graph and the exponential growth of the graph. The observation of the phenomenon is shown in Table 1 and Table 2.

3.3.4 Most frequent words in the dataset

The most frequent words in the training dataset are discussed in this section. Table 1 shows the most words with the highest frequency in the corpus. The Sepedi language has a Consonant-Vowel (CV) language word structure. This is the reason for having many single double character words. No Sepedi language word ends with consonant character. It always ends with one of the vowels. These words are called connectors. They are used to connect words to form a sentence.

Table 1: The highest occurring words in the dataset table.

Words	Frequency
le	69 270
ka	68 608
ya	67 005
e	41 937
ba	33 242
tsa	27 275

3.3.5 Least words in the dataset

Table 2 depicts the words that have a frequency of between 1 and 20, which indicate a lower frequency given that the dataset alone consists of more 70 000 words. These words alone have a meaning. But they cannot form a sentence alone without the connectors.

Table 2: The lowest occurring words in the dataset table

Words	Frequency
bapalelwago	1
mohlatsana	3
tekologo	5
ipoeletsa	8
mabaleng	12
mabjang	20

3.3.6 Word count per sentence frequency

As with the analysis of the frequency of the length of the words, the frequency of the length of the sentence was also measured as shown in Figure 4. It can be observed that the longest sentences with words above 50 have the lowest counts. However, the sentences with words between 18 and 20 recorded the highest frequencies.

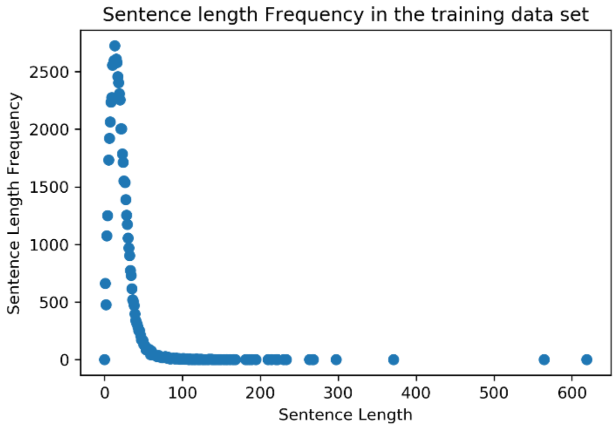

Figure 4. The word in a sentence frequency graph for training data

3.4 System development

The transformer-based machine learning building blocks are mostly based on attention (it can either be self-attention or multi-attention). The transformers consist of an encoder-decoder mechanism. That is, the focus is given to each word in a sentence one at a time, unlike RNNs where the system processes the whole sentence at once. Figure 5 explains the process of training a transformer model. The model takes in text as an input. As the computer does not understand the text as it is, the model uses the embedding space to map the text into vectors. The vectors contain the information about the distance between the words in each sentence. This information is passed through intermediate representations that consist of different layers, feedforward, SoftMax layer and attention mechanism. Transformer makes use of attention mechanisms, together with feedforward to apply focus on each word in the sentence at a time to understand the relationship between those words. The output of the encoder is treated as the input of the decoder. Applying the

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same process as the encoder, the SoftMax layer is then used to turn the vector values into probability distribution, thus predicting the output which is the next words in the sentence.

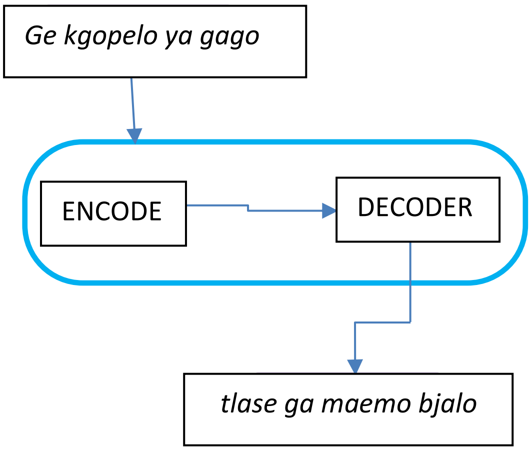

Figure 5. Process of training a transformer model

Due to the amount of dataset in hand, for this study we use a transformer-based machine learning technique for our text generation model (Vaswani et al., 2017). GPT-2 is a generation of GPT models (Alec et al., 2019). GPT-2 is trained using a huge internet text which has provided state of art performance. For the purposes of the experiments, we used a GPT-2 with 124M parameters. This version of GPT-2 has 12 layers. Since GPT-2 is a pre-trained language model, the process of fine tuning (using gpt2.finetune) involves training the final stage using the Sepedi dataset.

3.5 Evaluation

When developing a model, its performance needs to be evaluated to find out how good it is. GPT-2 Sepedi language model is evaluated based on the loss function and human-readability. The loss function is used to optimize the process with the aim of minimizing the model errors. Whereas human-readability allows the humans to read the generated text and provide the results based on their understanding of the sentences.

4. Results and discussions

The Sepedi text generation model was trained and fine-tuned based on the GPT-2 language model. During the training part, the training was trained and fine-tuned using 1000 steps which are printed every 10 steps. The model is trained on Google Colab, running on 16 GB RAM, 6GB GPU NVIDIA GEFORCE RTX PC.

Figure 6 shows the loss for value of the first 200 iterations. While there was a decrease in the loss as the steps increased, the loss was noisy as indicated by the spikes. The lowest loss value recorded was 2.8 obtained at step 180.

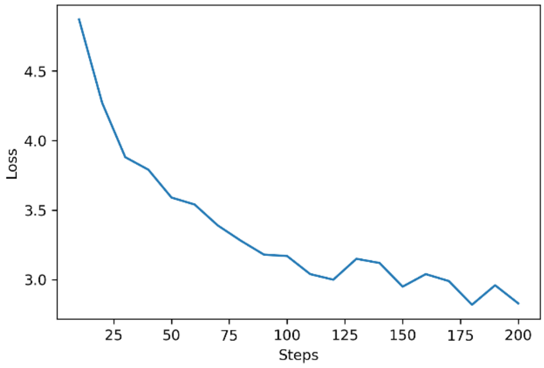

Figure 6. The training loss for the first 200 steps.

The processing steps were further increased to 1000 as shown in Figure 7. It was observed that the loss value was inconsistent per iteration where there were recorded high and low values during the evaluation. Further investigation is required to determine the effect of the model as the number of iterations go beyond 250.

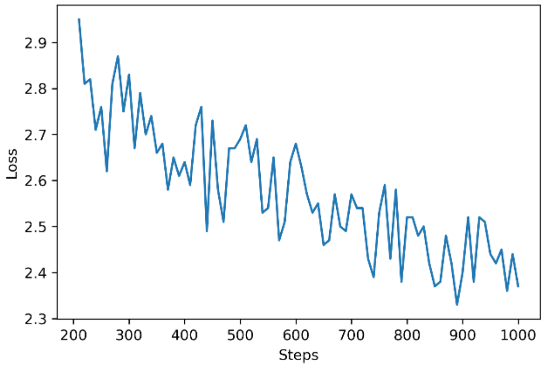

Figure 7. The training loss for the last 1000 steps

The GPT-2 model was fine-tuned using the Sepedi text dataset. Once the model was fine-tuned, we fed the model a sample of the dataset to check the performance of the model. Figure 8 represents the sample text as an input text for generating the output text. This may be termed a few-short training of the model where few examples are given as an input to guide the model with regards to the expected output. The generated output is syntactically correct to some degree. However, some parts of the output are grammatically incorrect. For example, the first part "*Ge e le gore go a hlokega gore o romele thuto …*" loosely translates to "*If it is necessary to send education* …". The performance of this model has improved

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as compared to the previously developed model for Sepedi using long-short term memory technique. A sample of the previously generated text was "*ga e a swanelwa go rekišwa*" which translates to "*it is not supposed to be sold*".

Sample input text
"Ge kgopelo ya gago e t šweletše."
Generated output text.
"Ge e le gore go a hlokega gore o romele thuto ye e t šwelago pele sebaka se sengwe le se sengwe dijo t ša godimo di swanet še fiwa let šatši leo le laet šwa sebopego le segalo di le tshepetxo ya dibjalo t ša ka tlase ga maemo bjalo ka ge e ka ba ya ka tlase ga tlaleletxo mohlala ge mawatle e tšeelwa phethagatša mellwane ya maleba ya"

Figure 8 Sample input text and the generated text

5. Conclusion

The process of text generation involves the use of computational linguistics to produce text that can be read and be understandable. Many factors, such as syntactic structure of the language, can affect the performance of the model. Languages, such as Sepedi, require the system to understand its syntactic structure due to the nature in which the Sepedi language is structured (Sepedi language uses consonant-vowel structure). The Sepedi text generation model was developed using the GPT2 algorithm. The model performed well in the first initial iteration of the algorithm. However, the model produced noisy results as the iterations were increased. The model was trained with limited data; however, the technique requires more data to perform well. The output text generated using this model produces a text that is syntactically correct and instances of grammatical errors. GPT-2 consists of the following models: small version model, medium version model, and large version model. It is not clear if the limitations of the data had an influence on the model performance as the number of iterations were increased. Due to hardware limitations, it was difficult to investigate further using large models. Future work will include the evaluation of the effect of the data size for transformer-based techniques. Also, more data from closely related languages will be sourced to analyse the effect on models of this size.

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A review on the criteria for adoption of cloud computing in South African Institutions and Business enterprises

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***Abstract*—Cloud computing has taken over the IT industry. Big enterprises such as Oracle, Microsoft and Amazon have developed world class state of the art products and services for Cloud Computing. These products serve and the needs and power many corporations, business institutions and enterprises across the world. Cloud computing is continuing to growing and attracting more businesses and birthing and transforming industries such as music streaming and online gaming. As we progress and move towards a 5G and become a 4th industrial society more cloud computing products and services will be developed and used. However, there are many issues that arise such as stability, reliability, security and fraud. Addressing these problems introduces complexity towards adopting cloud computing for small business enterprises leaving only big enterprises to be able to afford reliable cloud computing products. There are many outstanding works that have been previously published by scholars on cloud computing. This research paper provides a systematic review and a summary of some the outstanding works of scholars recently published and the different criterias used for clouding computing adoption by South African Institutions and Business enterprises.**

Keywords -*Cloud Computing, Adoption, Business Entreprises, And Information Technology*

I. Introduction

Most businesses and enterprises are looking ways to save cost and to heave efficient and effective computer systems that can enable them to easily adapt to their ever changing environments. Cloud computing is a IT paradigm that allows business and enterprises to manage and save their cost by only paying for IT services that they used and consumed than paying and owning the entire IT systems in their own data centers. Furthermore, cloud computing allows business and enterprises to focus on their core business activities because nitty and gritty of IT is managed and controlled by service providers. In that way business and enterprises do not have to dedicate their effort and investment to have dedicated data centres and skills to manage day to day activities. The speed and agility are the main drivers of cloud adoption in South Africa Johnston Prof et al. (2016). Cloud computing allows business and enterprises to access IT services from anywhere using any devices or gadgets through internet. Business and enterprises can only request the IT services as and when they require them, and release them as they are no longer require them. They manage to dynamically provision the services as the demand increases and de-provision the services as the demand decreases. The adoption of cloud computing by business and enterprises has increased over the years. The service providers have made the huge investments in building data centres around the global in ensuring that business and enterprises can access cloud services in their location proximity to where to do business to mitigate governance and compliances issues. Furthermore, to address performance issues like latency and bandwidth issues. Google, AWS, and Microsoft are among the global service providers that built data centers in South Africa.

Cloud computing is foundation for technologies like IoT, AI, machine learning. These technologies are important in the growth of economies around the world, fourth industrial revolution. South African government is also catching up, as department of Communications and Digital technologies published a Draft National Data and Cloud policy for public comment. South Africa have identified digital technologies that include cloud computing as key pillars for economic growth. BMIT forecasts the cloud services market growing at a CAGR of 28 percent over the next five years to R23.6 billion in 2023 in south Africa. In addition for example, IDC said Salesforce and its ecosystem of partners and customers will create 2.1 billion dollars in new business revenues and 5,240 new, direct jobs in the country by 2024. However, the adoption varies from country to country and industry to industry. There are hinders to adoption of cloud computing by business and enterprises. The hinders may range from financial, governance, organizational, environmental and technical among others Thobejane & Marnewick (2020). As mentioned by Laverty (2011) that "the three key areas of mobile, internet, and broadband will be critical to the spread of the model of cloud computing." in developing economies. Konstantinos et al. (2015) said that "cloud computing has the potential to transform the global ICT market techniques and contribute to

the boost of economic growth."
The purpose of this study is to review and formulate the holistic cloud computing adoption framework for South African Institutions and Business enterprises. The framework will guide organizations to focus of the primary and secondary cloud factors at strategic, tactical and operational level of an organization and enterprise.

The composition of the paper is organized as follows: Section II – Literature review and will examine most of the significant papers published on cloud computing in relation to the cloud adoption, Section III – Systematic review methodology, Section IV – will outline hypothesis and analysis, Section V – Conclusion and future work.

II. Related Work

Cloud computing is an IT solution in which IT services (hardware and software) are provisioned and used remotely by organizations through the internet as a subscription (pay-as-you-use) service managed and controlled by cloud computing providers Vaquero et al. (2008) , Leavitt (2009) , Mell et al. (2011). The organizations do not own and maintain any IT services as they only request what they need, and pay only for what they have consumed. Cloud computing services are IT services, where organizations are charged and pay for what they consumed. Cloud computing is an IT solution in which IT services (hardware and software) are provisioned and used remotely by organizations through the internet as a subscription (pay-as-you-use) service managed and controlled by cloud computing providers Vaquero et al. (2008) , Leavitt (2009) , Mell et al. (2011). The organizations do not own and maintain any IT services as they only request what they need, and pay only for what they have consumed. Cloud computing services are IT services, where organizations are charged and pay for what they consumed. From the definitions and according to the US National Institute of Standards and Technology (NIST) and Mell et al. (2011), the characteristics of cloud computing are: on-demand self-service, broad network access, resource pooling, rapid provisioning (elasticity) and pay-as-you-use (Buyya et al. (2009) , Rosenthal et al. (2010) , Mell et al. (2011)). There are three main cloud service models, namely Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) (Subashini & Kavitha (2011), Rountree & Castrillo (2013)). The IaaS is the foundation for cloud computing Vaquero et al. (2008), Leavitt (2009), Mell et al. (2011). Infrastructure as a service is instant computing infrastructure provisioned, and managed on the internet. The cloud providers are responsible for these computing infrastructures, compute, network and storage services. Platform as a Service (PaaS) is a type of cloud computing service that provides a platform to the organizations to install, run and manage the applications without worrying about the underlying infrastructure and platforms where the applications are installed. The cloud providers are responsible for updating, patching and troubleshooting the underlying infrastructure (compute, network, storage) and the platform-like databases (DBaaS) (Oracle, MySQL, Aurora), application development (e.g. Java, dot.net), and middleware applications (e.g. WebSphere) (Vaquero et al. (2008), Leavitt (2009), Mell et al. (2011). The main players in PaaS are Microsoft, Oracle, Google, among others. Software as a Service (SaaS) is a type of cloud computing service that provides organizations with software, which cloud providers are responsible for installing, updating, patching and troubleshooting a full stack of cloud services from infrastructure, platform and software layers Vaquero et al. (2008), Leavitt (2009), Mell et al. (2011). The organizations are only responsible to secure access to the applications and their data. The organizations use five main cloud deployment models (Vaquero et al. (2008), Leavitt (2009), Mell et al. (2011), which are namely public, private, hybrid, community and cloud-on-premise (Cloud@consumer). Deployment models are categorized according to where the cloud infrastructure is located Rountree & Castrillo (2013).

A. *South Africa*

There are various research studies in the past and present that aim at addressing the cloud computing adoption. The benefits of cloud computing propel the researchers and organizations to find way and strategies on how to effectively adopt cloud computing in order to envision and realize the cloud benefits. Microsoft (2021) indicate that there is traction from some of South African public sector departments and agencies. Microsoft gave example that "The Government Pension Administration Agency's (GPAA) migration to the Microsoft cloud enabled it to go paperless and introduce self service facilities to access data. This enabled the GPAA to address fraud and corruption and build more controls into their processes." ITweb (2021) indicated that the government have realized the benefits of cloud computing in particular during covid-19 pandemic because it allowed employees to work productively from home and also used cloud computing technologies to able to effectively communication with the public during the crisis co-ordination. And most of African countries businesses have increased their cloud spend. This was accelerated by the growing awareness and the presence of cloud global players like AWS, Google and Microsoft in South Africa. In most of cloud adoption the studies, Technology, organization and Environment (TOE) and technology acceptance (TAM) models were used as a theoretical lens. The adoption of cloud computing is still low in the emerging countries, like South Africa, especially in public sector when compared to private sector Mkhatshwa & Mawela (2021), Gillwald & Moyo (2017)). There are various factors that cited as standing block for cloud adoption. Mkhatshwa & Mawela (2021)highlight that the risks are security breaches, network infrastructure and redundancy, including skills and contract management. This was coupled with concerns about compliance with relevant legislation and risks associated with transboarder information flows. Moonasar & Naicker (2018) have found that South Africa has "gained momentum in cloud adoption, however cloud adoption is still a maturing concept". Mohlameane & Ruxwana (2020) indicated that developing countries like South Africa especially small and medium enterprises (SME) are

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not doing well in adopting cloud computing. They find that the existing ICT policies and regulatory laws are inadequate to address cloud computing developments, complexities and challenges.

B. Cloud Computing Challenges in South Africa

There are several and uncoordinated cloud factors that affect the adoption of cloud computing in South Africa. The majority of public sector organizations in South Africa are concerned about the availability and privacy of data in cloud. Moreover, the adoption strategies of cloud implementations were among the main concerns of the organizations. Van Der Schyff & Krauss (2014) found that to increase the adoption of cloud computing in Higher education sector in South Africa, the focus should be on understanding trust between adopters and service providers. Van Der Schyff & Krauss (2014) studies highlights various information security concerns, such as confidentiality, integrity and availability. Authors in Skolmen & Gerber (2015) found that the adoption of Cloud Computing in South Africa remains relatively low, one of the major concerns identified is information security within the Cloud Computing environment, in particular protection of personal information. Furthermore, Ayong & Naidoo (2019) in their study argued that trust is a dynamic mechanism through which the adoption variables can influence the decision to adopt cloud computing in South Africa SMEs. Lechesa et al. (2012) found that “Network limitations, customisation, security and cost concerns were raised as dominant factors affecting the adoption of ERP SaaS in South Africa.” Scholtz et al. (2016) found that there are technical and environmental factors that could hinder the adoption of these technologies in developing countries in South African government.

C. Developing economies

From the emerging economies in Africa the outlook is the same like in South Africa. In Malawi it was found that top management support, potential security risks and inadequate legal frameworks that may affect HEIs when adopting cloud computing Makoza (2015). Dahiru et al. (2014) found that the security, privacy and are the main inhibitors to cloud adoption sub-Saharan countries. Oguntala et al. (2017) research on cloud adoption indicates that fewer organizations in the African states are adopting cloud services. They found that like Nigeria some of the concerns by the organizations in addition to lack of awareness are “employee misconception of job loss, cyber threat, privacy issue and data theft.” Muhammad (2015) expressed that for emerging economies like Nigeria to fully adopt and release cloud benefits, organizations need to “in depth understanding of different technologies and expertise in various domains, of which guidelines are currently inadequate for adoption and building trust.” In Botswana, Khanda & Doss (2018), found that one of the main issues is the lack of cloud computing is the lack of awareness by users and companies. Nghihalwa & Shava (2018) also mentioned that awareness is very important in all aspects affecting cloud computing. For the executive management to buy in and make well informed decisions, they need to be aware of the technology and decide if its benefits are worth investing in for the Namibian government. Furthermore, Abubakar et al. (2014) found that SMEs in emerging markets are less concerned with challenges like security, privacy and data loss rather, they continue to show optimism in using the potential opportunities that cloud computing presents to them. From the study by Amponsah et al. (2016), security was also found to be insignificant when it comes to cloud on cloud adoption. On the contrary, effort expectancy, hedonic motivation, and social influence negatively influence cloud technology adoption in Ghana. Like Khanda & Doss (2018) and Nghihalwa & Shava (2018), Amponsah et al. (2016) recommend for an affective awareness campaigns to targeted potential cloud computing users in regard to cloud data privacy. In contrast, Abubakar et al. (2014) found however, the acceptance and interest in cloud services amongst SMEs are slow and discouraging. The study highlights cost reduction on IT infrastructure and maintenance, improved communication, scalability and business continuity as the main drivers of cloud adoption, whereas lack of knowledge, poor internet connectivity, security of cloud services, lack of trust and interoperability with existing systems were identified as barriers to adoption. Top management support, trial ability, competence of cloud vendors, resistance to new technology, compatibility and existence of IT infrastructure are realized as key factors influencing cloud computing adoption. Ray (2016) and Ogunlolu & Rajanen (2019) proposed unifying model of cloud adoption by organizations. Ogunlolu & Rajanen (2019) cover a systematic literature review was employed to investigate the adoption factors studied in previous empirical settings. The identified factors are in line with the technology-organization-environment framework and with the diffusion of innovation model, but new insights into the dimensions relevant to cloud adoption emerged from literature. For example, system availability and reliability, cost effectiveness, privacy and security, top management support, and market pressure are among the factors influencing adoption. Ray (2016) categorized environmental, organizational, technological, and financial. Bakasa & Pekane (2021), further revealed that security, cloud service provider adoption framework, data sovereignty, data latency, data center location and the disaster recovery strategy are considered for selecting a preferred CC service provider.

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Authors	County / Economy	Organisational	Financial	Governance	Environmental	Technical	People management
Bakasa and Pekane (2021)	South Africa / Developing	X	x		x	x	
Nghihalwa and Shava (2018)	Namibia / Developing	X			x	x	x
Muhammad (2015)	Nigeria / Developing	x			x	x	
Ray (2016)	India / Developing	x	x		x	x	
Ogunlolu and Rajanen, (2019)	Nigeria / Developing	X			x	x	x
Pablo and Rodas (2017)	Acoudor / Developing	x			x	x	x
Scholtz and Govender (2016)	South Africa / Developing				x	x	
Khanda and Doss (2018)	Botswana / Developing	x	x		x	x	
Gangwar, Date and Ramaswamy (2015)	Developed	x			x	x	
Moonasar and Naicker (2018)	South Africa / Developing	X		X	X	x	
Oguntala, Abd-Alhameed, and Odeyemi (2017)	Developed	x		x	x	x	
Ayong and Naidoo (2019)	South Africa / Developing	X	X	x	x	x	
Makoza(2016)	Malawi/Developing	X			X	x	
Amponsah, Panford and Acquah, (2016)	Ghana/Developing	X			X	x	
Mkhatshwa and Mawela (2022)	South Africa / Developing	X		X	x	x	

Table 1. Cloud Computing Governance Criteria

As visible in the table 1 above, there is no framework that is holistic and encompass all the important categories of cloud adoption and lack of cloud specific areas for organizations to focus on. For this reason, this study focuses on developing holistic cloud adoption criteria and procedure on how organizations and enterprises can execute it.

III. Systematic review Methodology

Systematic literature review reveal that there are six specific categories of cloud computing project complexities, which are organizational, financial, governance, compliance, legal, and technical Rai et al. (2015), Low et al. (2011), Morgan & Conboy (2013), Nedev (2014), Akar & Mardiyan (2016).

Table 2 provides a summary of cloud computing complexity categories and its related factors. The researcher performed systematic literature reviews to find these cloud computing categories and their related factors.

Table 2. Focus Areas

Cloud computing is a social-technical system, meaning it is not technology centric but recognize the requirements and interactions from technology, people, organization, environment and community aspects. To successfully implement cloud computing, organizations need have holistic approach when they address cloud computing project complexity. The implementation of cloud computing impact the organization, finance, governance, technology and compliance. These categories are interrelated with one another. Implementation of cloud computing affects the organization as whole. This means that senior management of the organization need to support this project. How the cost will be spend need to be taken into an account. Cloud computing changes the way organizations consume the IT services and the way the pay for cloud services, which the payment method used is mainly pay as you use. There are compliance matters that need to be looked at because cloud computing is distributed across the globe. Regulatory and standards compliances across the countries need to be adhered to, this goes together with legal aspects. Governance also play important in terms who is doing what in cloud computing ecosystem.

The main goal of this research was to develop adoption criteria conceptual framework to assist organizations to effectively adoption cloud computing. The goals of the research were first to explore. Second, to establish whether or not cloud computing is different from traditional information technology (IT). Third, by understanding the complexities brought by cloud computing to organizations. Fifty-one cloud computing project complexity factors were significant for organizations to understand when implementing cloud computing projects in business institutions. These factors were categorized into six categories, namely organizational, people management, environmental, technical, governance, financial, and complexity. Off the 51 complexity factors, seventeen are primary or core complexity factors that are key to successful implementation of cloud computing projects, while the remaining 35 are secondary complexity factors that are important for both cloud and traditional IT projects. To assist and guide organizations on how to address these complexity factors, propositions for each of the factors were developed.

A. Analysis and Findings

Cloud category	Primary focus areas	Secondary focus areas
Environmental	Data residency; Legal liabilities, Subpoena and electronic discovery; Lack of cloud computing standards; Auditing; Data protection and privacy	Contractual agreement; Law and regulations; Non-compliance with industry standards; Level of competition between stakeholders; Issues of internal politics; Internal support
Technical	Cloud migration; Vendor lock-in; Multitenancy	Compatibilities and interdependency; Insider access; Data loss; Identity and access management; Limited flexibility / customisation; Performance and availability; Technology novelty; Technological architectures and infrastructure, Quality
People Management	-	Project staffing; Offshore teams; Trust; Interested parties: Categories of stakeholders; Stakeholder interrelations; User involvement; Team experience and prior team performance; Leadership style; Team cooperation and communication
Organisational	Cloud providers going out of business; Jobs; Cloud benefits / relative advantage;	Risk probability, significance of impacts; Trust; Cloud security; Talent strategy and skills training; Organisational change (processes and effect); Organisational structures and interdependencies; Clear strategic objectives and goals (organisational); Organisational readiness; Senior management support; Awareness
Governance	Cloud project boundary; Data ownership; Software licensing	Service level agreement (SLA) ; Joint-venture partners; Poor enforcement of role definitions
Financial	Charge model; Cost model	Exchange controls; Procurement
Complexity	Uncertainties in cost	Pattern and rate of IT environment changes; Availability of resources for sharing (people, material and others); Co-evolution - relationship between IT development and business strategy; Impact of changes; Scope of changes; Frequency of changes; Technological maturity; Uncertainties and clarify of objectives or goals; Uncertainties of scope; Information uncertainty

Table 3. CC-IT Factors

These different cloud computing factors need to be mastered to ensure organizations can address them before and during cloud computing implementations. Priority should be given to the primary (core) cloud computing factors because these are factors that make cloud computing unique to traditional IT. Furthermore, the secondary cloud complexity factors are still important to be addressed because primary cloud computing are not isolated from them. These factors are interrelated and interdependent to one another. Depending on the context of cloud computing project, the impact and significance of some of these cloud computing project complexity categories and factors may vary.

IV. Conclusion

It is evident from this research paper that cloud computing has taken over and continues to dominate the IT Industry. Big enterprises such as Oracle, Microsoft, Amazon and Google to name a few are the world leaders in developing world class state of the art Cloud Computing products and services. These products service and serve the needs many corporations, business institutions and enterprises across the world. Cloud computing is continuing to growing and attracting more businesses and birthing and transforming industries. There are many outstanding works that have been previously published by scholars on cloud computing adoption. This research provided a systematic reviews of these works and how they can be leveraged to guide business institutions in South Africa on how to successfully adopt Cloud computing. Upon conclusion, the study found out that different cloud computing factors need to be mastered to ensure organizations can address them before and during cloud computing implementations. Priority should be given to the primary (core) cloud computing factors because these are factors that make cloud computing unique to traditional IT. These factors were categorized into six categories, namely organizational, people management, environmental, technical, governance, financial, and complexity. Off the 51 complexity factors, seventeen are primary or core complexity factors that are key to successful implementation of cloud computing projects, while the remaining 35 are secondary complexity factors that are important for both cloud and traditional IT projects.

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Optimizing Mobile Commerce to Improve Small and Medium Enterprises Markets

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Abstract
Mobile commerce (m-commerce) enables individuals and organizations to buy and sell products on the internet. Despite the growth of m-commerce in developed countries, research studies indicate that Small and Medium Enterprises (SMEs) in developing countries are still far behind in adopting m-commerce. The theory of Diffusion of Innovation (DOI) was adopted to underpin the study. A quantitative approach was used in this study. The researcher collected data from a random sample of 150 SMEs in South Africa, in the Limpopo province. The study used structural equation modeling (SEM) to analyze data. In this study, the results of SEM indicate that trialability is the most significant factor in predicting the adoption of m-commerce in South African SMEs. Furthermore, the findings of this study also show that relative advantage, compatibility, complexity, observability and owner/manager characteristics are not significant in predicting the adoption of m-commerce in South African SMEs.

Keywords SMEs, M-Commerce, Electronic Commerce, Benefits of Mobile Commerce, DOI

1. Introduction

In this age of the fourth industrial revolution (4IR), the adoption of different types of information technologies (IT), especially m-commerce is significant for competitiveness (Chau & Deng, 2018; Kademeteme & Twinomurinzi, 2019) and it provides SMEs with great opportunities to help them improve business processes (Sumaili et al., 2018), service delivery (Khaskheli et al., 2017; Chau & Deng, 2018; Chau et al., 2020), firm performance (Salimon & Kareem, 2021) and other aspects of their business such as sales (Sumaili et al., 2018), marketing (Maduku et al., 2016), and customer relationship management (CRM) (Sumaili et al., 2018; Utami & Astuti, 2019). According to (Sumaili et al., 2018; Chau et al., 2020; Salimon & Kareem, 2021), m-commerce has the potential to support SMEs by providing them with anywhere and anytime access capabilities. Research studies conducted by (Maduku et al., 2016; Chau et al., 2020) allude that this makes m-commerce the most powerful technological tool or digital platform that individuals and SMEs can adopt to improve marketing skills.

Furthermore, Khaskheli et al. (2017) note that in the world of business, m-commerce is growing faster than electronic commerce (E-commerce). A research study conducted by (Salimon & Kareem, 2021) reported that in 2017 in the United States of America (USA), m-commerce was expected to grow from ($156 billion) to ($ 336 billion) by the year 2020. On the other hand, Maduku et al. (2016) state that it is evident that the adoption of m-commerce is no longer a matter of choice, but required for the survival of both big organizations and SMEs.

According to several researchers (Maduku et al., 2016; Menisha & Wise, 2018; Sumaili et al., 2018; Ngibe & Lekhanya, 2019; Bvuma & Marnewick, 2020; Weaven et al., 2021), most SMEs in developing countries struggle to compete with big organizations and achieve a competitive advantage because they lack strategies and the right technology to conduct business. Chau et al. (2020), and Salimon and Kareem (2021) suggest that the adoption of new innovative technologies, particularly m-commerce can be beneficial for SMEs in developing countries, which often lack the right resources to conduct business and achieve a competitive advantage.

According to (Chau & Deng, 2018; Chau et al., 2020) the adoption of m-commerce enables SMEs to reach customers anywhere, and also to buy and sell products on the internet. Salimon and Kareem

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(2021) posit that, as a result, the adoption of m-commerce is becoming popular, especially in developed countries (Khaskheli et al., 2017; Ngubelanga & Duffett, 2021; Yahaya et al., 2022). Despite the growth of m-commerce adoption in developed countries. Chau et al. (2020) and Matlakala (2021) pointed out that SMEs in developing countries, such as South Africa, are still far behind in adopting m-commerce.

Additionally, in developing countries (Chau et al., 2020), few research studies have been conducted on the adoption of m-commerce by SMEs (Khaskheli et al., 2017; Tuffour et al., 2018; Chau et al., 2020). This research study will contribute to the literature in two ways: The study will first identify the factors that influence the adoption of m-commerce in SMEs. Second, the study will contribute to the literature by testing a conceptual model from the perspective of a developing country, South Africa.

According to Chau et al., (2020), most of the research studies found in the literature (Chau & Deng, 2018; Pipitwanichakarn & Wongtada, 2021; Salimon & Kareem, 2021; Fonseka & Jaharadak, 2022; Yahaya et al., 2022) were conducted in developed countries. Therefore, this gives a great opportunity for this research study to make a unique contribution to the literature on the adoption of m-commerce in SMEs in South Africa. The rest of this paper is structured as follows: Section two (2) covers a literature review; Section (3) covers the conceptual model and hypothesis; Section four (4) covers methodology and results.

2. Literature Review

2.1 Small and Medium Enterprises (SMEs)

There are many definitions in the literature that different countries have used to define SMEs (Sibanda et al., 2018; Kademeteme & Twinomurinzi, 2019; Masocha, 2019; Ngibe & Lekhanya, 2019). According to Maduku et al., 2016; Menisha & Wise, 2018; Kademeteme & Twinomurinzi, 2019; Matekenya & Moyo, 2022; van Staden, 2022) in South Africa, the definition of SMEs can be found in the National Business Act (102) of 1996, and they are defined as organizations or enterprises with 1-250 employees and are managed by a single person or more. Therefore, in accordance with the South African definition, in this research study, SMEs are classified as organizations with 1-250 workers, having an annual turnover of two million ZAR (R 2 million), and gross assets of less than ten million ZAR (R10 million) (Maduku et al., 2016; Kademeteme & Twinomurinzi, 2019).

According to (Kademeteme & Twinomurinzi, 2019; Bvuma & Marnewick 2020; Matekenya & Moyo, 2022), in the republic of South Africa, SMEs function in environments such as towns, cities, and villages. Saah (2021) alludes that SMEs play a significant role in the economic growth and development of South Africa. Furthermore, Maziriri (2018), Saah, (2021), Ngibe and Lekhanya (2019) also point out that SMEs play a significant role in the South African economy by creating jobs, reducing poverty, and contributing to the Gross Domestic Product (GDP).

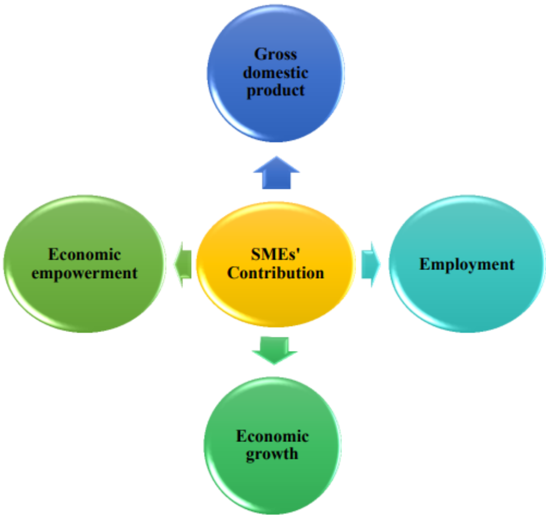

Figure 2. SMEs Contribution in South Africa (Source: adapted from Maziriri, 2018)

A study conducted by Matekenya and Moyo (2022) pointed out that in South Africa, SMEs contribute 56 percent to the creation of new job opportunities and approximately 50 percent to the Gross Domestic Product (GDP). Additionally, Matekenya and Moyo (2022) also claim that in South Africa, SMEs are expected to create more than 90 per cent of jobs by the end of the year 2030. van Staden (2022) mentions that the South African Department of Small Enterprise Agency (SEDA) specified that as SMEs in developed countries began to improve and adapt to technological changes which occur in the market, it is also important for SMEs in South Africa to also develop. Several scholars (Gümüs & Kütahyali, 2017; Chege & Wang, 2020; Kolawole

Olayemi & Festus Folajimi, 2021; Murithi, 2021; Saah, 2021) assert that SMEs are important in the global economy because they create new job opportunities and contribute to the GDP of many countries around the world.

Table 1. SMEs Contribution (Source: adapted from Chege & Wang, 2020)

Country	% of GDP	% of Job creation	Authors
Russia	(90 - 99%)	(50-60%)	Kademeteme & Twinomurinzi (2019)
China	(90-99%)	(50-60%)	Kademeteme & Twinomurinzi (2019)
USA	(52%)	(55%)	Olayemi & Folajimi, (2021)
Turkey	(99.8 %)	(73.5%)	Gümüs & Kütahyali (2017)
South Africa	(52-57%)	(60%)	Matekenya & Moyo (2022)
Ghana	(70%)	(49%)	Chege & Wang (2020
Nigeria	(50%)	(70%)	Chege & Wang (2020)

2.1.1 Challenges Faced by SMEs in South Africa

According to Saah (2021), SMEs play a significant role, and their contribution to the economy of developing countries, such as South Africa, cannot be ignored. Kademeteme and Twinomurinzi (2019), and Matekenya and Moyo, (2022) concur, stating that most SMEs are significant for the growth and development of the economy in various countries around the world. However, a study conducted by Bvuma and Marnewick (2020) argues that SMEs in South Africa are faced with challenges. Muriithi (2017) posits that the challenges SMEs in South Africa are faced with include the lack of IT skills (Bvuma & Marnewick, 2020), lack of technology to market the business (Maduku et al., 2016; Myeko & Iwu, 2019), lack of skills to manage the business (Bvuma & Marnewick, 2020), and a lack of suitable technologies to conduct business in international markets (Bvuma & Marnewick, 2020), etc.

Table 1. Summary of Challenges faced by SMEs in South Africa (Source: adapted from Bvuma & Marnewick, 2020)

SMEs Challenges	Author/Reference
• They don’t have the skills to market the business	Bvuma & Marnewick (2020)
• They lack suitable technologies to conduct business	Maduku et al. (2016)
• The cost of ICT infrastructure (hardware & software)	Bvuma & Marnewick (2020); Menisha & Wise (2018)
• They struggle to have an access to international markets	Maduku et al. (2016); Bvuma & Marnewick (2020)
• They lack knowledge about the adoption of ICT	(Menisha & Wise, 2018)
• They lack skills to manage the business	Bvuma & Marnewick (2020)
• They lack tools to assist them to collaborate with customers	(Bhorat et al., 2018); Bvuma & Marnewick (2020)
• Most SMEs lack IT education and IT skilled workers	(Bvuma & Marnewick, 2020)
• They lack funds to sponsor their business	(Muriithi, 2017); Bvuma & Marnewick (2020)
• They are faced with high competition in the market	(Weaven et al., 2021)

According to Maduku et al. (2016), Chau et al., (2020), and Salimon and Kareem (2021) the solution to overcome these challenges in SMEs is the adoption of new innovative technologies such as m-commerce.

2.2 Mobile Commerce (M-commerce)

Many organisations in the business world are witnessing advancements (Baral, 2021; Rakshit et al., 2021) and the growth of new innovative technologies (Cheng & Liu, 2017; Luo et al., 2018; Prasanna et al., 2019; Baral, 2021). According to (Chau et al., 2020; Chau & Deng, 2018; Khaskheli et al., 2017; Salimon & Kareem, 2021; Yahaya et al., 2022) m-commerce is a new innovative technology that can be adopted by organisations such as SMEs. Khaskheli et al. (2017) and Rakshit et al. (2021) posit that in business communities, m-commerce is growing faster than electronic-commerce (e-commerce). Research studies conducted by (Khaskheli et al., 2017; Fonseka & Jaharadak, 2022; Chau et al.,

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2020) discussed the difference between m-commerce and e-commerce.

E-commerce involves the use of personal computers (PCs) and laptops to conduct business transactions on the internet (Fonseka & Jaharadak (2022). M-commerce is distinguished by the use of mobile applications (m-applications) by using portable wireless devices such as smartphones, iPads, and tablet pc's to buy and sell products on the internet (Khaskheli et al., 2017; Chau et al., 2020). M-applications are useful to perform several things such as placing orders, buying, and selling products, delivering food to customers, ordering food from restaurants and booking accommodation (Rakshit et al., 2021).

According to Khaskheli et al., (2017) and Matlakala (2021), mobile devices such as iPads and cellphones are compatible with m-commerce because they are affordable and easy to carry. Matlakala (2021) alludes that the adoption of m-commerce allows SMEs to successfully compete with big organizations. Khaskheli et al., (2017) indicate that the good news about m-commerce is that it has turned the world into a digital platform where SMEs will no longer be limited from selling products to customers that are based in other countries.

The benefits of m-commerce, as highlighted by (Chau et al., 2020; Fonseka & Jaharadak, 2022), is that it can be used as a marketing strategy to provide goods and services to customers. Chau and Deng (2018) state that m-commerce can assist SMEs to meet customers' expectations by giving information faster. Furthermore, through m-commerce adoption, SMEs can improve firm performance and operational efficiency (Chau et al., 2020; Salimon & Kareem, 2021; Fonseka & Jaharadak, 2022).

Moreover, Chau et al. (2020) and Fonseka and Jaharadak, 2022), assert that m-commerce can help organizations such as SMEs improve marketing processes by enhancing online payment systems (Fonseka & Jaharadak, 2022; Salimon & Kareem, 2021). According to (Maduku et al., 2016; Waithaka & Mnkandla, 2017; Matlakala, 2021), nowadays, most people no longer have much interest in buying things from the shop physically, but they prefer to purchase products from their homes or work offices using mobile applications.

Matlakala (2021) indicates that the rate of m-applications utilization in South Africa is high, and the adoption of m-commerce will improve the performance of SMEs (Chau et al., 2020; Chau & Deng, 2018; Yahaya et al., 2022; Matlakala, 2021). Additionally, a study by Matlakala (2021) pointed out that 60 per cent of people in South Africa have access to mobile devices, m-applications and internet connections.

Salimon and Kareem (2021), posit that despite the benefits of m-commerce adoption, Chau et al. (2020) indicate that SMEs in developing countries are still far behind in adopting m-commerce. A study by Salimon and Kareem (2021) pointed out that China has the highest m-commerce adoption rate of 70.1 per cent, then followed by India with an adoption rate of 69.9 per cent, and the third being Taiwan with an adoption rate of 62.6 per cent. However, Ngubelanga and Duffett (2021) indicate that South Africa has a low m-commerce adoption rate of 58 per cent.

According to Chau et al. (2020), the benefits that m-commerce provides to individuals and organizations has resulted in several research studies to understand the adoption of m-commerce in a different situation. For example, a study by Chau and Deng (2018) developed a framework to understand the adoption of m-commerce by SMEs in Vietnam. The study used Technology-Organization-Environment (TOE) to develop a conceptual framework that can be used to identify critical factors influencing the adoption of m-commerce. The framework enables SMEs to identify factors influencing m-commerce adoption. However, this research study has some limitations.
Firstly, the study by Chau and Deng (2018) used a literature review and it is still in the process of developing a model. Secondly, the target population of this study was SMEs in Vietnam. Thirdly, the proposed framework did not discuss other factors such as relative advantage, trialability, and observability, which may influence the adoption of m-commerce by SMEs.

Yahaya et al. (2022) conducted a literature review on m-commerce adoption by SMEs. The study combined Task-Technology Fit (TTF) with the Unified Theory of Acceptance and Use of Technology (UTAUT) to propose a framework that can be used to identify factors that influence SMEs to adopt m-commerce in Malaysia. The results indicate that the proposed framework

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enables researchers to test and identify the factors that influence the adoption of m-commerce in SMEs. However, the framework proposed by Yahaya et al. (2022) did not address the factors that influence m-commerce adoption in SMEs from a DOI perspective. On the other hand, the study is in a process of reviewing literature and designing a framework. As a result, the study suggests that future research studies use a quantitative approach to test and validate the conceptual framework. Pipitwanichakarn & Wongtada (2021) conducted a study on m-commerce adoption. The study used a Technology Acceptance Model (TAM) to explain the adoption of m-commerce among street vendors in Thailand. The study collected data through a survey from 370 street vendors and analyzed it using structural equation modeling (SEM). The results show that the proposed framework is fit enough to explain the adoption of m-commerce to street vendors. However, the study was only limited to street vendors that are in Thailand. As a result, this study suggested that the results be duplicated and that future research studies be conducted in developed or developing countries. A study conducted by Tarhini and Al-badi (2019) proposed a conceptual framework by combining system quality, service quality, and information (SERVQUAL) with UTAUT2 to enable researchers to identify factors that may affect or influence the customers to adopt m-commerce in Oman. The researchers collected data through a survey from 530 m-commerce users and analyzed it using SEM.

The study by Tarhini and Al-badi (2019) found that behavior, performance, cost, trust, service quality, and working conditions positively influence m-commerce adoption. However, although this study used a quantitative approach, the proposed framework proposed did not discuss the factors that may either affect or influence the adoption of m-commerce from a DOI perspective. Another limitation of this study is that it only focused on customers in Oman, and only collected data in one country. As a result, the findings of this study cannot be generalized in developing countries such as South Africa. Salimon and Kareem (2021) proposed a conceptual framework by integrating three models, which were TAM3, UTAUT,2 and TOE. This study aimed to examine the factors that influence SMEs to adopt m-commerce in Malaysia. The study used a quantitative approach. Data was collected from 400 SMEs through a survey and analyzed using SEM. Salimon and Kareem (2021) found that computer self-efficacy, technology factors, and demonstrability positively influence the adoption of m-commerce in SMEs. However, the proposed framework failed to discuss other factors such as security, IT skills, etc. Secondly, the study only collected data from SMEs that were based in Malaysia.

Fonseka and Jaharadak (2022) proposed a conceptual framework by combing Porter's generic strategies and resource-based views (RBVs) to understand the impact of e-commerce in Sri Lanka. The purpose of this study was to examine the perception of SMEs managers on the impact of e-commerce adoption on business performance. The study used a quantitative approach. Data was collected from 389 SMEs through a survey. Fonseka and Jaharadak (2022) found that age, job title, gender and the level of education negatively affect the perception of SME owners on the impact of e-commerce. In addition, the limitation of this study is that it only focused on SMEs in Sri Lanka. The study suggests that future research studies be conducted in other countries. Maduku et al. (2016) used TOE to develop a multi-perspective framework to understand the key factors that influence the decision of SMEs in South Africa to adopt mobile marketing. The study used a quantitative approach and data was collected from 205 SMEs using a survey. Maduku et al., (2016) found that pressure from customers, relative advantage, top management support, cost and employees' knowledge about IT positively influence the decision to adopt mobile marketing. However, this study was conducted on the adoption of mobile marketing in South African SMEs. The proposed framework ignored other factors such as relative advantage, observability, compatibility and trialability that may influence SMEs to adopt mobile marketing. Another limitation found in this study is that data were collected only in the Gauteng province. Therefore, the findings of this study cannot be generalized to rural areas. The researchers recommended that future studies should be conducted in other provinces within South Africa.

A research study by Alduaij (2018) used TAM to identify the benefits of m-commerce adoption and the factors affecting the decision of users to adopt m-commerce. The study used a quantitative approach. The researcher collected data from

ISBN: 978-99949-0-888-2

1050 students through a survey and analyzed using SEM. Alduaij (2018) found that users' decisions to adopt m-commerce are influenced by the benefits of adopting m-commerce and the factors affecting the adoption of m-commerce. The limitation of this study is that it only used TAM to identify the benefits and factors affecting the students' decisions to adopt m-commerce in the country of Kuwaiti. The researchers suggested that future research studies should use other models to get more knowledge on the benefits and factors affecting the adoption of m-commerce.

3. Conceptual Framework and Hypothesis

The theory of Diffusion of Innovation (DOI) developed by Rogers (2003) was adopted to underpin the study. According to Matekenya and Moyo (2022), in South Africa, innovation is regarded as one of the key drivers of SMEs performance and, without innovation, SMEs in South Africa will find it difficult to adapt to change in business communities.

Saunila (2016), and Matekenya and Moyo (2022) define innovation as an application of a new product or a new way of doing business. As highlighted by Maduku et al., (2016), the decision to adopt innovative technologies, particularly m-commerce in organizations such as SMEs, is motivated by several benefits that it can provide to their working environment.

According to Shoniwa (2021), the five factors of DOI include, (1) relative advantage, (2) compatibility, (3) complexity, (4) trialability and (5) observability, and they were combined with an external factor which is owner-manager characteristics (Rasheed, 2018). According to Maduku et al. (2016) and Shoniwa (2021), relative advantage is associated with the benefits that m-commerce adoption can provide to SMEs. Therefore, this leads to hypothesis (H1):

H1: Relative advantage positively influences the adoption of m-commerce.

Compatibility refers to two or more things that can perform tasks without any conflict (Chau et al. (2020). M-commerce technology can be easily adopted by SMEs when it is compatible with their business processes Chau et al. (2020). Therefore, this leads to hypothesis (H2):

H2: Compatibility positively influences m-commerce adoption.

Complexity is associated with how difficult or easy a technology can be adopted and used (Shoniwa, 2021). According to researchers (Chau et al., 2020; Shoniwa (2021) organizations such as SMEs will only adopt m-commerce when it is not difficult, but easy to be used. Therefore, this leads to hypothesis (H2):

H3: Complexity positively influences m-commerce adoption.

According to Shoniwa (2021), observability is associated with the results that a technology, such as m-commerce, can produce. Salimon and Karee (2021), Chau et al. (2020) SMEs will adopt m-commerce if it will help SMEs conduct business both locally and internationally. Therefore, this leads to hypothesis (H5):

H4: Observability positively influences m-commerce adoption.

A study by Shoniwa (2021) stated that trialability is the degree to which technology can be tested on a limited basis. According to (Rogers, 2003; Chau et al., 2020; Shoniwa, 2021) trialability creates an opportunity for organizations to explore the benefits of adopting technologies such as m-commerce. M-commerce should be available on a trial basis to give SMEs enough time to evaluate it before a decision can be made to adopt it (Chau et al., 2020). Therefore, this leads to hypothesis (H5):

H5: Trialability positively influences m-commerce adoption.

A research study conducted by Rasheed (2018) stated that in SMEs' environment, the financial decision to adopt a new technology is influenced by owner-manager attitude. Therefore, this leads to hypothesis (H6):

H6: Owner-manager characteristics positively influence m-commerce.

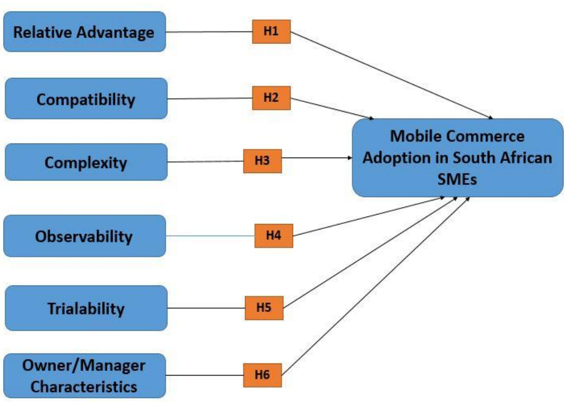

Figure 4. M-Commerce Adoption model

ISBN: 978-99949-0-888-2

4. Methodology and Results

A quantitative approach was used in this study (Rahman, 2016). The population of this study was 200 South African SMEs. A simple Random sampling technique was used because this gives each SME an opportunity of being selected. Two hundred (200) questionnaires were physically distributed to SMEs. The Five (5) Likert Scale was used in this study, where 1 = strongly disagree; 5=strongly agree. Out of the 200 questionnaires, only 150 were returned and data was analyzed using SPSS. This study is cross-sectional because data was collected only at one point in time (Mokwena & Hlebela, 2018). The participants were asked a question about if they have experience in m-commerce adoption and 39 per cent of respondents selected “yes” they have adopted m-commerce, while 0.66 per cent of respondents selected “no”. The response rate for this study was 75 per cent. Cronbach’s Alpha (CA) and all the 32 items were measured and found to be 0.831, which indicates a very good reliability.

Table 3. Reliability of the Questionnaire

CA	**CA on standardized items**	**Items**
(0.831)	(0.748)	(32)

In this study, all the constructs that were used to develop a model were tested to check if they were reliable and they were found to be more than 0.6, which indicates a very good reliability. The results are displayed in Table 4.

Table 4. The Reliability Constructs

Variables/ Construct	**CA**	**CA on standardized items**	**Items**
H1: Relative Advantage (Maduku et al., 2016)	[0.693]	[0.696]	Three [3]
H2:Compatibility (Shoniwa, 2021; Chau et al., 2020)	[0.706]	[0.708]	Three [3]
H3: Complexity (Shoniwa, 2021)	[0.742]	[0.749]	Three [3]
H4: Observability (Chau et al., 2020; Shoniwa, 2021)	[0.704]	[0.702]	Four [4]
H5: Trialability (Shoniwa, 2021)	[0.918]	[0.921]	Three [3]
H6: Owner-manager characteristics (Rasheed, 2018)	[0.664]	[0.662]	Three [3]

Table 5. Testing Hypotheses

Hypothesis	**β =Beta**	**(P-Value) =0.05**	**Remarks**
H1: Relative Advantage (Maduku et al., 2016)	[-0.83]	(0.321) >0.05	**H1** =Rejected
H2:Compatibility (Shoniwa, 2021; Chau et al., 2020)	[0.121]	(0.156) >0.05	**H2** =Rejected
H3: Complexity (Shoniwa, 2021)	[0.061]	(0.494) >0.05	**H3** =Rejected
H4: Observability (Chau et al., 2020; Shoniwa, 2021)	[0.087]	(0.325) >0.05	**H4** =Rejected
H5: Trialability (Shoniwa, 2021)	[-0.316]	(0.000) <=0.05	**H5** =Accepted
H6: Owner-manager characteristics (Rasheed, 2018)	[-0.031]	(0.690) >0.05	**H6** =Rejected

The findings in Table 5 indicate that all the five hypotheses (H1, H2, H3, H4 & H6) were not accepted, because they have a p-value of greater than 0.05 and only H5 was accepted with a p-value of less than (<) 0.05. However, although these hypotheses were rejected, there is a correlation among the constructs.

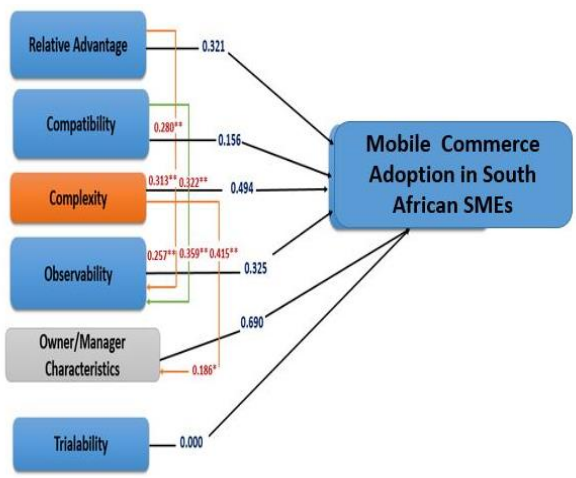

Figure 5. Results of Structural Equation Modeling

ISBN: 978-99949-0-888-2

Figure 5, in this study, illustrates that compatibility (Chau et al., 2020) correlates with relative advantage at 0.280**. Complexity (Shoniwa, 2021) with relative advantage and compatibility at 0.313** & 0,322**. Trialability (Chau & Deng, 2018; Shoniwa, 2021) correlates with both relative advantage and compatibility (Chau et al., 2020; Shoniwa, 2021; Maduku et al., 2016; Salimon & Kareem, 2021). In addition, observability (Salimon & Kareem, 2021; Shoniwa, 2021; Yahaya et al., 2022) is significant or correlates with relative advantage (Maduku et al., 2016), compatibility (Chau et al., 2020) and trialability (Shoniwa, 2021) at 0.257**; 0.359**; 0.415**; -0.192*. Owner-manager characteristics (Rasheed, 2018) correlate with complexity (Chau & Deng, 2018; Shoniwa, 2021) at 0.186*. Because the results in Figure 5.1 show that there is a correlation among the variables, relative advantage (Maduku et al., 2016); compatibility (Shoniwa, 2021); complexity (Chau & Deng, 2018; Shoniwa, 2021); observability (Shoniwa, 2021), trialability (Shoniwa, 2021); owner-manager characteristics (Rasheed, 2018).
This implies the following.

H1: relative advantage (Chau et al., 2020) positively influences m-commerce adoption in SMEs in the Republic of South Africa. The findings of this study are in line with a recent study conducted by Njenga et al., (2019).

The findings by Njenga et al., (2019) indicated that 95 per cent of participants agree that relative advantage positively influences Cloud Computing adoption in higher institutions in Kenya.

H2: Compatibility (Shoniwa, 2021) positively influences m-commerce adoption in SMEs. The results of this study also agree with the study by Njenga et al., (2019) who stated that 96 per cent of individuals agree that compatibility (Chau et al., 2020) influences the adoption of Cloud Computing.

H3: Complexity (Chau et al., 2020) positively influences the adoption of m-commerce within SMEs in South Africa. The findings are in agreement with Shoniwa (2021) who indicated that 83 per cent of individuals agree that complexity positively influences SMEs to adopt Cloud Computing. In this study, according to the results in Table 5, H4 (observability) negatively influences m-commerce adoption in SMEs. The results in Table 5 are in agreement with Njenga et al. (2019) who found that 65 per cent of participants concur that observability does not influence m-commerce adoption in SMEs.

H5: Trialability positively influences m-commerce adoption in SMEs. The results are consistent with Zadeh et al. (2017), who stated that trialability creates an opportunity for SMEs to explore and understand the benefits of adopting the technology.

H6: Owner-manager characteristics (Rasheed, 2018) positively influences m-commerce adoption in SMEs. The results are consistent with a study by Chau et al., (2020) who found that owner-managers knowledge about information technology (IT) influence the adoption of m-commerce in SMEs.

Contribution to Research

This research study contributes to the knowledge of m-commerce by presenting factors influencing the adoption of m-commerce which were validated.

Implications for SMEs' owners and managers

M-commerce may help inform SMEs' owners and managers about the factors influencing the adoption of m-commerce in South African SMEs. When adopted properly, m-commerce can make buying and selling products faster and easier for SMEs. From the results of this study, one factor was significant that influences the adoption of m-commerce in South African SMEs. The factor reported is trialability. The results provide valuable insight for SMEs' owners and managers which implies that there will be a need to evaluate their organizations' readiness to adopt m-commerce.

Limitations and Future Research

This study has some limitations. First, this research study only focuses on the adoption of m-commerce in SMEs in South Africa. As a result, future research studies can also be conducted in other developed and developing countries to explore the adoption of m-commerce in SMEs. Second, the study investigated factors that influence the adoption m-commerce in South African SMEs.

Therefore, future studies can be conducted to explore the benefits and challenges of m-commerce adoption in SMEs. Third, the population for data collection is SMEs in the South African market that include both the adopters and non-adopters. As a result, the differences in how they perceive things could create a bias for the empirical results. A comparative study on the factors influencing m-commerce adoption in SMEs between adopters and non-adopters of m-commerce could be conducted to have suggestions for SMEs owners and managers to facilitate the diffusion of m-commerce in SMEs. Finally, this study used a quantitative method (a self-administrated cross-sectional survey) to investigate factors associated with the adoption of m-commerce by South African SMEs. However, the cross-sectional survey only shows the perceptions, beliefs and experiences of respondents towards m-commerce adoption at a particular point in time. As a result, future research studies could be conducted using a longitudinal survey to give more information that explain the factors associated with m-commerce adoption.

5. Conclusion

The findings of this study show that relative advantage, compatibility, complexity, observability & owner/manager characteristics are not significant in predicting the adoption of m-commerce in SMEs in South Africa. The study also found that there is a correlation between the constructs. However, although there is a correlation between the constructs, only one hypothesis is acceptable for this research study according to the coefficient analysis, which is H5 (trialability).

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Academic and Skills Credentialing Using Distributed Ledger Technology (DLT) and W3C Standards: Technology Assessment

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Abstract
The ongoing push for the 4th industrial revolution is setting the stage to digitise, persist and verify identity along with credentials. Academic and skills credentials are currently verified manually and have much scope for automation using cryptographic techniques but requires standardisation to facilitate future systems interoperability. The Distributed Ledger Technology (DLT) and World Wide Web Consortium (W3C) Verifiable Credentials (VC) standards presents the possibility to achieve this credential verification automation. To accomplish this, an understanding of various DLTs and requirements for a viable skills tracking system is important. Therefore, this research aims to access the selected DLTs against the assessment criterion presented and an analysis has been completed to determine which DLT is suitable for the proposed system. The DLTs are assessed in terms of their ability to support the rapid prototyping of such a system and provide recommendations to guide a future development path from the perspective of standards compliance. We conclude that few DLTs possess the maturity to provide proper requirements coverage due to the emergent nature of the DLT space. Additionally, this paper presents the high-level requirements to achieve a minimally viable solution that can demonstrate such digital credential verification in the academic and skills tracking context.

Keywords: distributed ledger technology, blockchain, standardisation, verifiable credentials, skills tracking

1. Introduction

The current system to verify qualifications in South Africa (SA) is known as the South African Qualifications Authority (SAQA) verification service, where all achieved qualifications are stored in the National Learners' Records Database (NLRD) (Ntshangase & Msosa, 2022). This is a centrally hosted database that will require some changes to improve the efficiency of their current verification process. A key challenge listed in their strategic plan for 2020/21 – 2024/25 is financial sustainability due to the current system having too many manual elements: *"Many of our processes are manual, outdated, and time-consuming. With adequate resources, SAQA can automate and streamline its processes; employ artificial intelligence to repetitive processes where necessary; improve productivity; and develop innovative solutions to complex problems"* (South African Qualifications Authority (SAQA), 2019).

From a security perspective, there are societal issues related to unethical human behaviour that technology will not solve (Schneier, 2019). For example, adopting the World Wide Web Consortium (W3C) Decentralised Identifier (DID) and Verifiable Credentials (VC) standards could give the current system the ability to identify, track and audit all system actors, but it cannot identify malicious actors that issue fraudulently signed credentials. There have been innovations in cryptographic threshold signatures that could improve the situation (Sonnino et al., 2018) and disincentivise unethical behaviour or impersonation by requiring a threshold number of actors from a quorum to jointly authorise academic credential issuers such as universities. This quorum of signatures could represent authoritative entities from across the world, or from within the country that acts as the Accreditation Authority (AA) (Gräther et al.,

2018) to prevent lone bad actors from compromising the system's integrity.

From an efficiency perspective, there could be much to gain when adopting the mentioned W3C standards and associated technologies to streamline administrative overhead as it becomes automated through cryptographic signature verification, and also fosters the move towards self-sovereign identity (Bai, 2022). By additionally adopting a Distributed Ledger Technology (DLT), a temporal immutable history of events and attestations about credentials (DID documents) and actors (DIDs) can be persistently timestamped and proven without a trusted third party or central authority. The decentralized aspect of DLT provides a means of redundant storage of timestamped credential attestations that cannot be mutated by anyone except the owner of the attestation. In addition, a form of Content Addressable Storage (CAS) could be used to also persist the credential information (apart from the attestation metadata). This is to mitigate the risk of the learner or subject from losing their credential document and, to alleviate NLRD system administration and maintenance efforts.

The job markets in both SA and the United States (US) are encountering various challenges and there seems to be a push to create newer types of digital credentials at the risk of credential proliferation (Hurder, 2020). This research assumes that mechanisms are in place to prevent this proliferation and rather focuses on the selection and use of emerging technologies and standards to assist institutions such as SAQA in reducing their operational costs and to facilitate future interoperability. The latest South African data, from 2014, shows that there were approximately 600 foreign qualification verifications per day, and an average of 222,410 local NLRD visits or queries per month (Bolton, 2017), and it is indicated that these queries are related to qualification verifications. In 2016, another qualifications verification entity, the Managed Integrity Evaluation (MIE), also verified 8500 qualifications on average per month (Parliamentary Monitoring Group, 2016). If we assume that these numbers can be added together to ballpark estimate the DLT back-end requirements for verifications per second, we arrive at ((222410 + 8500) * 12 = 365) + 600 = 8192 verifications required per day (which is the assumption our proposed solution is based on). According to the Higher Education Management Information (HEMIS) 2017 data, there are an additional 190, 000 thousand tertiary graduates each year in SA that need to be registered or 190000=365 = 520 per day. All this registration and verification could be streamlined by cryptographic verification with a decentralised, persistent identity.

The difficult task at hand, however, becomes the proper selection of the technologies in question that would provide adequate security, performance, capability, and scalability to achieve such a solution. This is challenging due to the disruptive, emerging, and ever-changing nature of the DLT space. Therefore, this research aims to assess various technologies to answer various questions and gain insight towards selecting a credential and skills tracking system using DLT technologies and accompanying technologies. These technologies can support commercialisation at scale, whilst also complying with the emerging W3C VC and DID standards, the General Data Protection Regulation (GDPR) (as we aim for an internationally recognizable system) and the South African Protection of Personal Information Act (POPIA). These standards then act as a selection filter as there are far too many DLT projects to review that do not consider standardization and future interoperability.

The remainder of the paper is structured as follows: Section 2 briefly outlines the method and reasoning behind the selection. Section 3 provides a summary of each of the candidate DLTs related to their ability or inability to satisfy the assessment criteria. Section 4 provides a summary of analysis after the assessment. Section 5 elicits some important requirements necessary for a minimally viable credential tracking solution, and thus present the proposed system requirements. Finally, Section 6 concludes the study.

2. Method

The first requirement for credential verification is to have a means of identifying stakeholders within the skills and credential tracking system. Thus, the DLT selection and assessment process starts off from the perspective of the W3C DID and VC standards, particularly focussing on the DID method registry (Draft Community Group, 2019). The registry lists all the development entities that have defined or implemented a DID method. In summary, we view the candidate or selected DLTs through the lens of the available DID methods. To identify suitable DLT technology candidates in terms of developer adoption, the registry list was sorted by the DLTs that can host the most amount of different DID method implementations. Therefore, the process of selecting DLTs is based on a non-probability sampling method (which was adopted because there are various DLTs, and it limits the scope to a manageable sample size). The DLTs that support the most DID method implementations are Ethereum, Hedera Hashgraph and Hyperledger Indy. Below is a list of all the selected DLTs and the reasons for their selection:

- Ethereum, because of the aforementioned developer community adoption due to it supporting nine DID methods.
- Hedera Hashgraph, because it supports two DID methods, placing it in second place regarding developer adoption related to standardisation.
- Hyperledger Indy (a.k.a. Sovrin), because it is specifically intended for the standard W3C DID and VCs.
- HoloChain, due to its application- or agent-centric, nonblockchain (non-data-centric) approach, which might scale better than data-centric approaches.
- Inter-Planetary File System (IPFS), because it focuses on storage rather than a blockchain, since credentials contained in DID Documents need to be persisted.
- Factom, because it focuses on generically registering any asset (credentials, property etc.) which aims towards broader prototype context expansion.
- IOTA, because it is fee-less and has low-resource requirements nature (Bhandary et al., 2020) since it focusses on the Internet of Things (IoT) context.

To assess these selected DLT technologies and to ease support of the initial prototyping phase and achieve a minimal viable solution, the following Assessment Criteria (AC) was followed:

- **AC-1**: Does it support a threshold signature scheme where a subset of the credential issuer quorum can cryptographically authorise institutions to issue credentials?
- **AC-2:** Scalability in terms of transactions per second? Even though the scalability requirements for this context are low, the public utility nature of DLTs could cause the tragedy of the commons where others overuse the system, causing it to become slow.
- **AC-3:** How many active addresses there are to indicate developer community and public adoption?
- **AC-4**: Are there documentation examples that illustrate DID document usage to sketch an idea of DID method maturity?
- **AC-5**: Does it feature encrypted DID document storage as well, or does it only store hashes of DID documents on a ledger?
- **AC-6**: Does it have a test or mock-setup for development purposes to avoid paying token costs during testing?

To address these questions, an analysis is performed against the 7 selected DLTs and the results are depicted in section 4.

3. DLT Technologies

This section provides details about the DLT technologies selected in section 2 for the assessment.

3.1. Ethereum

Ethereum is a permissionless, opensource blockchain that features multiple consensus mechanisms and is open to anyone who wishes to participate in its ecosystem. Due to the complexity, measuring the throughput and latency of such a network is difficult as this metric is a function of many parameters and variables along with multiple consensus mechanisms. A best-case scenario experiment from a formal analysis by (Schäffer et al., 2019) which centralises the network to one node, indicates: *"Our experiments show that with a block period of 1s, a block size large enough to fit 1 000 transactions into the block, an Amazon Web Services (AWS) Elastic Compute Cloud (EC2) instance of type c5.4xlarge, and a network of a single node, the throughput can be as high as 328 transactions per second (tps) on average"*. From practical measurements, Ethereum can currently process approximately 15tps (Rankhambe & Khanuja, 2019) which might be problematic if decentralized application development gains momentum and, because of the many non-native tokens that are hosted on the Ethereum platform. However, it seems that progress has been made considering Ethereum Improvement Proposal (EIP) #2028, which will provide 9000tps when executing smart contracts and 18,000tps for regular ledger transaction verifications, according to a recent announcement (Dalvit, 2020).

For the period from January 2018 to July 2020, the approximate median of the number of active Ethereum addresses were 500,000 (Bitinfocharts, 2020). Ethereum is also the second biggest market cap platform, which should count in its favour in terms of community. This, in conjunction with the 9 DID method implementations supported by the Ethereum platform, ranks it first for prototype development purposes. Although the *did:signor* DID method is listed as being capable of running on nine different DLTs, no additional documentation or examples were found, thus showing lack of documentation. As of July 2020, there are only two Ethereum associated DID methods that stood out in terms of documentation maturity along with privacy and security considerations, namely, *did:jolo* and *did:selfkey* by jolocom.io (Jolocom, 2019) and selfkey.org (SelfKey, 2017) respectively. These two Self Sovereign Identity (SSI) solutions also aim for GDPR compliance and user-centric data and identity control and provide technical detail encapsulations with open-sourced software libraries. SelfKey is an SSI ecosystem that uses Ethereum as their DID persistence mechanism, but stores credential DID documents on the user's device with more options for DID document storage planned for future development, including integration with a Trezor hardware wallet to secure private keys (SelfKey, 2017). Jolocom is an SSI protocol that also uses Ethereum as its DLT for timestamping attestations and provides DID document persistence via the IPFS CAS as their DID document storage mechanism, which is the same format used to store academic credentials for this solution context. They feature a flexible design with future additions planned to choose different DID document storage back-ends along with IoT device identity management. The white-paper has a better focus on VCs where they aim to satisfy all of Christopher Allen's SSI requirements and also have proper VC and DID documentation examples (Jolocom, 2020). The ten requirements for SSI stipulated by Christopher are: user centricity, control, access, transparency, longevity, portability, interoperability, consent, minimized data disclosure, and protection (Allen, 2020).

3.2. Hedera Hashgraph

Hedera Hashgraph is a permissioned DLT with 12 nodes spread out predominantly across the US and Europe as of July 2020 (DragonGlass, 2020). Depending on the number of nodes, geographical regions and transaction size, Hashgraph's throughput varies from 4,000 to 250,000tps with a latency variation of 20 to 0.04 seconds (Baird & Luykx, 2020). It shows real-world practical use but, in the permissioned setting where nodes are hosted by trusted entities and enrolled through a more formal process. As of 30 July 2020 there were 41,515 active accounts and 217,825,175 transactions processed since 17 August 2019, equating to an average usage of 7.25tps concerning its current real-world throughput demand (DragonGlass, 2020).

The Hashgraph *did:hedera* method is accompanied by many guides (Hashgraph, 2020c)(Hashgraph, 2020a)(Hashgraph, 2020d) and software examples. It is intended to enable the developer to have granular configurability and flexibility regarding their application at the cost of more development or prototyping overhead. The Hashgraph ecosystem features the Hedera Consensus Service (HCS) for token transactions and timestamping of DID associated attestations and includes an integrated Hedera File Service (HFS) to store credentials in DID document format. Application actors can communicate by sending authenticated messages over the HCS in DID document format. All DID documents can be encrypted or unencrypted and allows access control per business application where the servers that host the business application network are registered in an address book which resides in the HFS of the Hashgraph DLT (Hashgraph, 2020b).

DIDs and verifiable credential DID documents can be submitted to a topic identifier and consequently grouped per business application. DID topic access can be controlled by signatures which also support threshold signatures (Hashgraph, 2020b). These signatures achieve a core requirement for the academic AA mentioned in section 5.

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3.3. Hyperledger Indy / Sovrin

Hyperledger Indy is a permissioned DLT which is specifically designed for the SSI DID and VC use case, and was pioneered by the Sovrin Foundation (Li et al., 2020). Their DID method is referred to as did:sov. Hyperledger Indy uses the Plenum Redundant Byzantine Fault-Tolerant (RBFT) (Hyperledger Architecture Working Group (WG), 1985) which is based on Practical Byzantine Fault-Tolerant (PBFT) (Castro & Liskov, 2002). It applies redundant instances of the protocol to prevent faulty or malicious nodes from degrading the system's performance. No studies were found that measure and analyse the throughput of Indy's Plenum RBFT, but it is suspected it could be lower than PBFT's 1025tps (Hao et al., 2018) due to its additional redundancy that should theoretically trade-off efficiency. Additionally, no details regarding how many DIDs or active addresses there are on the Hyperledger Indy DLT were found, but there seems to be corporate adoption according to (Gubler, 2019). In terms of documentation, their documentation is scattered across various domains making it difficult to discern which sources of information to trust and how to structure one's learning experience as there is much information redundancy as follows:

- wiki.hyperledger.org/display/indy/Documentation+Index
- wiki.hyperledger.org/display/indy/Hyperledger+Indy
- github.com/hyperledger/indy-node
- github.com/hyperledger/indy-plenum
- github.com/hyperledger/indy-crypto
- github.com/hyperledger/indy-sdk
- github.com/hyperledger/indy-hipe
- readthedocs.org/projects/indy-hipe
- indy.readthedocs.io
- sovrin.org

There has, however, been a proposal to improve their documentation as described in Chapter 17 of their Indy Project Enhancements Documentation (Hardman et al., 2019) to:

1. *"Make better documentation that helps users and contributors to more easily understand, use, and contribute to our code."*
2. *"Help maintainers eliminate duplicated or deprecated content and give everyone a way to efficiently index and search all our documentation across all our repositories."*
3. *"Provide new users a clear path on how to implement the Indy code within their projects, driving adoption of the project and lowering developer burnout."*

There is an extensive walk-through on how to use their higher level VC exchange library named Libvcx (Kulic, 2019). Hyperledger provides tutorials for various programming languages in the Hyperledger Indy Software Development Kit (SDK) documentation that provides granular steps to follow to start developing, but the tutorials were difficult to interpret. A better approach would have been to present a fully working example repository per language with code comments instead of links to individual source files that are wrapped in markdown (Boyd, 2019). Although, this might have been done to reduce documentation efforts on their side. From Chapter 5 of the Indy Project Enhancements Documentation (Hardman et al., 2019), Hyperledger Indy aims to wrap a secret encryption layer around a pluggable storage layer to enable various options for information or DID document storage. However, there seems to be only one storage mechanism, namely RockDB that is used to store credential data (Boyd & Bakov, 2019).

3.4. Inter-Planetary File System (IPFS)

IPFS is a CAS protocol designed to create a permanent, decentralised method of data storage and distribution or sharing, without requiring mutual trust between nodes. IPFS aims to transform the Internet from being a location-based to being a content-based distributed file network and offers the following properties:

- Eliminating the Hypertext Transfer Protocol (HTTP) problem of broken links as an address will always point to the same content added to the IPFS network, because even a slight change in the content will result in a different address.
- Providing censorship resistance considering that web content is not dependent on a single entity.

IPFS has been widely advertised as the new *"permanent web"*, which refers to the permanent reference of the content to which an IPFS address points. Frequently, IPFS is combined with blockchains to store off-chain the actual files while maintaining in the blockchain only the hash-based pointers (or timestamped attestations)

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to those files (Politou et al., 2020). IPFS synthesises innovative ideas from prior peer-to-peer (P2P) systems, including:

- Distributed Hash Table (DHT) as implemented in the Kademlia protocol for the coordination and maintaining of metadata (Politou et al., 2020).
- BitTorrent inspired communication protocol, BitSwap, to coordinate networks of untrusting peers (swarms) to cooperate in distributing pieces of files to each other (Cohen, 2003).
- Version Control Systems (Git) for supporting file versioning and efficient distribution (Politou et al., 2020).
- Self-certifying File System (SFS) technique for server authentication and to establish a secure communication channel to remote file systems (Politou et al., 2020).

The IPFS DID method (*did:ipid*) supports DIDs on the public and private IPFS networks. It utilises the Interplanetary Linked Data (IPLD) suite, which is a set of tools for describing links (represented in JavaScript Object Notation (JSON)) between content-addressed data, such as IPFS files, Git commits, or Ethereum blocks (libp2p, 2020a). To achieve this, IPLD depends on Content Identifiers (CIDs) for content addressing which is a self-describing, flexible, and an interoperable way of expressing cryptographic hashes. It utilises various multi-formats to accomplish a flexible self-description, namely multi-hash for hashes, multicodec for data content types, and multi-base to represent the base encoding of the CIDs itself (IPFS, 2018). The *did:ipid* DID method also utilises the Inter-Planetary Name System (IPNS) for creating and updating mutable links to IPFS content. The method has minimalistic design goals; a DID trust anchor based on the IPFS and Libp2p protocol (a framework and suite of protocols for building peer-to-peer network applications). A repository exists containing the libp2p specifications that are independent of language or implementation, including wire protocols, addressing conventions, and other "network level" concerns (libp2p, 2020b). The specifications repository serves as a coordination point and a venue to drive future developments in libp2p. Today, implementations of libp2p exist in several languages, with varying degrees of completeness, and the most complete implementations are in Go and JavaScript, with Rust support maturing rapidly. The community is actively working on implementations in python and the Java Virtual Machine (JVM) via Kotlin (libp2p, 2020a). To further enhance security, blockchains and other DLTs could be utilised to anchor the artefacts of the DID method (IPFS, 2018). Currently, asymmetric cryptographic primitives, Rivest–Shamir–Adleman (RSA) and Edwards Elliptic Curve 25519 (Ed25519) are supported, and there are plans to support the elliptic curve used in Bitcoin namely, secp256k1.

3.5. IOTA

IOTA is a DLT that permits hosts in a network to transfer immutable data among each other. It is designed for the IoT industry, which provides secure communications and payments between IoT devices (Foundation, 2020). IOTA's underlying consensus protocol is Tangle, a consensus-building data structure made of a Directed Acyclic Graph (DAG). In the IOTA DAG, graph vertices represent transactions and edges represent approvals. Publishing a transaction in IOTA requires linking a new transaction to any two previous transactions and validating their transaction data. This approach addresses two major issues presented by traditional blockchain-based DLTs, i.e., latency and fees. IOTA offers fast validation, and no fees are required to add a transaction to the tangle. All participants in the network play the same role of issuing and validating transactions and are equally responsible for the consensus (unlike other blockchains where miners are required to validate transactions). Therefore, the cost of a transaction involves only the computational cost of validating two other transactions (Silvano & Marcelino, 2020). IOTA has a throughput of 1500tps with a 1-5minutes or longer transaction time (Foundation, 2020).

IOTA offers Masked Authenticated Messaging (MAM), a communication protocol that includes the functionality to emit and access an encrypted data stream over their Tangle consensus protocol (Zichichi et al., 2020). These streams assume the form of channels, i.e., a linked list of ordered transactions. Once a channel is created, only the owner can publish encrypted messages on it and users in possession of the MAM channel encryption key are authorized to decode the message. MAM also enables users to subscribe and follow a stream of data, generated by some device (Zichichi et al., 2020). The TangleID DID

ISBN: 978-99949-0-888-2

method referred to as did:tangle is intended to implement DIDs and DID documents whilst optimising MAM for key management and related features across the Tangle. The owner of seed in MAM can create a channel structure to transfer the messages. TangleID stores and manages corresponding DID documents on the MAM channels, and uses the initial channel-id as the DID's idstring, whereby each revision of the DID document is recorded on the message of the endpoint afterwards (Su & Wei, 2019). Currently, it can support either Tangle on Mainnet or Tangle on Devnet. There is also a possibility of building on top of Bee (an IOTA Control agenT (ICT)), as long as the interfacing module is complete and a repository is available for further details (Bee, 2020). To create a unique tangle DID, an initial channel needs to be generated with a Merkle-tree signature scheme on top of Winternitz onetime signatures (Su & Wei, 2019).

3.6. Holochain

Holochain is an alternative approach to blockchain and is an open-source framework used to build distributed applications in a P2P network (Holochain, 2020a). Similar to IPFS, it uses a combination of technological techniques (DHT, Gitbased content versioning, digital signatures, peer validation and a gossip protocol) to retrieve and manage its distributed storage. Holochain maintains substantial storage space and network bandwidth, making the system more scalable than a blockchain. This is achieved because Holochain requires each peer to keep its own data within its local storage and each peer is not required to synchronise its own data with all peers in the network (Frahat et al., 2019). Nevertheless, some nodes are responsible for backups to ensure that data is available in case the owner of the data goes offline. Considering the speed of retrieving data, the DHT technique used by Holochain speeds up retrieving data since the data processing is distributed between multiple peers participating in the network (HOLO, 2018). Holochain is not dependent on a global leader consensus, thus limiting the use of computing power (Janjua et al., 2020).

The Holochain *did:holo* method provides examples to assist developers with prototyping and provides details on how to ensure privacy and data security. To run a Create, Read, Update, Delete (CRUD) operation, one must set up local DeepKey instance (*How to Setup DeepKey on Multiple Devices*, 2020) and make Application Programming Interface (API) calls to a Holochain conductor as documented in their developer documentation (Holochain, 2020b). Holochain is a lightweight P2P framework with improved performance characteristics than a *"traditional"* blockchain, i.e., Bitcoin or Ethereum. A write operation to Holochain's DHT takes less than 2 seconds to be accepted whilst key generation takes about 15 seconds (Ulahanna et al., 2019). Unlike most blockchain-based or blockchain-derived projects, Holochain does not have a set tps because it does not have a central point through which all transactions must pass. Instead, Holochain is a generalized protocol for distributed computing with limitless scalability (Forum, 2019).

3.7. Factom

The Factom blockchain is a decentralised publication protocol for building record systems that are immutable and independently verifiable. Factom is built to house data, it exists as a layer above Bitcoin and Ethereum blockchains, and anchors into both every ten minutes. In theory, an attacker would have to compromise Factom, Bitcoin, and Ethereum all at the same time to alter the records, which might be nearly impossible (West, 2020). The cost of using the Factom protocol is a fixed $0.001 per kilobyte (KB) entry and unlike other blockchains, block size is unlimited. Like most other blockchains, Factom does not have the limitation to store everything within a transaction context. According to the Factom real-time explorer, all chains, entries, and transactions are caught up within 1–2 seconds, meaning one need not wait for block confirmation, you can see or share your transactions or data entries instantly after submission to the network. Factom employs a dual-token mechanism which further protects data integrity, and these are:

- Factoids (FCT) - coins that are used to decentralise the network and prevent spam by users. They carry a variable value in relation to the U.S. dollar. They are rewarded to the platform's Authority Node Operators (ANOs) in return for running the protocol's servers and validating new data blocks.
- Entry Credits (EC) - carry a fixed price of one-tenth of a U.S. Penny ($.001) and can be purchased by organisations, in return for storage space on the system. One EC allows an entity to write up to

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1KB of data to the blockchain. They have no monetary value and can be purchased with Factoids or with any currency, but only through the Factoid platform (Platform, 2020). Entry Credits are non-transferable and are assigned to one public key on the chain. Therefore, organisations can overcome any stipulations against holding or transacting in cryptocurrencies.

The Factom DID method referred to as *did:factom* describes the low-level data structures and rules for DIDs, DID documents, resolution and registration on Factom itself. Currently, it only supports Factom *"mainnet"* and *"testnet"*, but can be extended to support any number of public or private Factom networks (LLC et al., 2019). This method provides concise examples for DID documents; however, no documentation exists for implementations. The fixed low price data entry means that DIDs also have a fixed low price on Factom. DIDs are primed to become the standard identity solution on top of the Factom protocol, mostly replacing the native identities and replacing the so-called node or server identities that are in place today on the Factom blockchain.

4. Analysis

This section provides a concise analysis based on the above discussed DLT technologies. From understanding the technologies, we can now compare all the assessed technologies and find the most suitable by comparing them against the stipulated criteria. During this qualitative assessment, it was observed that all the DLT technology candidates feature a test or mock setup, usually in the form of a test-net or dev-net to avoid paying unintended testing and prototyping costs. This is assessment criteria (**AC-6**) presented in section 2 and the results are depicted in Table I. The remainder of the criteria are listed in Table I where a ".." indicates a non-definitive "*No*", as no information could be found related to this criterion. Where there was definitive information indicating the lack of a particular criterion, a "*No*" is presented in the table. A "*Yes*" indicates the satisfaction of a criterion associated with a particular DID method and DLT.

Table 1. DLT Assessment Criteria Measurement Matrix

DLT/DID Method	AC-1	AC-2	AC-3	AC-4	AC-5	AC-6
did:jolo	..	..	Yes	Yes	Yes	Yes
did:selfkey:	..	..	Yes	Yes	..	Yes
did:hedera	Yes	Yes	..	Yes	Yes	Yes
did:sov	..	..	Yes (corporate)	Yes	..	Yes
did:ipid	..	No (Huang et al., 2020)	..	..	..	Yes
did:tangle	..	..	..	..	Yes	Yes
did:holo	..	Yes	..	..	Yes	Yes
did:factom	..	..	..	..	..	Yes

Out of the seven selected DLT technologies, Table I shows that, when compared against the assessment criteria presented in section 2 (consisting of six criterion), only Hedera Hashgraph meets five of the requirements. The other technologies, mostly fall under the undefined category "..". However, because we aim to build the system now, the "*undefined*" is treated as a *"no"* for this assessment. It is worth noting that, because of the improvements towards DLTs, some of the criterion might be met soon. Thus, the most scalable candidate with proper quantitative practical scalability measurements is Hedera Hashgraph, although, it is more centralised due to its permissioned network configuration.

The second candidate in terms of assessment criteria satisfaction is Jolocom which uses IPFS for DID document persistence and Ethereum as DLT for attestation anchoring or timestamping. Although it doesn't have threshold signature capabilities yet, it might support it by the time of the development phase, and it will be monitored going forward because it has good developer documentation and examples. All the other DLTs and DID method candidates seem to be lacking, which indicates the new and emergent nature of the DLT space and the inability for them to satisfy the requirements to be outlined in Section 5 in their current state, particularly for rapid prototyping purposes.

5. The proposed solution requirements

In this section, we define a conceptual proposed solution requirements that abstracts a decentralised academic and skills credentialing

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system. For this proposed system, we plan to incorporate a DLT, W3C VC and DID standards. This paper presented a DLT based assessment, and with that, we can continue with the development of the system. However, some requirements for using the W3C standards needs to be addressed, which is accomplished by this section. More details about the standards, but not the requirements for the intended system, are provided in this paper (Pretorius et al., 2021). There are three main players for the W3C VC data model (issuer, holder and verifier) which are depicted in Figure 1.

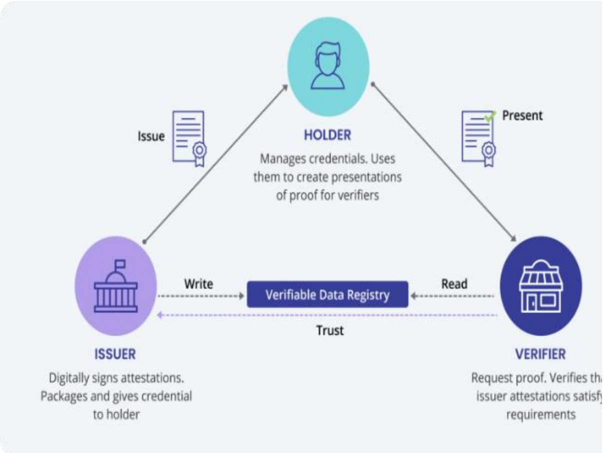

Figure 1. W3C VC data model ecosystem overview (Affinidi, 2021)

To consider what is needed for a minimally viable credential tracking and verification solution, we conducted research and collected several requirements which are discussed in the following sections. From (Gräther et al., 2018) and (Gresch et al., 2019), it was established through stakeholder engagements and interviews with certification authorities that the requirements can be classified into three predominant sections, namely: issuer-, verifier- and holder or subject requirements. We refer to these requirements in shorthand as Issuer Requirements (IR), Verifier Requirements (VR) and Holder Requirements (HR).

5.1. Issuers

Issuer requirements relate to the AA quorum of size k and the certificate issuing entities such as universities or online educators. The AA must issue an accreditation credential to each university or educator, and each educator then issues the academic or skill-set achievement credentials towards the learners. Only a to-be-determined *n* of *k* signatures will be required to issue the accreditation credential towards institutions. Below are the requirements:

- **IR-1**: The system should allow only accredited certificate issuers to generate certificate credentials (Gräther et al., 2018) and (Gresch et al., 2019), and enable them to search, browse as well as list learner DIDs or issued credentials and examination results associated with a learning course (Gräther et al., 2018).
- **IR-2**: The solution should import credential data and examination results from, for example, the SAQA NLRD (Gräther et al., 2018). The credentials must be digitally signed using the issuer private key and registered on a DLT during the import phase. The credential must be stored in a decentralized CAS (Gräther et al., 2018).
- **IR-3**: The solution should allow certification authorities to queue, sign, issue and timestamp credential information in bulk, or one-by-one on a DLT (Gräther et al., 2018).
- **IR-4**: The solution should allow certification authorities to revoke the credential certificate when plagiarism was detected, or when the credential expiry date has been reached (Gräther et al., 2018).

5.2. Verifiers

Verifier requirements relate to entities such as employers, job recruiters, SAQA and anyone who wishes to verify a credential related to a DID since all actors will require at least one DID to participate in this system and these are the requirements:

- **VR-1**: The solution must allow any system actor (issuer, verifier, or subject) to verify the authenticity of any credential by looking up the timestamped metadata on the DLT, as well as verifying the cryptographic issuer and holder digital signatures. The solution should provide the ability to select and queue multiple credentials to be verified in bulk (Gräther et al., 2018).
- **VR-2**: The verification process and interface should be as automated as possible and hide technical details (Gresch et al., 2019).

5.3. Holders or Subjects

Holder requirements relate to both the distributed CAS and learner (a.k.a. the *subject*) and puts the learner in control of their data which is in alignment with the GDPR requirements:

- **HR-1**: The solution must allow credentials to contain an event list that will notify a list of associated DIDs or actors when certain credential access events occur, e.g., credential expiry, credential read- and verification events. This notification list should be configurable by the learner or subject, which is also the holder. The credential should also contain default notification events to notify the issuer and learner when the credential expires, unless it is a permanent certificate (Gräther et al., 2018).
- **HR-2**: The solution must allow learners to create, manage and share job application portfolios with other DID identified actors. This requirement seems related to W3C verifiable presentations, which should prevent anyone from copying information from this view as it is read-only information (Gräther et al., 2018).
- **HR-3**: The solution must notify learners when verifiers read or verify their credentials after a credential or verifiable presentation has been shared (Gräther et al., 2018). This could be accomplished by maintaining credential stateful metadata within a distributed and encrypted CAS mechanism in the form of another DID document.

With these requirements, we can then ensure that the prototype is in line or meets all the stipulated requirements for it to be accepted as a viable solution. From the analysis, it was discovered that from the eight selected DLTs, Hedera Hashgraph was the most appropriate for the intended system when compared against the requirements. Therefore, it is worth noting that Hedera Hashgraph also can satisfy prime requirement **IR-1** (built-in threshold signature capability) above, and has proper documentation and software development guides. However, it is worth noting that some of the requirements can only be tested during the implementation process. The *did:hedera* DID method and associated back-end is therefore our primary candidate to realise this skills tracking and credentialing solution and ensure that the above mentioned requirements are met.

6. Conclusion and future work

In this paper, we focus on how DLT technologies can be a key technology to enable academics and skills credentialing, tracking and verification system. Various DLT technologies have been introduced over the years since inception. With that, it is vital to choose a DLT technology that meets the requirements of the proposed system. Therefore, this paper provides an assessment of DLT technologies that have been picked in a non-probability sampling method. To successfully conduct the assessment, the seven selected DLTs were assessed against the assessment criterion discussed in section 2. Furthermore, the proposed solution is presented which aims to utilise VCs, DIDs and W3C; and, with that, certain requirements have been discussed in section 5. These requirements go into detail as to what is required for a viable credentialing or skills tracking system. With the proposed solution already in place, and results from the assessment, the remaining thing is to employ the selected DLT technology to develop a demonstratable prototype. DLTs are gaining momentum and new improvements are introduced frequently. A baseline assessment for a skills tracking system was presented, and there is a possibility for change in future. Thus, it is vital to remain updated with these improvements.

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The Design of the IoT-based Smart Bin System

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Abstract
Waste management is one of the major problems facing the world today. The trash spillover from garbage/trash/dust bins and the waste handling facilities creates unnecessary waste that needs to be managed. For example, in certain areas, trash spillover generates pollution as well as various hazardous situations. In this regard, unmanaged trash may be the root cause of spreading various diseases as well as creating huge waste management and health issues. To overcome the challenges, as well as maintain public health and cleanliness, this paper proposes the design of an Internet-of-Things (IoTs) based garbage monitoring system that measures the level of garbage in the bins and alerts the relevant stakeholders. It uses an ultrasonic sensor, load sensor, Arduino board, GPS Module, buzzer, and a motor and trash bin (with lid) to design the system. A sensor network was used to collect the levels in the trash bins and remotely trigger the required controls using IoTs. An ultrasonic sensor is interfaced with an Arduino board to check the level of trash and display the data on a dashboard. The administrator will then execute the required notification and dispatch authorized action. In this regard, waste management will be efficient, and overspill managed.

Keywords: IoT-based bins, Smart bin, Smart Trash bin

1. Introduction

The issue of waste has been a challenge facing the world, especially in developing countries. Both public and private dwellings have increased the volume of waste, especially during the COVID-19 period where lockdown exacerbated the level of food consumption by people who did not have work. For example, during the COVID-19 period, the littering of gloves and wipes increased by double the amount in the initial stages of the pandemic; they subsequently fell after the facemask policies, which then led to an increase in littering of facemasks by double (Roberts, et al., 2022). The latter led to trash bins overflowing and the environment being littered. This affected the environment with a significant amount of personal, protective equipment (PPEs) - facemasks, gloves, and other protective wear (Hantoko, et al., 2021).

South Africa has successfully grown a recycling economy built on the hard work of an active informal waste sector (Malele, 2022). The informal waste sector stimulates job creation and enterprise development. For example, waste pickers will collect the necessary waste and re-sell it to recycling companies. Malele (2022) described the waste pickers' work and how much they make in a month. Surely, the collection of garbage/trash could put food on the table of unemployed people. The collection of trash or garbage in urban household areas is one of the most difficult and demanding tasks in certain areas across South Africa. It is because the trash generated day by day is unpredictable, and it is perceived that, in most cases, the waste space becomes bogged down due to irregular trash removal. This makes proper trash maintenance mandatory, and it implies that there is a need for a better smart trash monitoring and management system in urban areas for both municipal and industrial systems. Unfortunately, in most cases, the trash is overflowing creating a challenge for those who are supposed to remove it.

To other people overflowing trash bins create an opportunity for economic participation. For example, some people would use plastics to make carpets and sell them to tourists. In certain areas, trash spillover generates pollution (i.e., materials that could be recycled and non-recycled) as well as various hazardous situations and scenarios (i.e., bad smell, as well the unpleasant look and feel of the environment).

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This paper proposes the design of an automated Smart Bin Monitoring System that uses the Internet of things (IoT) as a contribution to addressing the waste management challenges, also known as The IoT-based Garbage Monitoring System. This paper is structured as follows: section 1 introduced the paper, section 2 will provide some similar studies and gaps, section 3 will provide the study methods, section 4 will provide the results, and section 5 will provide the conclusion.

2. Literature Review

The challenges of overflowing or spillover waste of trash bins and their day-by-day management issues continue to be a waste management and climate change issue. Different techniques for handling the spillover challenges have been proposed by different authors (Engelbrecht, et al, 2022; Malele, 2022; Ravi, et al, 2021; Aguila, 2019; Sharma, 2018; Ghadage and Doshi, 2017; Parkash, 2016; Kurre, 2016).

Although, the average waste generated by an individual is increasing daily and no one can control it, due to the number of start-up units aimed at using technology, this challenge could be combated (Parkash, 2016). Currently, different developers, designers and entrepreneurs are working on appropriate technology solutions aiming to manage the waste emanating from potential waste producers such as households, malls, dumping facilities, etc (Malele, 2022).

A system by Kurre (2016) facilitates the process of waste management using the dumpster level monitoring system, IR sensors and monitoring the level of the trash inside the bins using ultrasonic sensors placed on top of the bin. Unfortunately, IR sensors are not reliable, especially in sunlight areas.

Ghadage and Doshi (2017) proposed a system that solves issues faced in trash management by using infrared sensors, fire detection, and sensors for detecting moisture to separate dry and wet trash. Although, as an advantage, the system could alert the authorities if the fire is dictated on the trash. due to the use of infrared (IR) sensors, which cannot be used in the sunlight, the waste would be effectively managed.

Sharma, et al (2018) implemented a trash level monitoring system using an ARM controller and ultrasonic sensors and a fire sensor. The system also deals with the monitoring of harmful gases. The system alerts users based on four types of trash: domestic, paper, glass, and plastic. The system was designed such that when the sensor data value exceeds the threshold value, the updated data values and notification is sent to the Android through the GSM connection. This system also provides the bin with LEDs to indicate the status. The drawbacks of the implemented system were its components. For example, the speed of the ARM is limited, and it has limited calculation capacity. To solve the challenge, Aguila, et al., (2019) used the Arduino Uno.

A solution by Aguila, et al., (2019) monitors waste management in real-time to keep track of the bin's capacity. This application assists local government to properly manage waste. The system comprises an ultrasonic sensor to measure the volume of the bins, a load cell to measure the weight of the bin, and an Arduino Uno which controls the systems operation. The system alerts the municipality once the sensor reaches a particular level, and the signal is sent to the Arduino. The system by Aguila, et al., (2019), gives the users power to monitor the local government; however, in most countries local government is non-effective. Hence, a system proposed by Engelbrecht, et al., (2022) enables the user to be in control and receive rewards through their trash disposal.

Engelbrecht, et al., (2022) proposed a Smart Self-managing Recycling Bin system that is coupled with a rewards program to improve recycling awareness at the consumer level. A Raspberry Pi, strain gauges, a web application written in C# and a Dotnet core framework were used to develop this system. The system weight measurements with the strain gauges were 97 per cent accurate at 7 per cent tolerant. The system allowed users to be rewarded for recycling. Unfortunately, the Smart Self-managing Recycling Bin system focused a lot on the weighing side of the waste business, rather than on the consumer side.

This paper expands the Engelbrecht et al., (2022) work by including an IoT monitoring system and a separation technique using the weighing system for dividing the trash. This feature was not fully implemented in this paper, however, as the machine learning section was not included in this paper. Furthermore, it should be noted that the type of components used in all reviewed system

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solutions showed a disadvantage. For example, most systems used infrared sensors that, when exposed to light, are not reliable. This paper used reliable components such as an Arduino Uno controller instead of an ARM controller.

3. Methodology

The proposed system was developed and designed following the hardware and software designs. The research design used to complete the task is illustrated in Figure 1 with the following narrative. To determine which hardware components and related software were necessary, a literature review, particularly related work, was conducted. It yielded the gaps that needed to be addressed, and the types of software and material that could be used to develop the system.

Different software applications (Arduino Software (IDE), MySQL, JavaScript and PHP, and Fritzing) were developed and used to facilitate the smartness of the bin and allow the sensors to function well. The Arduino Software was used to construct and design the coding part of the system that, for example, would read sensor data and help with decision making (Badamasi, 2014). MySQL was used for creating the database that will log the system usage, and Java Scripts and PHP were used to create the system dashboard.

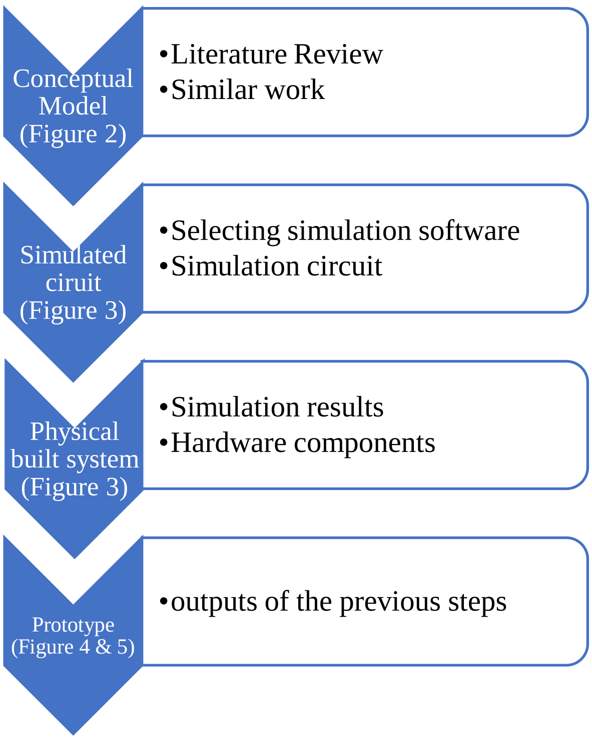

Figure 1. The proposed system research design.

The literature review work was followed by the conceptualization of the intended system which yielded a conceptualized model provided as a system block diagram in Figure 2. The system block diagram comprises the ultrasonic sensors, the Arduino microcontroller, and the GPS module. The Ultrasonic sensors are used to detect the level of garbage in the trash bin, and it will send this information to the Arduino, which is the system controller. The load sensor is used to detect the weight of the trash.

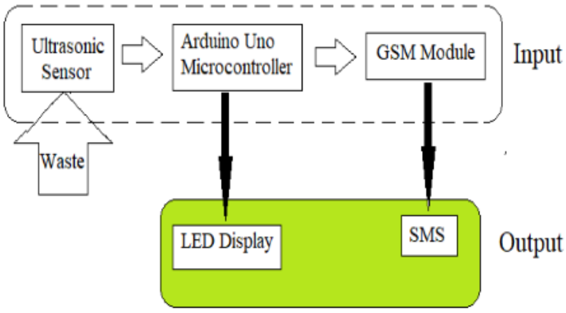

Figure 2. The proposed system block diagram.

Figure 2 was used to design a simulation circuit block diagram (see Figure 3). The simulation of the block diagram in Figure 3 was designed using Fritzing (an open-source electronics design software) and then it was simulated. The feasibility of the simulation task showed that if the physical circuit block diagram is built, it will operate effectively.

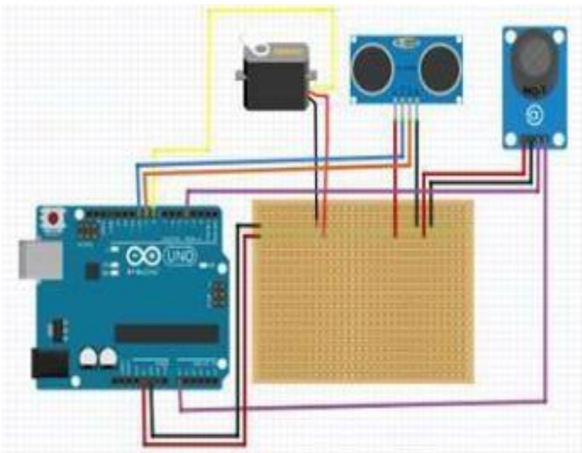

Figure 3. The simulation block circuit diagram

Using Figure 3, the physical circuitry of the IoT-based Smart Bin system was developed (see Figure 4). An ultrasonic sensor is connected to an Arduino board, the GPS Module, and the load sensor. The Arduino microcontroller is used to interface the sensor system with the GPS. This

ISBN: 978-99949-0-888-2

will help in managing garbage collection efficiently. Furthermore, the buzzer is connected to the Arduino board. A motor is also connected for closing and opening the lid.

The integration of the physical circuit led to the development of the prototype (see Figure 5). The circuit helped to develop a smart scale that was integrated with a bin to develop the IoT-based Smart Bin System. The scale was large enough to handle trash of about 10kg. The scale was connected to the buzzer to indicate any larger loads.

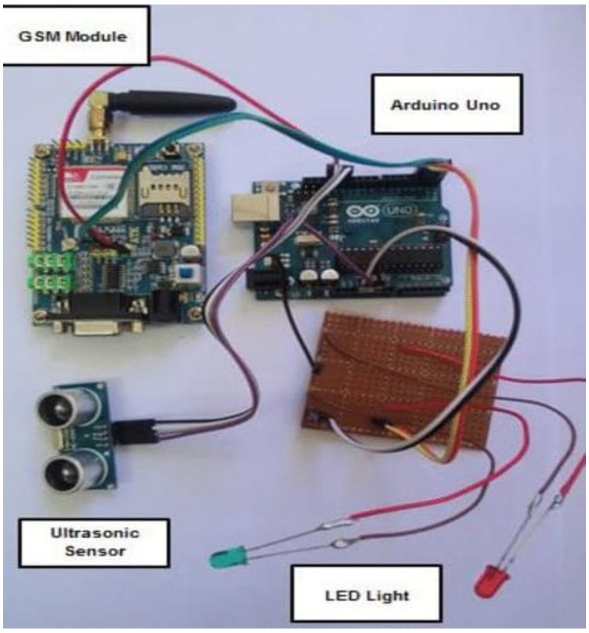

Figure 4. The physical circuit diagram of the proposed IoT trash bin system.

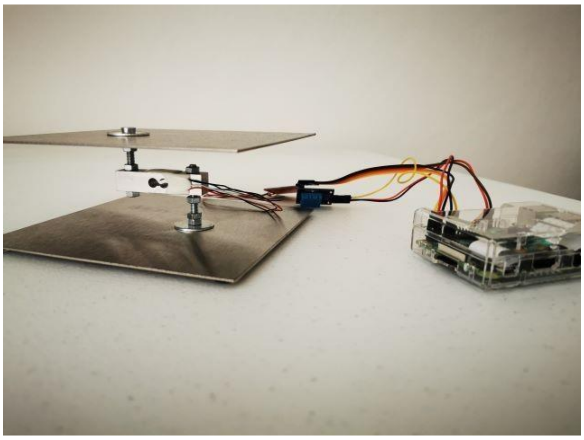

Figure 5. The IoT smart system prototype read for integrating the trash bin.

4. Results and Discussion

Figure 6 illustrates the final prototype, the IoT-based Smart Bin System. The level of garbage in the trash bin could be detected with the help of an ultrasonic sensor. When the measured value of sensors exceeds a certain threshold value, then the buzzer goes ON indicating that a dustbin is full; this information, with the GPS location where the trash bin is located, is then communicated to the dashboard for an administrator to view or monitor. The dashboard (Figure 7) will show in which area the trash bin is located by comparing coordinates, updating the location, and informing the concerned local authorities.

Figure 6. The IoT-based Smart Bin System.

The booting performance of the system is indicated in Table 1. After the start, the IoT-based Smart Bin System controller begin to sense the trash at 25cm when the lid was 90℃ open. At this degree, the motor will begin to run after a delay of 6 seconds. If the trash load is bigger than 10kg, then the system alerts the user by sending a SMS using the GSM module. Then, the system automatically sends the alerts to the user and simulates sending them to the authorities. Simulates because the first phase of the project was to design the system to focus first on the user side.

Table 1. The system booting and functionality method.

Condition	Performances
Arduino Controller = Working	Sensing Distance = 0 – 25 cm.
Motor = Working	Lid open = 90 Degree Delay open lid = 6 sec.
Ultrasonic Sensor = Working Servo	Delay close lid = 10 sec.

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Arduino Controller = Working	Initial Condition Load Sensor ON Buzzer OFF Lid Locked NO
Ultrasonic Sensor = Working Buzzer = Working	level Sensing Load sensor ON Buzzer OFF Lid Locked NO
Load Sensor = Working Lid = Working	Condition 100 garbage level sensing Load sensor ON Buzzer ON Lid Locked YES

Similar user alerts would be sent to the local authorities through e-mail. Unfortunately, that phase was not done, except for the allowance that the IoT-based smart bin user can send the e-mail manually. The capability of the system to send the e-mail automatically will give the local authority a chance to attend to the problem.

Table 2. The load for testing the IoT smart bin.

Item Name	Smart Bin Scale	Comment
1 kg bag of rice	1.0834 kg	No Buzz
Pieces of wood	10.077 kg	Buzz
Speaker System	3.7996 kg	No Buzz
Printer	2.7864 kg	No Buzz
6 bricks	13.869 kg	Buzz
Aluminium disc	15.849 kg	Buzz
Fan scraps	6.5036 kg	No Buzz
Pieces of Tyres	10.864 kg	Buzz
Car battery	14.308 kg	Buzz
Pair of Shoes	0.5261 kg	No Buzz
Weight vest	9.88 kg	Buzz

Table 2 presents the load that was used to test the IoT-based smart bin systems. When the ultrasonic sensors detect the load at 25cm while the lid is 90^{o} open, if the load is larger than 10kg, then the system will buzz. If the lid is less than 90^{o} open then it will be difficult to insert the load; however, if, in some method, the load is placed inside the trash and the lid is closed, the weigh system will measure the weight; if it is 10kg or greater, then the system will buzz and send the alert. The admin will notify the authorities and they will expect to send the local trash collecting truck.

Figure 7 illustrates that the system performance in Table 1 and the related communication are captured through Blynk–the system dashboard (Syufrijal & Rif'an, 2018; Gsangaya, et al, 2022). All values are shown on the dashboard even if the trash bin is empty or half full. For example, if the trash bin is half full, the dashboard will indicate "Smart Dustbin is 50 per cent Full" at the Blynk, and the yellow LED will light up once. The yellow LED lights five times to signal that the trash bin has reached a 75 per cent threshold, and this helps to avoid the trash overspilling. The red LED always lights up when the system has reached its capacity of 100 per cent. The latter leads to an actionable task of collecting the trash bins which is sent through an e-mail message.

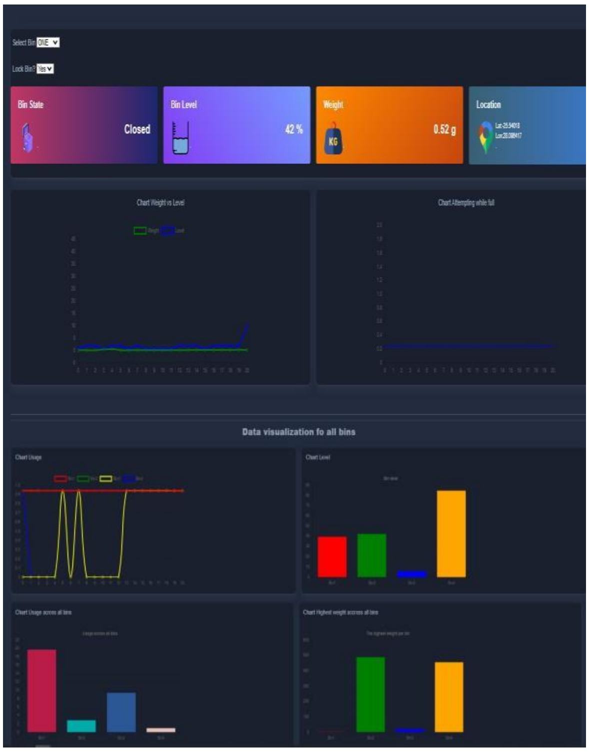

Figure 7. The IoT smart system Blynk dashboard Interface.

The dashboard was designed to represent the four Key Performance Indicators (KPI): (i) Bin State – represents whether the selected bin is either open or closed., (ii) bin level represents the current level of the trash in the selected bin., (iii) trash weight represents the weight in kilograms of the selected bin, and (iv) bin location represents the current location of the selected bin. Furthermore, the dashboards comprise three-line graphs and three bar graphs. Line graph 1 – indicates the breakdown of the relationship between the weight and bin level; Line graph 2 – indicates the breakdown of the opening and closing mechanism

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(the bin locks (closed) when it is not in use); and Line graph 3 – indicates the bin that is being used the most. Bar graph 1 – indicates the breakdown of the level of trash in the bins throughout; Bar graph 2 – indicates the combined usage of the bins; and Bar graph 3 – indicates the combined weight of the bins. The advantage of this IoT-based smart bin monitoring system was its ability to continuously measure the trash levels in the trash bins, place values on the dashboard for monitoring purposes and alert the concerned user. This makes the user a continuous part of the solution.

The limitation of this IoT-based smart bin monitoring system is the lack of a dashboard interface that could allow the authorities to see how many households have a full trash bin. The latter will allow the authorities to dispatch a truck for several households (instead of only one) with a full trash bin. To mitigate the risk of fruitless expenditure, by sending a truck toward only one house, the IoT-based smart bin monitoring system will be expanded to include a mechanism of automatic alert to the authorities and the trash dispatch unit. Once the authorities receive the alerts, the action that they will take will be sent back to the households (user).

5. Conclusions

The IoT-based Smart Bin System is based on an Arduino microcontroller. It is useful in improving the efficiency of trash management in developing countries, especially in areas where the trash is found to be overspilled from trash bins. The IoT-based Smart Bin System controller senses the trash at 25cm when the lid was 90℃ open. After a delay of 6 seconds, the motor runs and assists in measuring the load. For every load that was 10kg and more, a buzzer signals and sends a GSM module to send the alert message to the user. All the activities were recorded by the system dashboard, Blynk. The latter included the system performance as well. For example, all values are shown on the dashboard, even if the trash bin is empty or half full, e.g., the message that would reflect on the dashboard would be "Smart Dustbin is 50 per cent full" then the yellow LED will light up. If the trash bin is full, then the red LED will light up and the dashboard message will be "Smart Dustbin is 50 per cent full". The advantage of this system was its ability to continuously measure the trash levels in the bins and alert the concerned authorities. The latter helps to avoid overspilling and gives an actionable task of collecting the trash bins. Unfortunately, at the time of presenting this paper, no work was done to make sure the authorities, such as the municipality, are directly notified; only simulated work was carried out. In future, the dashboard for the authorities should be designed and be used to link the municipality for closing the IoT -based and smart aspect of the bin when viewed from the authorities' perspective. The latter should be noted as this paper presented the user perspective.

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The use of Software as a Service to improve the Dynamic Capabilities of South African Small and Medium Enterprises

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Abstract
Business aspects such as sales, human resources management (HRM), marketing, accounting, and customer relationship management (CRM) are important for Small and Medium Enterprises (SMEs). Therefore, it is anticipated that SMEs will get to benefit from using innovative technologies (IT) such as Software as a Service (SaaS). SaaS is a Cloud Computing model where applications, resources, and services are provided by the service provider (SP) to SMEs and accessed via the internet. SaaS may transform SMEs. One of the major benefits of SaaS is its dynamic capabilities. Despite the benefits of SaaS, the utilization of this technology in SMEs, particularly in developing countries is still limited. This research study aims to develop a conceptual model for the use of SaaS to improve the dynamic capabilities of South African SMEs. In this study, the theory of Technology-Task-Fit (TTF) will be adopted and used to underpin the study. A positivist research paradigm will be adopted. The study will use a quantitative research approach and data will be collected from 344 SME managers in South Africa using a questionnaire. Structural equation modeling (SEM) will be applied in this study to analyze the data.

Keywords: SMEs, Dynamic Capabilities, Cloud Computing, SaaS, Task-Technology-Fit

1. Introduction

The Coronavirus disease (COVID-19), which began in November 2019 has caused untold human suffering across South Africa (Kalidas et al., 2020) and left an indelible impact on the Small and Medium Enterprises (SMEs) sector (Kalidas et al., 2020; Kamarudin et al., 2022; Pratama et al., 2021). According to Kamarudin et al. (2022), COVID-19 is a pandemic that is not limited to any part of the world. COVID-19 caused a global economic slowdown and SMEs were unable to conduct business because of the restrictions. Several scholars (Maziriri, 2018; Ngibe & Lekhanya, 2019; Saah, 2021; Matekenya & Moyo, 2022) pointed out that SMEs in South Africa play a significant role in economic development. According to (Kademeteme & Twinomurinzi, 2019; Matekenya & Moyo, 2022) in South Africa, the definition of SMEs is found in the National Business Act (102) of 1996. For the aim of this research study, the definition of SMEs provided by the National Business Act (102) of 1996 is used to define SMEs.

According to Kademeteme and Twinomurinzi, (2019), the National Business Act (102) of 1996 defines SMEs as organizations with one (1) to two hundred and fifty (250) workers (Maziriri, 2018), with an annual turnover (ATOV) of R2 million (Maduku et al., 2016; Ngibe & Lekhanya, 2019; Matekenya & Moyo, 2022) and gross assets (GA) of less than (<) R10 million (Maziriri, 2018; Masocha, 2019; Bvuma & Marnewick, 2020). According to (Ndiaye et al., 2018; Kalidas et al., 2020) SMEs are important in the global economy worldwide, in both developed and developing countries. As highlighted by (Matekenya & Moyo, 2022), in South Africa, SMEs are essential because they create job opportunities, reduce poverty (Maduku et al., 2016) and they also contribute to the Gross Domestic Product (GDP) (Ngibe & Lekhanya, 2019; Saah, 2021).

According to Matekenya and Moyo (2022), SMEs in the republic of South Africa contribute 50 per cent to the Gross Domestic Product (GDP and approximately 56 per cent to the total employment. They also pointed out that by the year 2030, these organizations are expected to create more than (>) 90 per cent of new job

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opportunities. However, despite the role and importance of SMEs in the South African economy (Saah, 2021). The COVID-19 Coronavirus caused a global economic slowdown and SMEs were most affected because they do not have resources to survive the crisis (Kalidas et al., 2020; Kamarudin et al., 2022)

Due to movement and travel restrictions implemented to reduce the spread of the virus, SMEs in South Africa faced a tremendous loss (Kalidas et al., 2020). As a result, SMEs resort to the use of new innovative technologies (IT) such as Software as a Service (SaaS) to conduct business (Mokwena & Hlebela, 2018; Loukis et al., 2019; Khayer et al., 2020). According to (Mokwena & Hlebela, 2018; Martins et al., 2019; Tju et al., 2020) the use of SaaS provides SMEs with many benefits, including ease of use, anywhere and anytime access capabilities, cost reduction, improved collaboration, and knowledge sharing. Nevertheless, scholars (Mokwena & Hlebela, 2018; Khayer et al., 2020) argue that despite the numerous benefits of SaaS, the rate of acceptance and use of this technology (SaaS) is still limited, especially within SMEs in developing countries (Adane, 2018; Loukis et al., 2019; Khayer et al., 2020). Therefore, this allows this study to make a unique contribution to the literature on the use of SaaS in SMEs in South Africa.

The rest of this paper is structured as follows: Section two (2) covers a literature review; Section (3) covers related works; Section (4) covers the conceptual model and hypotheses; Section (5) covers research methodology and design.

2. Literature Review

2.1 Challenges Faced by SMEs in South Africa

In South Africa, SMEs are found in places such as villages, towns, and cities (Bvuma and Marnewick (2020). As previously indicated by (Maduku et al., 2016; Maziriri, 2018; Ngibe & Lekhanya, 2019; Kalidas et al., 2020; Murithi, 2021; Matekenya & Moyo, 2022) SMEs are important in South Africa as they are responsible for creating new job opportunities, reducing poverty and contributing to the GDP. However, SMEs in South Africa are faced with many challenges (Bvuma & Marnewick, 2020; Matekenya & Moyo, 2022; van Staden, 2022).

A study by Bvuma and Marnewick (2020) indicates that in South Africa, SMEs are faced with challenges, including lack of access to the international market (Maduku et al., 2016), lack of management skills to manage the business (Muriithi, 2017), high competition from rivals (Maziriri, 2018; Ngibe & Lekhanya, 2019), lack of information technology (IT) infrastructure to perform business operations (Bvuma & Marnewick, 2020), and lack of funds to sponsor the business (Bvuma & Marnewick, 2020; Matekenya & Moyo, 2022). As a result, to avoid being vulnerable to these challenges, SMEs need to develop dynamic capabilities (Teece, 2018; Kademeteme & Twinomurinzi, 2019; Rashidirad & Salimian, 2020; Weaven et al., 2021).

2.2 Dynamic Capabilities and SMEs

According to (Kademeteme & Twinomurinzi, 2019; Rashidirad & Salimian, 2020; Senshaw & Twinomurinzi, 2021) the aim of developing dynamic capabilities in this age of the 4th Industrial Revolution (4IR), is to use Cloud Computing (Adane, 2018), and SaaS to improve the performance of SMEs (Mokwena & Hlebela, 2018; Loukis et al., 2019; Martins et al., 2019; Khayer et al., 2020). Several scholars (Teece, 2018; Schoemaker et al., 2018; Rashidirad & Salimian, 2020) define dynamic capabilities as the ability of SMEs to systematically solve challenges they encounter in the market (Fatoki, 2021), to sense new opportunities and threats (Rashidirad & Salimian, 2020) and to make appropriate decisions (Fatoki, 2021).

According to (Kademeteme & Twinomurinzi, 2019; Pitelis & Wang, 2019), dynamic capabilities are defined by three components, namely: innovative categories (Senshaw & Twinomurinzi, 2021), absorptive (Kademeteme & Twinomurinzi, 2019a) and adaptive capabilities (Senshaw & Twinomurinzi, 2021).

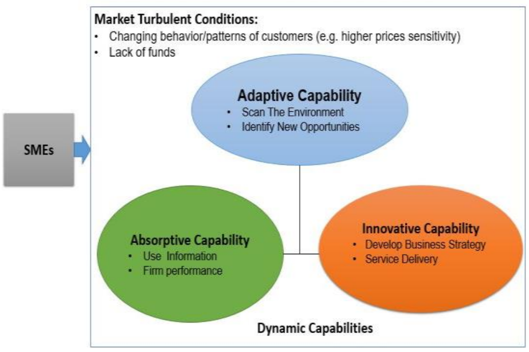

Figure 1. SMEs Dynamic Capabilities (Source: adapted from Weaven et al., 2021)

2.2.1 Adaptive Capability

Kademeteme and Twinomurinzi (2019) define adaptive capabilities as the ability of SMEs to scan the business environment (Schoemaker et al., 2018), to identify threats (Rashidirad & Salimian, 2020) and new business opportunities (Teece, 2018). According to Kademeteme and Twinomurinzi (2019), adaptive capabilities are used to identify new opportunities in the market, that will lead to the creation of new ideas (Senshaw & Twinomurinzi, 2021) and business strategies that enable SMEs to adapt to the dynamic business environment (Senshaw & Twinomurinzi, 2021).

2.2.2 Absorptive Capability

The ability of SMEs to identify the importance of new information (Kademeteme & Twinomurinzi, 2019) and then use it to benefit the organizations and improve firm performance is called absorptive capability (Senshaw & Twinomurinzi, 2021). Absorptive capabilities enable SMEs to acquire knowledge from the market to improve marketing skills (Maduku et al., 2016; Abbas et al., 2018; Sumaili et al., 2018; Schoemaker et al., 2018; Kademeteme & Twinomurinzi, 2019; Pitelis & Wang, 2019).

2.2.3 Innovative Capability

According to (Teece, 2018; Kademeteme & Twinomurinzi, 2019; Senshaw & Twinomurinzi, 2021; Jayasuriya & Perera, 2021), innovative capabilities are the ability of SMEs to create new ways of offering products and services. According to Senshaw and Twinomurinzi (2021), innovative capabilities enable SMEs to develop business strategies that benefit from the surrounding environment (Kademeteme & Twinomurinzi, 2019).

A study conducted by Sumaili et al. (2018) noted that SMEs with dynamic capabilities will usually find it easy to successfully compete with large organizations in the market. However, Rashidirad and Salimian, (2020) argue that dynamic capabilities are not sufficient to improve firm performance. A study by Luo et al., (2018) proposes that the use of Cloud Computing can improve dynamic capabilities. According to Kamarudin et al., (2022), during this challenging period of (COVID-19), innovative technologies such as Cloud Computing (Khayer et al., 2020), including Software as a Service (SaaS) provide SMEs with various benefits and strategies to manage their business (Mokwena & Hlebela, 2018; Martins et al., 2019) and improve dynamic capabilities (Mokwena & Hlebela, 2018; Loukis et al., 2019; Weaven et al., 2021; Kamarudin et al., 2022).

2.3 Software as Service (SaaS) in SMEs and Dynamic Capabilities

Business aspects such as sales (Sumaili et al., 2018), marketing (Maduku et al., 2016), customer relationship management (CRM) (Sumaili et al., 2018), and payroll are important for SMEs (Kamarudin et al., 2022). Therefore, it is anticipated that SMEs will benefit from using SaaS (Kamarudin et al., 2022). According to Majengo and Mbise (2022), SaaS is a Cloud Computing model where applications, resources, and services are provided by the service provider (SP) to SMEs and accessed via the internet. Majengo and Mbise (2022) indicate that SaaS provides SMEs with many benefits, including low cost (Mokwena & Hlebela, 2018), data protection and recovery (Kamarudin et al., 2022), scalability (Mokwena & Hlebela, 2018), enough time to market products (Mwaniki & Ondiek, 2018; Majengo & Mbise, 2022), collaboration, flexibility and knowledge sharing (Majengo & Mbise, 2022), data reliability and availability (Kamarudin et al., 2022).

Table 1. Benefits of SaaS in SMEs (Source: adapted from Kamarudin et al., 2022)

Benefits of SaaS in SMEs	Description & Reference
Low cost	SaaS enables SMEs to reduce costs (Mokwena & Hlebela, 2018)
Data protection and recovery	Data is encrypted, which prevents access from unauthorized users. SMEs can recover data lost due to disaster (Kamarudin et al., 2022)
Scalability	SMEs can increase and reduce the number of users at any time (Mokwena & Hlebela, 2018)
Enough time to market products	SaaS enables SMEs to cover sales and

ISBN: 978-99949-0-888-2

	promotions (Kamarudin et al., 2022)
Collaboration and sharing of information	SaaS is available 24/7. This allows SMEs to be flexible when performing tasks. SMEs can share information with customers (Mokwena & Hlebela, 2018)
Data reliability and availability	Data is stored offsite and backed up in different locations. As a result, information can be restored when the server is lost (Kamarudin et al., 2022)

According to Luo et al. (2018) Cloud Computing, SaaS is a driver of dynamic capabilities. The use of this technology can improve the dynamic capabilities of SMEs once it is integrated into organizational business processes (Luo et al., 2018; Majengo & Mbise, 2022).

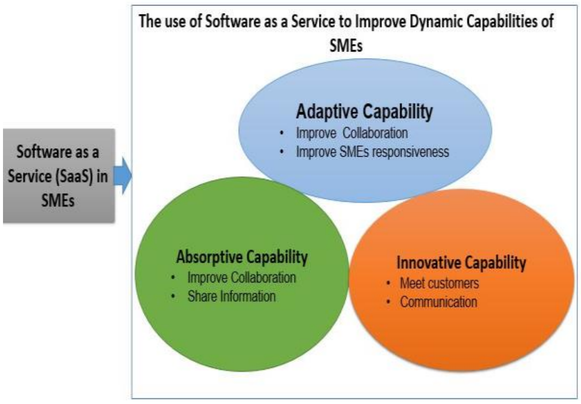

Figure 2. The Use of SaaS to Improve Dynamic Capabilities of SMEs (Source: adapted from Weaven et al., 2021)

Several scholars (Parida et al., 2016; Senshaw & Twinomurinzi, 2021) argue that adaptive, absorptive, and innovative capabilities are important for SMEs. According to (Parida et al., 2016; Mwaniki & Ondiek, 2018; Neicu et al., 2020) the use of SaaS can improve the absorptive capabilities of SMEs using online communication platforms such as Gmail to share information and collaborate with customers.

Furthermore, SaaS can also be used to develop business processes that improve SMEs adaptive capabilities (Parida et al., 2016); for example, managing information (Mwaniki & Ondiek, 2018; Senshaw & Twinomurinzi, 2021). Moreover, SaaS can be used to improve the innovative capabilities of SMEs (Parida et al., 2016; Khayer et al., 2020). Moreover, the use of SaaS can improve innovative capabilities (Martins et al., 2019). For example, SaaS can be used in SMEs to reduce costs (Parida et al., 2016), maintain collaboration with customers and stakeholders (Majengo & Mbise, 2022), reach customers, and sell products (Parida et al., 2016).

3. Related Works

The benefits that SaaS provides to SMEs have resulted in several research studies to understand the use of SaaS to improve dynamic capabilities (Assante et al., 2016; Luo et al., 2018; Mokwena & Hlebela, 2018; Majengo & Mbise, 2022).

A study conducted by Mokwena and Hlebela (2018) on the adoption of SaaS within SMEs in South Africa used the diffusion of innovation (DOI) theory to identify factors affecting the adoption of SaaS in SMEs in South Africa. The study used a questionnaire to collect data from 131 South African SMEs. The results of this study indicate that the cost of SaaS and complexity positively influence the adoption of SaaS within SMEs in South Africa. However, the limitation of this study is that it did focus on the use of SaaS to improve the dynamic capabilities of SMEs.

Sumaili et al., (2018) proposed a research study on the adoption of dynamic capabilities of mobile information and communication technology (ICT) within SMEs in Namibia. The study used interviews to collect data from 40 participants. The findings showed that dynamic capabilities positively influence the adoption of mobile ICT in SMEs. Nevertheless, the study by (Sumaili et al., 2018) is limited to the adoption of mobile ICT within SMEs only in Namibia.

Hussin et al., (2019) conducted a study on the practices and benefits of Cloud Computing by SMEs in Malaysia. The study used a questionnaire to collect data from 387 SMEs. The study found that most Malaysian SMEs in the service and manufacturing sectors have experience in using Cloud Computing services. However, the limitation of this study is that it only focused on SMEs in Malaysia. As a result, the findings of this study cannot be generalized to SMEs in South Africa. Kamarudin et al. (2022) conducted a

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literature review on exploring the potential of Cloud Computing for SMEs in Malaysia. The study showed the benefits and challenges of Cloud Computing adoption in SMEs.

A study by Khayer et al. (2020) used the technology-organization-environment (TOE) theory to develop a conceptual framework for the adoption of Cloud Computing by SMEs in Malaysia. The study used a questionnaire to collect data from 209 SMEs. The study by Khayer et al. (2020) found that (1) innovativeness, (2) top management support, (3) technology readiness, (4) competitive pressure, and (5) data security positively influence the adoption of Cloud Computing in SMEs. However, the limitation of this study is that it is only collected data from SMEs in Malaysia.

Majengo and Mbise (2022) proposed a conceptual framework based on the DOI and TOE to understand the adoption of Cloud Computing by SMEs in Tanzania. The study used regression analysis to test the framework on data collected from 139 SMEs. The results of the study conducted by Majengo and Mbise (2022) showed that (1) compatibility, (2) awareness, (3) relative advantage, (4) reliability and availability, (5) cost of SaaS, (6) data security, (7) top management support (TMS) and (8) trading partners' pressure negatively influence the adoption of SaaS by SMEs. Despite the contribution of this study, the study has some limitations. The study by Majengo and Mbise (2022) used DOI and TOE to identify factors influencing the adoption of SaaS by SMEs in Tanzania, which means other factors from other frameworks, such as Task-technology-Fit (TTF) have not been investigated. Additionally, this study characterized SMEs according to the SME policy of Tanzania. As a result, the findings of this study cannot be generalized to SMEs in South Africa.

A study by Owoseni and Twinomurinzi (2018) used the dynamic capabilities (DCs) theory to understand how SMEs use mobile applications to improve dynamic capabilities in Lagos, Nigeria. The study used a survey to collect data from 1162 SMEs. The study found that the use of mobile applications improves innovative, adaptive, and absorptive capabilities. Despite the contribution of this study, the study has some limitations. This study failed in creating a relationship between the use of mobile applications and SME's capability to identify new opportunities and threats in the market. In addition, the study only collected data from SMEs in Nigeria. As a result, the findings of this study cannot be generalized to SMEs in South Africa.

A study conducted by Weaven et al. (2021) developed a framework for the use of dynamic capabilities by SMEs to survive an economic downturn. The study used interviews to collect data from 40 SMEs in Australia. The results show that performative routine aspects positively influence the use of dynamic capabilities for surviving an economic downturn. However, this study has limitations. The study used interviews to collect data. As a result, it is recommended that future research studies use a quantitative approach to collect data and validate the results. In addition, the proposed framework by Weaven et al., (2021) ignored factors influencing the use of SaaS to improve the dynamic capabilities of SMEs in developing countries.

Kademeteme and Twinomurinzi (2019) conducted a study on dynamic capabilities. The purpose of the study was to investigate the role of SME's dynamic capabilities in evaluating ICT. The study used a questionnaire to collect data from 222 SMEs. The results indicate that SMEs in South Africa only have absorptive and adaptive capabilities, but they do not have innovative capabilities. The study also found that dynamic capabilities do not influence SMEs to use ICT technologies. In addition, the study ignored factors that influence the use of SaaS to improve the dynamic capabilities of South African SMEs.

The similarity between the research studies conducted by (Mokwena & Hlebela, 2018; Sumaili et al., 2018; Owoseni & Twinomurinzi, 2018; Weaven et al., 2021) is that they focused on the role of dynamic capabilities, the adoption of SaaS and the adoption of mobile ICT and applications in SMEs. Furthermore, research studies conducted by (Hussin et al., 2019; Khayer et al., 2020; Kamarudin et al., 2022; Majengo and Mbise, 2022) discussed the challenges and benefits of Cloud Computing adoption within SMEs. As result, this study departs from those studies (Mokwena & Hlebela, 2018; Sumaili et al., 2018; Owoseni & Twinomurinzi, 2018; Hussin et al., 2019; Khayer et al., 2020; Weaven et al., 2021; Kamarudin et al., 2022; Majengo & Mbise, 2022) by developing a conceptual model for the use of SaaS to improve dynamic capabilities of South African SMEs.

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4. The Proposed Conceptual Model and Hypotheses

The adoption and use of SaaS in SMEs have been investigated using different theoretical frameworks (Adane, 2018; Mokwena & Hlebela, 2018; Loukis et al., 2019; Khayer et al., 2020; Majengo & Mbise, 2022).

In this study, the theory of Technology-Task-Fit (TTF) will be adopted and used to develop the conceptual model. TTF is suitable for this study because it has been used to understand the relationship between IT and firm performance (Nurmadewi & Mahendrawathi, 2019).
The study used literature review to identify factors that influence the use of SaaS to improve the dynamic capabilities of South African SMEs. To develop a conceptual model, this study borrowed factors from TTF theory (task characteristics, technology characteristics & individual characteristics).

A study by Annisa and Er (2019) note that TTF is significant in the use and performance of information system (IS). TTF has been applied in several research studies; for example, on the impact of the internet of things (Sinha et al., 2019); big data analytics in mobile Cloud healthcare systems (Wang et al., 2019); Cloud Computing adoption (Tripathi & Jigeesh, 2015); the use of Cloud Computing in SMEs (Wamuyu, 2017). According to Annisa and Er (2019), TTF is built around three constructs and they are task characteristics (Wamuyu, 2017; Wang et al., 2019), technology characteristics (Annisa & Er, 2019; Wamuyu, 2017), and individual characteristics (Tripathi & Jigeesh, 2015; Sinha et al., 2019).

Mohammed et al., (2017) define task characteristics as the actions carried out by people to complete their tasks. The use of SaaS enables SMEs to be innovative (Matekenya & Moyo, 2022), improve firm performance (Majengo & Mbise, 2022), improve service delivery (Kamarudin et al., 2022), and share information with customers (Mokwena & Hlebela, 2018; Kamarudin et al., 2022). Therefore, this leads to the following hypotheses (H1, H2, H3 & H4):

H1: Innovation influence Task-Technology-Fit to improve DCs of SMEs.
H2: Firm performance influence Task-Technology-Fit to improve DCs of SMEs.
H3: Customer service influence Task-Technology-Fit to enhance DCs of SMEs.
H4: Sharing information influence Task-Technology-Fit to enhance DCs of SMEs.

According to Mohammed et al., (2017), characteristics refers to the technological factors influencing the use of SaaS in SMEs and they are data security (Kamarudin et al., 2022), cost savings (Mokwena & Hlebela, 2018), and internet access (Majengo & Mbise, 2022). A study by Majengo and Mbise (2022) notes that SaaS is available 24/7 and resources can be accessed anytime via the internet. Mokwena and Hlebela (2018) allude that SaaS enables SMEs to reduce costs. A study by Kamarudin et al. (2022) states that data stored in the Cloud is well secured and also encrypted to prevent unauthorized access. Therefore, this leads to the following hypotheses (H5, H6 & H7):

H5: Data security influence Task-Technology-Fit to improve DCs of SMEs.
H6: Internet access influence Task-Technology-Fit to improve DCs of SMEs.
H7: Cost savings influence Task-Technology-Fit to enhance DCs of SMEs.

Individual characteristics refer to the perception that SME owners have about the use of ICT (Parida et al., 2016; Khalil, 2020), the experience they have in using the technology (Mokwena & Hlebela, 2018), and the technology skills that they possess (Obradovic, 2022). A study conducted by Mokwena and Hlebela (2018) indicates that 74,79 per cent of SMEs in South Africa are familiar with SaaS. In addition, research studies by (Loukis et al., 2019; Martins et al., 2019; Khayer et al., 2020) confirm that SMEs have the skills, knowledge, and experience in using SaaS. Therefore, this leads to the following hypotheses (H8, H9 & H10):

H8: Perception about ICT influence Task-Technology-Fit to improve DCs of SMEs.
H9: Technology experience influence Task-Technology-Fit to improve DCs of SMEs.
H10: IT skills influence Task-Technology-Fit to enhance DCs of SMEs.

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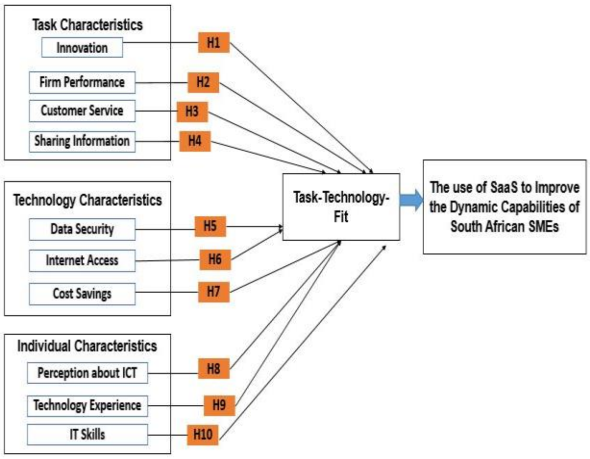

Figure 3. A conceptual Model for the use of SaaS to improve the dynamic capabilities of South African SMEs

5. Research Methodology and Design

According to Snyder (2019), research methodology is the way of conducting research by following step-by-step methodological processes (Abutabenjeh & Jaradat, 2018). This study will use a quantitative research design. According to Saunders et al. (2019), quantitative approach focuses on developing hypotheses and collecting data to test the theory. A positivist research paradigm (Saunders et al., 2019) will be used in this study.

According to Kivunja and Kuyini (2017) positivism paradigm is associated with a quantitative approach and it relies on a deductive approach and the testing of hypotheses (Saunders et al., 2019; Snyder, 2019). Data will be collected from a random sample of 344 SMEs in South Africa using a questionnaire with close-ended questions. According to Blom, (2020) simple random sampling will give each SME an equal chance of being selected. The Five Point (5) Likert Scale was used in this study, where (1 = strongly disagree; 5=strongly agree). The data collected from participants will be entered into Statistics Package for Social Scientists (SPSS). To analyze data, this study will use Structural equation modeling (SEM). The proposed conceptual model will be validated using AMOS SPSS.

Contribution to Research

This research study will contribute to the knowledge of SaaS by presenting a model on the use of SaaS to improve the dynamic capabilities of South African SMEs which will be validated.

Managerial Implications

This study intends to assist South African SME owners and managers to realize that the use of SaaS is more of an adaptive challenge than a technical challenge. The results of this study will add more to the understanding of the importance of the critical factors for the use of SaaS. This means that SMEs owners are expected to understand the benefits of SaaS by learning from other SMEs who have experience in using the technology. This study also shows that customer service and sharing information stimulates the use of SaaS, which means that SMEs should be aware of what their customers want through using the technology.

6. Conclusion

The purpose of this study is to develop a conceptual model for the use of SaaS to improve the dynamic capabilities of SMEs. The proposed conceptual model will help South African SMEs' owners and managers to identify factors that influence the use of SaaS to improve the dynamic capabilities of SMEs. The study found that the three constructs of TTF theory (task characteristics, technology characteristics & individual characteristics) play a significant role in the use of SaaS to improve the dynamic capabilities of SMEs.

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The Impact of Smartphones on Student Creativity at a South African University

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Abstract
Research indicates a general increase in smartphone ownership, with the student population being the leading proportion. Among other notable effects of this change could be an enhanced collaboration between learners and lecturers on the one hand, and an increase in sleep deprivation and attention deficits in students on the other hand. Such unsettling revelations call for the investigation of the impact of smartphones on learning outcomes. This paper investigates the impact of smartphones on students' creativity. Based on the interactions and outcomes theory, the study assesses how smartphone-facilitated processes, person-to-smartphone interaction, and smartphone-enabled environment affect students' creativity. A hundred and five (105) students at a South African university were surveyed using online questionnaires. General Linear Model (GLM) MANOVA was used as the analysis method. The results reveal that only smartphone-facilitated processes and student-to-smartphone interaction significantly affect student creativity. This signals smartphones' potential in setting a learning environment supporting student creativity at the individual level. Universities could leverage this potential to design better learning management systems that integrate smartphones to improve learning outcomes.

Keywords: smartphone impact, students' creativity, higher education, mobile phones use, interactions and outcomes theory, person-to-smartphone interaction, smartphone-facilitated processes, smartphone-enabled environment.

1. Introduction

Despite the increase in smartphone use and ownership (Czerniewicz & Brown, 2010), studies about the use of mobile devices like smartphones to foster student creativity in higher education are still rare (Jahnke & Liebscher, 2020). In South Africa for instance, 2017 statics reported over 20 million South Africans using smartphones, with an expected increase beyond 25 million by 2022. Interestingly, students are leading the adoption of smartphones (Shakoor et al., 2021). The International Telecommunication Union (ITU, 2021) suggest that 60 to 69% of the South African population owns a smartphone, with student owners as high as 98.5%. In this 21st century, smartphones' features attract students who have made them an important part of their daily lives (Shakoor et al., 2021; Singh & Samah, 2018).

Yet, there is a lack of studies that have addressed the impact of these devices on student creativity (Said-Metwaly et al., 2017). Most of the research in this area focuses on the benefits of smartphones in learning (Yusuf et al., 2015). Tan Ai Lin et al. (2018) attribute this shortage to the complex and multidimensional nature of creativity. Moreover, among a limited number of studies addressing the impact of smartphones on student creativity, the focus is made mostly on developed countries (Wu et al., 2012). This study addressed this gap by particularly looking at students in developing countries, especially in South African university settings.

Based on the interactions and outcomes framework, this study seeks (1) to assess the role of smartphone-facilitated processes on student creativity (2) to evaluate the role of the person to smartphone interaction in nurturing student creativity, and (3) to examine the effectiveness smartphone-enabled environment/climate in enhancing student creativity. This study only focused on the impact of smartphones impact on than focusing on all the mobile devices' impact on students' creativity. The efficiency of a smartphone differs from that of a laptop or

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desktop computer in terms of enriching student creativity.

Unlike Jahnke and Liebscher (2020) who approached the topic from the instructor's perspective, this study considers the perspective of students. It intends to investigate the impact of smartphones on student creativity to help them learn to optimise smartphone usage to enrich their creativity. Nevertheless, the study could enable instructors to understand the effectiveness of smartphones in enabling student creativity. The research study provided valuable insights for decision-makers and stakeholders of universities for better learning policies.

The rest of the paper proceeds as follows. The next section covers related works and gives some background to the approach as well as the research model and hypothesis framing this study. Section 3 describes the methodology followed in conducting the study. The results are presented and section 4 and discussed in section 5. Section 6 concludes the paper.

2. Related Works

Kuznekoff and Titsworth (2013, p. 2) are concerned that "instructors face many challenges as they compete for students' attention among a variety of communication stimuli". Smartphones use in classrooms is perceived as distractive to students and their effective use for learning purposes is still experimental (Kaimara et al., 2019). This has sparked the interest of various scholars to call for investigations in this area. This research study was a response to this call.

Many studies have been conducted to investigate the impact of smartphones on learning. Aheto and Cronje (2018) studied the influence of laptops and smartphone ownership and supported design students' learning among South African and Ghanaian university students. The results revealed that a "smartphone is important towards the academic success of 94 (78%) of the participants" surveyed (Aheto & Cronje, 2018, p. 102). Hossain (2019) and Shakoor et al. (2021, p. 863)'s studied smartphone impact on learning behaviour and academic performance of students respectively in Bangladesh and Islamabad. Shakoor et al. (2021) showed "a positive correlation and impact of smartphone usage on academic performance" while Hossain (2019) revealed smartphone negative impact on academic performance due to inappropriate usage.

They have not been lots studies focusing specifically on smartphones' impact on student creativity. The most related study found in literature, Elphick (2018), took a capability approach, investigating the impact of iPad usage on students' perceived digital capability which included students' creativity. In this study, the focus is on smartphone impact specifically on students' creativity in the context of learning remains rare. The term impact refers to an effect or influence that one thing has on the other. Elfeky and Masadeh (2016) and (Singh & Samah, 2018) claim that smartphones influence student creativity either positively or negatively.

A smartphone is a personal digital assistant (PDA) with enhanced functionality. It is a mobile device with more features and enhanced communication capabilities enabling them to connect to the internet and is highly multifunctional (Park & Chen, 2007) "Smartphones can be useful in academic settings by allowing browsing for additional information, organising the study process online, and facilitating communication between peers and instructors" (Rozgonjuk et al., 2019). Smartphones can significantly improve the process of information access and delivery since they are mobile (Elfeky & Masadeh, 2016). However, smartphone use is limited by issues such as small screen size, short battery life and inadequate memory (Park, 2011, p. 82). Moreover, their use in the classroom is controversial due to their seemingly distractive effect on students when inappropriately used (Kaimara et al., 2019). Indeed, "spending time on mobile phone negative effect of mobile phone and application usage while studying has the negative effect on students' academic performance" (Hossain, 2019, p. 164). But, although it is suggested that smartphones may contribute lower academic achievement in some contexts, it is unclear how smartphone usage contributes to lower outcomes (Hartley et al., 2020).

Creativity "has proven over the years to be difficult to define and measure due to its complex and multidimensional nature" (Said-Metwaly et al., 2017, p. 240). It is often defined subjectively, but at least one of the four Ps which are process, person, press/climate and product have to be reflected in a good definition (Torrance, 1993). Commonly, "creativity means to contribute to something novel and valuable" (Jahnke & Liebscher, 2020, p. 3). Lin and Wu (2016) defined creativity as a process of solving problems with

ISBN: 978-99949-0-888-2

creative thinking. This research will adopt Holyoak and Morrison (2005, p. 352)'s the definition which defines creativity as a product i.e. the "ability to produce work that is novel (i.e., original, unexpected), high in quality, and appropriate (i.e., useful, meets task constraints) ".

In short, studies have attempted to study the impact of mobile devices on student learning outcomes mostly in terms of academic performance, in some cases digital capability. There have not been many studies entirely dedicated to the creative aspect of the learning outcome of smartphone usage. This knowledge gap is also related to the understanding the of concept of creativity itself. The next sub-sections explore how creativity could be studied and measured in other to make sense of the study findings later.

2.1 Approaches to Studying Creativity

This research adopted the confluence approach of borrowing approaches and ideas from various scholars about the 4Ps (process, person, product and press) proposed by Said-Metwaly et al. (2017) as can be seen in table 1. This enabled the researchers to adequately gain a holistic understanding and apply the right tools to measure creativity.

Table 1. Approaches to studying creativity (Holyoak & Morrison, 2005)

	Approach description
Mystical	Associate creativity with mystical beliefs and divine intervention. As far as this approach is concerned, a creative person is an empty vessel that a divine being would fill with inspiration which eventually transforms them to become creative. This transformation would enable the person to generate divinely inspired ideas, forming an extraordinary product
Pragmatic	Interested in understanding rather than in testing the validity of creativity, emphasising only practice rather than theory.
Psychodynamic	Claims that creativity arises from the tension between conscious reality and unconscious drives. Writers and artists produce creative work as a way of expressing their unconscious desires in a publicly acceptable fashion. The wide range of unconscious desires ranges from love, wealth, power and fame among others.
Psychometr	Proposed by Guilford (1950) while addressing the American Psychological Association, Psychometric considers the use of everyday objects like paper and pencil tasks to test one's creativity
Cognitive	Seeks an understanding of the mental representations and processes underlying creative thought. It associates creativity with perception or memory, arguing that creativity and intelligence are related to each other.
Social-personality and	Emphasis is put on personality variables, motivational variables, and the sociocultural environment as sources of creativity. Researchers such as Amabile (1983) and Eysenck (1993) suggest that certain personality traits often characterize creative people. Through correlational studies and research contrasting high and low creative people, a large set of potentially relevant traits has been identified
Evolutionary	Initiated by Campbell in 1960, it comprised two basic steps in the generation and dissemination of creative ideas: (1) Blind variation, by which the creator randomly generates ideas without any assurance that the idea will be considered worthy in the world of ideas. (2) Selective retention, the scholar either retains the selected ideas for the future or lets them die out based on the assessment
Confluence	Driven by the determination to capture a holistic understanding of creativity. Scholars have been trying to develop reliable tools to understand and measure creativity for a long time. The confluence approach to creativity borrows concepts from earlier approaches to come up with a reliable way of studying and measuring creativity. "Many more recent works on creativity hypothesize that multiple components must converge for creativity to occur"

ISBN: 978-99949-0-888-2

2.2 Approaches to Measuring Creativity

Much of the research on creativity has been done to establish dependable approaches or instruments to measure it. The ambiguity surrounding creativity measurements is accredited to the lack of consensus amongst scholars and researchers in terms of defining creativity. The challenge is establishing a uniform/universal definition for creativity has compelled various researchers to develop different instruments for measuring it. The different instruments developed for measuring creativity are a direct reflection of how particular scholars conceptualise the notion of creativity. Currently, the developed instruments are categorised into four distinct approaches representative of the four major categories of activity definitions. These categories include process, product, person and press also known as the four Ps (Said-Metwaly et al., 2017).

Based on their analysis, Said-Metwaly et al. (2017) suggested that creativity is mostly defined and measured through four approaches: process, person, product, and press (environment or climate). These turn out to be part of the interactions and outcomes framework developed by Schneck (2011)'s while researching creativity and leadership in an organisational setting. Figure 1 represents a modified model for this research. This research assessed how students use smartphones to enhance their creativity from various points of view. Students can use their smartphones to interact with each other, and access and disseminate information. The wide access to information exposes them to a range of creative possibilities illustrated rate by the model in Figure 1.

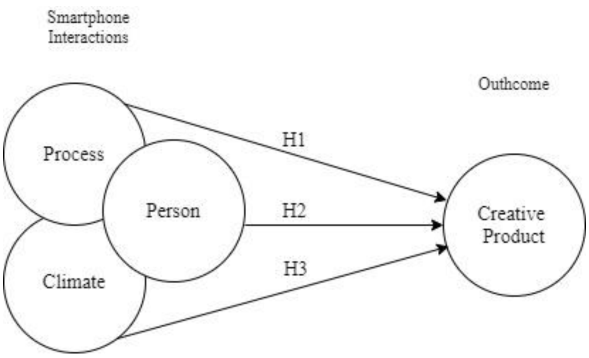

Figure 1: Interactions and outcomes framework - adapted from (Schneck, 2011)

The following subsections elaborate on each of the four components of the model, three of which represent the studies' independent variables (Smartphone-facilitated process, person-to-smartphone interactions, and smartphone-enabled climate/ press) and one representing the dependent variable (Product/ creativity). This elaboration generates three hypotheses (H_1, H_2, and H_3) which are further tested in this study.

2.2.1 Smartphone facilitated Processes

Campbell (1960)'s proposed an evolutionary approach to creativity arguing that the generation of creative outcomes happens systematically and through continuous assessments. claims that individuals come up with a collection of ideas which are presented to go through the elimination process referred to as 'survival for the fittest (Campbell, 1960). In his argument, weaker ideas are eliminated while those that are considered worthy are promoted to the subsequent steps until the most creative idea is selected.

Similarly, Torrance (1993) suggests that creativity can be assessed by carefully following and evaluating the process that leads to the creation of a creative product. While analysing the process, creativity can be detected in learning, thinking, teaching, problem-solving, development and other processes (Kim, 2017; Torrance, 1993). In the context of this research, smartphone facilitated processes are those processes enhancing learning, thinking, problem-solving and other processes made possible through the aid of a smartphone.

As an educational psychologist, Torrance (1993) acknowledges that there are other aspects of looking at creativity, but he prefers the process perspective. While commenting on Eysenck (1993)'s view of creativity from the person's perspective, Torrance (1993, p. 232) argues that "Just as it was natural and useful for Eysenck (1993) to choose to start with personality as a focus, it was natural and useful for me to begin with a process focus".

Considering all these insights, we contextualize and group these measurements into a Smartphone-facilitated process construct and posit that *Smartphone-facilitated process influences product/creativity* (H_1)

2.2.2 Person to Smartphone interaction

In the context of this research study, scholars like Kipling (1985) who subscribe to the mystical approach to creativity supported the "person to smartphone interaction" perspective. Kipling (1985) argues that creativity is attributed to a

ISBN: 978-99949-0-888-2

mysterious force or daemon that takes over the individual enabling them to produce creative outcomes. While elaborating on this, (Kipling, 1985) accredits his creative writing to the "Daemon" that lives in the writer's pen. "My Daemon was with me in the Jungle Books, Kim, and both Puck books, and good care I took to walk delicately, lest he should withdraw. When your Daemon is in charge, do not think consciously. Drift, wait and obey" (Kipling, 1985, p. 162).

In the same way, social-personality and social-cognitive scholars argue that creativity can be understood from the personality point of view. They claim that it is crucial to understand the person's profile, how they behave and the information they have access to. Among the scholars who cherish this approach is (Amabile, 1983), Eysenck (1993) and Sternberg (1985). Amabile (1983) explained that the information available to a person does not constitute creativity. However, personal traits, skills and other factors in the person domain can result in creative outcomes. Eysenck (1993), a personality psychologist from the Institute of Psychiatry of the University of London, also believes creativity should be studied from a person's perspective. Given their specialisation, Eysenck (1993) chose to develop a theory of creativity with the person or personality view approach (Torrance, 1993).

Scholars who subscribe to this view believe that creative people behave in a certain way and can be identified by their behaviour/character traits. Sternberg (1985) associates creativity with many characteristics such as easily connecting ideas, detecting differences and similarities, questioning social norms and flexibility among others. (Holyoak & Morrison, 2005) pointed out that various research contrasting high and low creative individuals has been carried out over time. He argues that a creative person should show independence of judgment, self-confidence, attraction to complexity, openness to experience and risk-taking abilities (Holyoak & Morrison, 2005).
In the context of this research, person-to-smartphone interaction was concerned with those personalities or traits that can be associated with smartphone use and lead to the creation of active products at the same time (Said-Metwaly et al., 2017). Thus, it could be hypothesised that *Person-to-smartphone interaction influences product/ creativity* (H_2)

2.2.3 Smartphone enabled Climate / Press

Some scholars believe that creativity is boosted by the environment in which one resides or operates. Simonton (2008) conducted numerous studies in diverse cultures and realised a statistical link between creativity and environmental variables. These variables included cultural diversity, war, availability of role models, availability of resources such as financial support, and several competitors among others (Simonton, 2008). According to Hashemi (2011, p. 2477) smartphones enable "the acquisition of any knowledge or skill through using mobile technology, anywhere, anytime". He believes that the ability of smartphones to bridge gaps plays a role in creativity.

In the context of this research, a smartphone-enabled climate/press refers to the smartphone-induced environmental effects influencing the creation of a creative product (Said-Metwaly et al., 2017). The focus will be put on several indicators including the availability of resources. Hence, it is hypothesized that *Smartphone-enabled climate/press influences creativity/ product* (H_3)

2.2.4 Products / Creativity

In their articles, Guilford (1950) and (Torrance et al., 1974) opted for the approach of assessing creative products to detect creativity. Guilford (1950) proposed that without an outcome (product), it is challenging to assess and acknowledge the presence of creativity. He suggested that creativity can be studied using usual/ordinary materials like paper and pencil tasks. In this endeavour, Guilford (1950) came up with the Unusual Uses Test, requiring one to think of as many uses for a common object as possible. While Guilford (1950)'s unusual uses test focuses on the number of alternative uses, Torrance et al. (1974) developed the Torrance Tests of Creative Thinking that searches for particular characteristics in an outcome before it can be declared to be creative. According to Guilford (1950), creative abilities are present when a creative outcome is produced, however, the level of creativity is determined by product "fluency (total number of relevant responses), flexibility (number of different categories of relevant responses), originality (the statistical rarity of the responses), and elaboration (amount of detail in the responses) " (Holyoak & Morrison, 2005, p. 354).

ISBN: 978-99949-0-888-2

3. Methodology

This section discusses and justified the methodology used to conduct this research, from philosophy to data collection and analysis techniques. This study adopted a positivist philosophy and epistemology that proposes that only observable and measurable phenomena can be accepted to provide credible information that can constitute acceptable knowledge (Wahyuni, 2012).

The study was deductive since it was guided by the interaction outcome theory and therefore adopted a deductive approach. The research findings provide a firm ground to prove or disprove this some concept of the theory. The study was cross-sectional In adherence to the ethical standards, the researcher obtained the required ethics approval from the University's Ethics Committee. The researcher secured the required permission before engaging with the participants. Research participants were fully informed about what the research entailed, making it clear that their participation was voluntary. The participants could drop the study at any time they felt like. The survey was anonymous to preserve respondent privacy.

3.2. Data Collection

This study targeted university students to collect primary data to study the phenomena under investigation. The sample was randomly selected among students at one South African university. The researcher used an online questionnaire, designed using Qualtrics software.

Table 2. Questionnaire guide

Construct	Questions	Reference
Person	5-19	(Holmes, 1970; Kumar & Holman, 2014; Moultrie & Young, 2009; Sundgren & Dimena, 2005)
Process	20-27	
Press/Climate	28-47	
Product	48-55	
Open-ended	56-57	

The questionnaire predominantly comprised close-ended questions supplemented by two open-ended questions to limit the respondent to the available options while open-ended questions allowed the respondents to express their views without being limited to a range of options. The responses were rated on the Likert scale: (1) Strongly agree, (2) Agree, (3) Somewhat agree, (4) Neither agree nor disagree, (5) Somewhat disagree (6) Disagree (7) Strongly disagree. The questions were intended to data-mine the variables in the research model and the questionnaire guide made sure that this was achieved. The major constructs in the model included person, process, press/climate and product. Each of the questions in the questionnaire was testing one or more of these constructs. Table 2 summarises the constructs, corresponding questions and references.

Data Analysis

Data was analysed quantitatively since this approach provides an objective perspective on the study. The research employed SPSS for quantitative analysis to test the hypotheses and assess the strength of relationships. This involved identifying relationships between variables. The researcher used the MANOVA tests to test the hypotheses. Visual representation of the data included graphs, charts and tables.

4. Results

This section reports the study's findings. The initial section gives some demographic information to understand the sample background. Next is the analysis prerequisite including validity and reliability testing and factor analysis. The main analysis and findings are presented in the last three sections representing the testing of the three null hypotheses associated with the study's hypothesis discussed earlier.

4.1 Demographic information

Table 3. Sample background

	Frequency	Percent	Cumulative Percent
What is your gender?			
Male	33	31.4	31.4
Female	70	66.7	98.1
Prefer not to answer	2	1.9	100.0
Total	105	100.0	
What is your age group?			
<20	25	23.8	23.8
20-29	69	65.7	89.5
30-39	6	5.7	95.2
40-49	4	3.8	99.0
>50	1	1.0	100.0
Total	105	100.0	
Do you own a smartphone?			
Yes	105	100.0	100.0
How many smartphone applications do you use on average per day			
1-3	27	25.7	25.7
4-6	51	48.6	74.3
7-10	16	15.2	89.5
10+	11	10.5	100.0
Total	105	100.0	

ISBN: 978-99949-0-888-2

The study's targeted population was students at a South African university. All none responses and partially answered questions were excluded from the research study. A total of 192 responses were collected through questionnaires and only 150 responses were retained after the data cleaning process. Of the 105 students who took part in the study, 33 were male, 70 were female and two students preferred not to disclose their gender, as reflected in Table 3. Most of the respondents were 20 years old-old. All respondents declared to own a smartphone, with about half of them using four to six applications on average per day.

4.2 Validity and reliability tests

As a prerequisite of any quantitative analysis, validity and reliability tests were performed. The KMO and Bartler's tests were used to determine if the data collected was sufficient as shown in Table 4. In addition to this, Bartlett's Test of Sphericity reflected a chi-square of 2631.553 at df = 1275 and a significance level of 0.000 which is less than 0.001 ($p < .001$). Table 4 indicates that the correlations are not near zero laying the foundation for confidence in the final factor analysis outcomes (Leech et al., 2015).

Table 4. KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.639
Bartlett's Test of Sphericity	Approx. Chi-Square	2631.553
	df	1275
	Sig.	.000

Before hypothesis testing, dependent variables should be tested to see if they are correlated to confirm that they are moderately correlated. If r is 0, it reflects no relationship at all among the data sets making it unnecessary to proceed with the MANOVA. Output in Table 5 from the results reflects r=-0.013, r=-0.109 and r=0.319 for product evaluation, product creation and product assessment respectively. These are ideal results to proceed with hypothesis testing through MANOVA tests.

Table 5. Dependent variables correlations

		When am generating new ideas, I do not tend to evaluate them until I have generated many ideas	I enjoy the process of creating new ideas whether they lead to a product or not	I think a final product that is not readily observable through the senses can emerge in a creative act.
When I am generating new ideas, I do not tend to evaluate them until I have generated many ideas	Pearson Correlation	1	-.013	-.109
	Sig. (2-tailed)		.897	.267
	N	105	105	105
I enjoy the process of creating new ideas whether they lead to a product or not	Pearson Correlation	-.013	1	.319**
	Sig. (2-tailed)	.897		.001
	N	105	105	105
I think a final product that is not readily observable through the senses can emerge in a creative act.	Pearson Correlation	-.109	.319**	1
	Sig. (2-tailed)	.267	.001	
	N	105	105	105

**. Correlation is significant at the 0.01 level (2-tailed).

4.3. Factor Analysis

A data reduction technique known as factor analysis was used to reduce data while maintaining the credibility of the model variables, leading to hypothesis testing. Specifically, exploratory factor analysis was performed, using the component factor analysis (CFA) technique to reduce the data while upholding the impact of the variables in a given model (Denis, 2018). CFA operates by extracting components/factors detected from the questions testing the model and revealing the strength with which each of the questions loads onto the identified components through Pearson's correlation (Aldrich, 2018). Questions loading highly on the same component are assumed to be measuring the same factor and therefore should be aggregated to reduce the number of questions while maintaining the effect of the key variables.

The eigenvalues for the 51 new components were displayed. The initial eigenvalues showed 8.364 for Component 1. equivalent to 16.400% (8.364/51 × 100) of the total variance when all 51

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variables are considered. Next was an eigenvalue of 4.084 for Component 2, which means that it accounts for 8.008% of the total variance for all variables. This percentage is not related to the variance of the first component; therefore, the two taken together (16.400 +8.008) can be said to account for 24.408% of the variance for all variables. Following this same trend, the first 15 components account for up to 70.914% of the variance for all 51 variables.

This was visualised in the scree plot in Figure 2, which graphs the eigenvalues on the y-axis and the 51 components on the x-axis. Components above the "elbow" portion are those that are selected (Aldrich, 2018). In the case of this research, Components 1 to 15 are above the "elbow, accounting for 70.914 of variance in all 51 variables. The scree plot provides extra evidence supporting the 15 components solution for this factor analysis problem. This means that the first 15 components can explain 70% of the relationships in the interaction and dependant variable, outcomes part of the model.

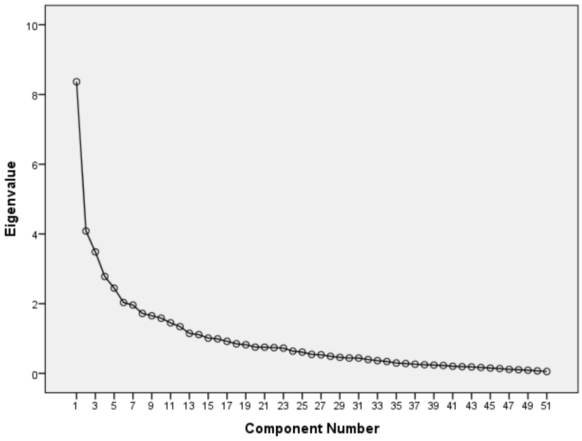

Figure 2. Scree plot

4.1 Assessing the role of smartphones in facilitating creative processes

A between-subjects MANOVA was conducted on three dependent variables in the "product" construct (evaluation, creation, observation). This statistic tests the null hypothesis that the variance-covariance matrices are the same in all three groups. If the matrices are equal indicating that the assumption of homogeneity is met, this statistic (P-value) should be non-significant. Table 6 indicated that for this data, p = .335 (which is greater than .05); hence, the covariance matrices are roughly equal, and the assumption is defensible (Leech et al., 2015). Therefore, all the MANOVA tests (Pillal's Trace, Wilks's Lambda, Hotelling's Trace and Roy's Largest Root) used in Table 6 below are delivering credible results that can be based on to either accept or reject the hypothesis but Nancy (2015) recommends Wilk's lambda which is the dominant test used in this research study.

The four MANOVA multivariate tests in Table 7 examine whether the two smartphones facilitated process variables differ on a linear combination of the dependent product/creativity variables: evaluation, creation, and observation. The last raw tells us whether Smartphone facilitated (processQ20And26) had an effect on any of our dependent variables. Four different types of multivariate test results are given and Wilks'

Table 7. Smartphone facilitated processes Multivariate Tests

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[d]
Intercept	Pillai's Trace	.941	482.730[b]	3.000	91.000	.000	.941	1448.190	1.000
	Wilks' Lambda	.059	482.730[b]	3.000	91.000	.000	.941	1448.190	1.000
	Hotelling's Trace	15.914	482.730[b]	3.000	91.000	.000	.941	1448.190	1.000
	Roy's Largest Root	15.914	482.730[b]	3.000	91.000	.000	.941	1448.190	1.000
processQ20And26	Pillai's Trace	.329	1.043	33.000	279.000	.409	.110	34.417	.903
	Wilks' Lambda	.704	1.029	33.000	268.807	.430	.110	33.298	.888
	Hotelling's Trace	.373	1.014	33.000	269.000	.452	.111	33.461	.890
	Roy's Largest Root	.169	1.429[c]	11.000	93.000	.173	.145	15.714	.712

a. Design: Intercept + processQ20And26
b. Exact statistic
c. The statistic is an upper bound on F that yields a lower bound on the significance level.
d. Computed using alpha = .05

Table 9. Person to smartphone multivariate tests

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[d]
Intercept	Pillai's Trace	.807	125.325[b]	3.000	90.000	.000	.807	375.974	1.000
	Wilks' Lambda	.193	125.325[b]	3.000	90.000	.000	.807	375.974	1.000
	Hotelling's Trace	4.177	125.325[b]	3.000	90.000	.000	.807	375.974	1.000
	Roy's Largest Root	4.177	125.325[b]	3.000	90.000	.000	.807	375.974	1.000
personQ8And9	Pillai's Trace	.438	1.311	36.000	276.000	.119	.146	47.189	.976
	Wilks' Lambda	.620	1.300	36.000	266.643	.127	.147	46.021	.971
	Hotelling's Trace	.523	1.287	36.000	266.000	.136	.148	46.343	.973
	Roy's Largest Root	.252	1.934[c]	12.000	92.000	.040	.201	23.210	.882

a. Design: Intercept + personQ8And9
b. Exact statistic
c. The statistic is an upper bound on F that yields a lower bound on the significance level.
d. Computed using alpha = .05

Table 12. Smartphone-enabled climate multivariate tests

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[d]
Intercept	Pillai's Trace	.978	237.494[b]	3.000	16.000	.000	.978	712.483	1.000
	Wilks' Lambda	.022	237.494[b]	3.000	16.000	.000	.978	712.483	1.000
	Hotelling's Trace	44.530	237.494[b]	3.000	16.000	.000	.978	712.483	1.000
	Roy's Largest Root	44.530	237.494[b]	3.000	16.000	.000	.978	712.483	1.000
ClimateQ32To34AndQ35To37	Pillai's Trace	1.523	.843	66.000	54.000	.747	.508	55.651	.768
	Wilks' Lambda	.089	.918	66.000	48.630	.630	.553	60.210	.788
	Hotelling's Trace	4.488	.997	66.000	44.000	.511	.599	65.825	.813
	Roy's Largest Root	3.144	2.572[c]	22.000	18.000	.023	.759	56.588	.912
climateQ40To43	Pillai's Trace	1.494	.939	57.000	54.000	.593	.498	53.536	.807
	Wilks' Lambda	.109	.941	57.000	48.533	.590	.523	53.179	.779
	Hotelling's Trace	3.602	.927	57.000	44.000	.610	.546	52.826	.752
	Roy's Largest Root	2.016	1.910[c]	19.000	18.000	.088	.668	36.292	.763
ClimateQ32To34AndQ35To37 * climateQ40To43	Pillai's Trace	1.994	.810	132.000	54.000	.832	.665	106.973	.827
	Wilks' Lambda	.026	.875	132.000	48.869	.727	.702	115.283	.839
	Hotelling's Trace	8.171	.908	132.000	44.000	.668	.731	119.844	.830
	Roy's Largest Root	4.444	1.818[c]	44.000	18.000	.085	.816	79.984	.830

a. Design: Intercept + ClimateQ32To34AndQ35To37 + climateQ40To43 + ClimateQ32To34AndQ35To37 * climateQ40To43
b. Exact statistic
c. The statistic is an upper bound on F that yields a lower bound on the significance level.

lambda provides a good and commonly used multivariate F (in this case F = 1.029, df = 33, 268, p = .430) (Nancy L. et al., 2015). This F is significant since P<0.5 indicates that there are statistically significant differences among the smartphone facilitated process variables on a linear combination of the three dependent variables.

Since the smartphone facilitated processes (processQ20And26) reflect a significant effect on the dependent variables (product evaluation, product creation and product observation). It could be confidently confirmed that smartphone-facilitated processes influence creativity/product. The associated null hypothesis (H_{01}) which states that Smartphone facilitated processes do not influence product/creativity is rejected.

Table 6. Box's Test of Covariance Matrices

Box's Test of Equality of Covariance Matrices[a]

Box's M	89.616
F	1.067
df1	66
df2	3142.499
Sig.	.335

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.[a]
a. Design: Intercept + processQ20And26

ISBN: 978-99949-0-888-2

5.2 Assessing the role of smartphones in facilitating creative processes

Table 8 shows a between-subjects MANOVA that was conducted on three dependent variables in the "product" construct (product evaluation, product creation and product observation). This statistic tests the null hypothesis that the variance-covariance matrices are the same in all three groups. Therefore, if the matrices are equal indicating that the assumption of homogeneity is met, the (P-value) should be non-significant. For this data p = .740 (which is greater than .05); hence, the covariance matrices are roughly equal, and the assumption is defensible (Leech et al., 2015).

Table 8. Box's Test of Covariance Matrices

Box's Test of Equality of Covariance Matrices[a]

Box's M	41.859
F	.851
df1	42
df2	4200.042
Sig.	.740

Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.[a]
a. Design: Intercept + personQ8And9

The four MANOVA multivariate tests in Table 9 examine whether the two "person to smartphone interaction" variables differ on a linear combination of the dependent output/product variables: evaluation, creation, and observation. Results in the last row show that if "person to smartphone interaction" personQ8And9 affected any of our dependent variables. Four different types of multivariate test results are given, and Wilks' lambda provides a good and widely used multivariate F (in this case F = 1.300, df = 36, 266, p = .127) (Leech et al., 2015). This F is significant since P<0.5 indicates that there are statistically significant differences among the "person to smartphone interaction" variables on a linear combination of the three dependent variables.

The "person to smartphone interaction" reflects a significant "effect" on the dependent variables (product evaluation, product creation, and product observation). Thus "person to smartphone interaction" significantly influences creativity/ product. Therefore, the null hypothesis (H_{02}) which states that smartphone-to-person interaction does not influence creativity/product is rejected.

5.3 Examining the effectiveness of smartphones in creating a conducive climate/press for creativity.

Unlike the first two hypotheses, GLM two-factor multivariate analysis of variance was used to test this hypothesis since it contains two independent variables and multiple dependent variables (Leech et al., 2015). There are many independent variables in the "climate" construct that needs to be reduced before proceeding to hypothesis analysis. A sig (2-Tailed) value greater than 0.05 reveals no statistically significant correlation between the two variables. A Sig (2-Tailed) value is less than or equal to 0.05 reflecting a statistically significant correlation between two variables (Field, 2009). From the outcome in Table 10, climate32to34 and climate35to37 are very statistically significant with a sig(2-tailed) value of 0.000. They have therefore aggregated before testing the hypothesis. Due to the nature of the data having multiple dependant and independent variables, a Two-Way Multivariate Analysis of Variance GLM was selected for hypothesis analysis. The four MANOVA multivariate tests in Table 11 examine whether the "smartphone-enabled climate" variables differ on a linear combination of the dependent creativity/ product variables: evaluation, creation, and observation.

Table 10. Climate variables correlation

Correlations

		climateQ28And29	climateQ32To34	climateQ35To37	climateQ40To43
climateQ28And29	Pearson Correlation	1	.112	.180	.051
	Sig. (2-tailed)		.255	.066	.608
	N	105	105	105	105
climateQ32To34	Pearson Correlation	.112	1	-.391**	-.031
	Sig. (2-tailed)	.255		.000	.754
	N	105	105	105	105
climateQ35To37	Pearson Correlation	.180	-.391**	1	.125
	Sig. (2-tailed)	.066	.000		.204
	N	105	105	105	105
climateQ40To43	Pearson Correlation	.051	-.031	.125	1
	Sig. (2-tailed)	.608	.754	.204	
	N	105	105	105	105

**. Correlation is significant at the 0.01 level (2-tailed).
d. Computed using alpha = .05

Based on Wilk's Lambda test results, smartphone-enabled climate variables ClimateQ32To34 And Q35To37, and climate40To43 have P values of P=0.630 and P=0.590 respectively all of which are greater than 0.5. As a result, the effects of a smartphone-enabled climate (ClimateQ32To34 And Q35To37 and climateQ40To43) on a linear combination of dependant variables are not statistically significant and so is the interaction which is 0.727.

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Therefore, the smartphone-enabled climate has no significant effect on the dependent variables (product evaluation, product creation, and product observation). Thus smartphone-enables climate does not significantly influence creativity/ product. Therefore, the null hypothesis (H_{03}) which states that Smartphone enabled environment/climate does not influence creativity/product is supported. Table 13 summarise the hypothesis testing activities.

Table 13. Hypothesis testing summary

Hypothesis	Outcome
H_{01}: Smartphone-facilitated processes do not influence product/creativity.	Rejected
H_1: Smartphone-facilitated process influences product/creativity.	Supported
H_{02}: Person-to-smartphone interaction does not influence product/creativity.	Rejected
H_2: Person-to-smartphone interaction influences product/creativity.	Supported
H_{03}: Smartphone-enabled climate/press does not influence creativity/product.	Supported
H_3: Smartphone-enabled climate/press influences creativity/product	Rejected

5. Discussion

Based on the interactions and outcome theory, this study assumed that students' use of smartphones could enhance their creativity from various points of view. Students could use their smartphones to interact with each other and access and disseminate information. The wide access to information exposes them to a range of creative possibilities.

Considering insights from Campbell (1960), Torrance (1993), and Eysenck (1993), measurements were contextualized and group into Smartphone-facilitated process which was hypothesized to influences product/creativity. The data supported this hypothesis aligns with literature suggesting that the smartphones-based process can be useful in academic settings because it would allow "browsing for additional information, organizing the study process online (Rozgonjuk et al., 2019). An additional smartphone-facilitated process highlighted in the literature was around the improvement of the process of information access and delivery since they are mobile (Elfeky & Masadeh, 2016). In this way, smartphone usage may enhance creative learning and better outcome.

Person-to-smartphone interaction was concerned with those personalities or traits that could be associated with smartphone use and could lead to the creation of active products at the same time (Said-Metwaly et al., 2017). Thus, it was hypothesised that Person-to-smartphone interaction influences product/ creativity. Which was supported by data. This support means that smartphones could be seen as somehow upskilling a student at a personal level. Smartphone is mobile devices with more features and enhanced communication capabilities enabling a student to connect to the internet and is highly multifunctional (Park & Chen, 2007). The significance of Person-to-smartphone leads to student creativity in some ways.

Smartphone-enabled climate/press referred to the smartphone-induced environment bringing student creativity (Said-Metwaly et al., 2017). The focus was on several indicators including the availability of resources. Hence, it was hypothesized that Smartphone-enabled climate/ press influences creativity/ product. The rejection of this hypothesis means smartphone facilitating communication between peers and instructors (Rozgonjuk et al., 2019) does not significantly affect student creativity. The environment or climate within a student operating via a smartphone may not affect the outcome of them being more creative than if they used traditional social interconnection in their learning environment.

Overall, the significance of these results means that smartphones are not just a distractive tool for students as perceived when used in classrooms (Kaimara et al., 2019). It has the potential to enhance students' learning outcomes. It was noted that the literature mostly studied the impact of smartphones on academic performance. Assuming that creativity could be one aspect of academic performance in a certain setting, its significance echoes Aheto and Cronje (2018)'s and Shakoor et al. (2021) study finding of smartphones being "important towards the academic success. However, Hossain (2019) and Kaimara et al. (2019) revealed that smartphones negatively impact academic performance due to inappropriate usage. This warning still resonates with this study's result which only suggested some aspects of creativity that is significant. It is not yet clear which aspects of academic performance creativity would affect. Elphick (2018) capability approach tends to suggest that creativity relates to students perceived digital capability. But future research could explore this area further to offer a better explanation.

6. Conclusions

The findings are that two of the three alternative hypotheses were supported by data. Findings reflected that smartphone-facilitated processes have a significant influence on creativity. It was also discovered that student to smartphone interaction had a significant influence on nurturing creativity. However, there was no sufficient evidence from the tests to confirm that a smartphone-enabled climate has a significant influence on creativity. Digital communication tools, like smartphones, will still influence practices of teaching and learning in many ways. Scientists should enact intensify experiments to understand how these tools impact classroom communication and subsequent learning outcomes. There is a potential for smartphones' role in setting a learning environment supporting student creativity at the individual level. Universities should consider the role of smartphones in designing better learning management systems that integrate them for better learning outcomes. This study's result only concerned two aspects of creativity that is significant. It is not clear which aspects of academic performance creativity would affect yet. Future research could explore this area further to offer a better explanation. Further research is conducted to investigate the impact of smartphones on students' learning outcome aspects such as communication skills.

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Artificial Intelligence Hybrid Algorithm for System Reconfiguration to Reduce Power Losses in the Distribution System

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Abstract
A number of algorithms that aim to reduce power system losses and improve voltage profiles by system reconfiguration have already been proposed, but they are still subject to several limitations. Hence, new algorithms can be developed, or existing ones can be improved so that this important issue can be addressed more appropriately and effectively. To understand smart grids, distribution network, which is a key component of Distribution System Reconfiguration (DSR), is presented in this study as an accurate and effective solution. To determine the intended optimum reconfiguration and effectively rearrange the connectivity of the distribution networks, it uses a variety of heuristic optimization techniques. In this paper, a hybrid artificial intelligent method, made up of the genetic algorithm (GA) and particle swarm optimization (PSO), is developed. Using the standard IEEE 33-bus distribution network on MATLAB, the proposed method's validity and efficacy have been evaluated. The findings demonstrate the proposed approach's robustness and demonstrate that it minimizes the average power loss of independent runs while requiring less processing time. The comparison of results shows that HGAPSO has a better solution than GA and PSO.

Keywords: Radial Distribution Network, Network Reconfiguration, Power Loss Reduction, Voltage Improvement, Optimization Algorithm

1. Introduction

In electrical distribution systems, DNR is a key measure of optimization and a method for automating operations. During normal operations, the distribution dispatcher determines if a switch must be ON or OFF based on the operational state. Thus, it gives smoother loads, eliminates overloads, and improves voltage quality, reduces network losses, and boosts efficiency (Anderson. Soder, L., 2018). To minimize the scope of the power cut, isolate the fault-prone area and restore power as soon as the fault is fixed. The most important method of improving the efficiency and security of the distribution system is DNR, which increases security and efficiency in the distribution system.

The Distribution Network Reconfiguration (DNR) associates one of the indicators with the best mode of operation of the distribution network, so it can ensure that the feeder lines are well connected and can meet the heat capacity of feeder lines, as well as voltage reduction, transformer capacity, and so on. The distribution network includes several switching devices. The distribution network is a nonlinear hybrid optimization problem. Improving the methods and algorithms for Distribution network optimization is the topic of considerable research right now. Although it can provide local optimization, it is not capable of handling realistic situations (Borut, M. 2016).

An algorithm that uses randomized search mechanism for global optimization is known as GA. The effect of this program has been praised in the Distribution network optimization program. This is a random search algorithm based on linearity. When it comes to global search, it outperforms many other algorithms, but when it comes to local search, its performance is heavily influenced by disparity (Ehsan, M. 2011). Using local search, simulated annealing is efficient in global search, but not good in local search, and its development is slow. GA makes use of the probabilistic leaping property of simulated annealing to find the global optimum solution at random. Important details from parents are overlooked when offspring arrive in GA.

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PSO is more flexible, memory-efficient, and faster at achieving convergence than GA. In contrast, PSO performs poorly compared to GA when it comes to global convergence. This research proposes HGPSO, which combines the advantages of GA and PSO to solve the multi-objective distribution network optimization problem.

Section switches and intercom-section switches are two types of switches used in the power distribution system. To achieve the lowest network loss possible, DNR's primary function is to detect whether switches are turned ON-or-OFF. (Hooshmand, M. Ataei, Y. 2014).

The paper continues as follows. The problem formulation in Section 2 addresses several optimization techniques for power system analysis, specifies sensitivity variables and the multi-objective function equation. The selection criteria for the suggested optimization algorithm, the stages involved in implementation, and flow diagrams are covered in Section 3 methodology. The results are displayed in section 4 in tables and graphs. Section 5 is a conclusion.

Distribution firms and independent power producers will be able to lower real power loss in their networks because of this study effort. By taking advantage of this reduction, they may reduce their risk of fines and compensations, increasing their profit margins (Hosseini, SA. Gholamian, V. 2013). Independent power producers will be able to simply and dependably incorporate small-scale renewable energy sources into their networks because of this effort. This is crucial given the industry's transition to green energy. The results of this investigation will also significantly affect other people. Customers will profit from this since they will feel comfortable using their devices with constant voltage profiles (Hosseini, SM. 2012).

2. Problem formulation

2.1. Function for multi-objective optimization

In an optimization problem involving multiple objectives, it is generally more advantageous to convert the multi-objective into a single-objective, then solve and optimize the single-objective function. Utility function approach: the method used in this study is the weighted-sum technique and lexicographic ordering approach (Hosseinian, F. Razavi, Y. 2016). Since the overloads of the main transformer and feeder line play different roles with respect to the load balancing weight, the objective function is the load balancing weight. The objective function is constructed as follows, using the fundamental model as a starting point. A multi objective function is a multi-objective function that combines all objective functions using a weighted-sum algorithm (Jasmon, T. Solangi, A. 2013).

2.2. System Power Flow Sensitivity Factors

When a certain quantity of power is injected into any one of the system's buses, for example, bus I and bus j, the change in the amount of power flowing in a transmission or distribution line between those two buses is particularly determined by the system flow sensitivity (Jin Zhong, S. 2019). The injection of complex power by a source into a system bus, say a power system bus i^{th}, is described as follows.

$$S_i = P_i + Q_i = V_i J_i^* - i = 1,2,\dots\dots,n \quad (1)$$

With respect to ground, V_i is the voltage at the i^{th} bus, and J_i^* is injected into the bus by the source current. Source current is given by

$$J_i = \sum_{j=1}^{n} Y_i V_{J;\,=1,2,\dots.n} \quad (2)$$

Alternatively, the following is the outcome of using equation 3 as a substitute in the complex conjugate equation of power injection:

$$P_i - jQ_i = \sum_{j=1}^{n} Y_i V_{J;\,=1,2,\dots.n} \quad (3)$$

One gets the following equation when combining the real and imaginary parts:

$$P_i = R_e\{V_i * \sum_{j=1}^{n} Y_i V_J\} \quad (4)$$

$$Q_i = -\mathrm{Im}\{V_i * \sum_{j=1}^{n} Y_i V_J\} \quad (5)$$

Polar form V_i and Y_{ij} are expressed as:

$$V_i = |V_i| e^{j\delta i} \quad (6)$$

$$Y_i = |Y_i| e^{j\delta i} \quad (7)$$

2.3. Load balancing model

In this approach, the goal is to meet the required limitations of load balancing the distribution system after reconfiguration. To represent load

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levels on transformers and feeder lines, we use the ratio of mean loads (McDonald, J.R. 2016). When the switch is turned ON, the bus bar voltage swings within the permitted range, while the current via the main transformer and feeder line fluctuates within the rated range:

$$V_{i\,min} \leq |V_i| \leq V_{i\,max} \quad (8)$$

Where Vmin is the bus bar voltage's minimum limit, Vmax is the bus bar voltage's maximum limit, and Imax is the load capacity of the main transformer and feeder line (Mohammad, A. 2019). The distribution network's power flow limitation: AP=D (9)

Node-branch, represented by A, Power represented by P, and load requirements represented by D. The capability limitation:

$$1ILi + + 1pI = 1 \quad (10)$$

I1, which represents the current flowing through the element. Ipl, which represents the maximum current flowing through it. The letter Li represents the number Li. a collection of elements

3. Proposed method

3.1. Genetic algorithm

A multi objective function is a multi-objective function that combines all objective functions using a weighted-sum algorithm. Genetic Algorithms are a type of unconstrained optimization approach that mimics natural evolutionary adaptability (Nando, F. Ochoa, V. Eknath, F. 2011). The Genetic Algorithm starts the natural selection and evolution process, with the goal of solving an optimization issue using the objective function f. (x). The N-dimensional vector of optimization parameters denoted as x 1, 2...xN. The GA's primary building pieces are genes and chromosomes. The optimization parameters encoded in binary code, string by the standard GA (Nehrir, MH. 2013).

- Initialization and encoding
- The fitness function
- Crossover
- Mutation
- Selection

GA's search direction guided by the fitness value.

$$F = C_{max} - f,\ f < C_{max} \quad (11)$$

- Cmax is the supplied constant,
- F is the given function.

Synthetic networks have limited conditions, which, provided by fitness set f, the penalty item Mp, and the penalty factor M. Then f written as follows:

$$f = Mp + Z \quad (12)$$

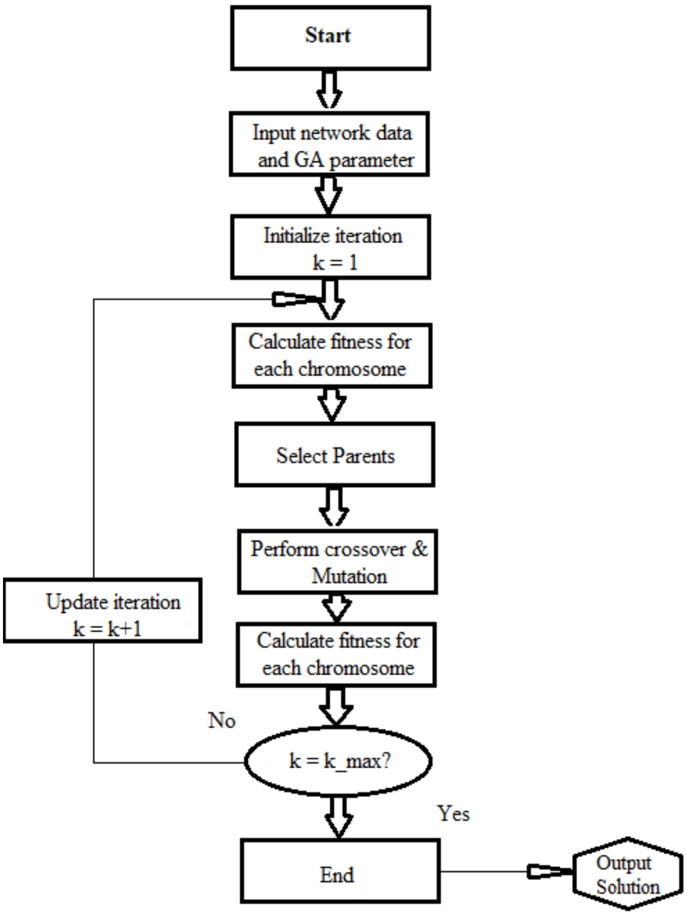

Figure 1. A basic GA algorithm

3.1.1. Crossover and modification

User preferences determine the majority of crossings and mutations. There is a crossover operator among them. To create candidate offspring, chromosomes are crossed over in pairs and crossed over with a probability Pcross. The likelihood of paternal chromosome crossing is typically between 0.6 and 1.0. With a probability of Pmut, some of the potential offspring's genes are inverted (Prasad, A. Jaya L. 2012). This process is known as mutagenesis in the GA. In turn, this leads to the creation of a new population. For the population to avoid early convergence, the mutation operator makes sure that there is variety within it. To determine the likelihood of mutation, 0.01 or 0.1 is typically employed (Sai, B.R. Barjeev Tyagi, U. 2011).

3.1.2. Selection

This operator produces a mating pool by selecting excellent chromosomes based on chromosomal fitness scores. There are other methods for doing this, but Roulette Wheel Selection is the most popular. The fit of each potential solution determines how biased roulette wheels are. The population has M strings; thus the wheel is spun M times. By carrying out this action, the computed measure takes the fitness of candidates from the previous generation into account (Sinarami, VC. Veera, D. 2012).

3.2. Algorithm for particle swarm optimization

The social behavior of birds flocking or fish schooling inspired Particle Swarm Optimization. Randomly arranged particles populate the search space in the beginning of the technique. Each particle contributes to the problem's solution and has a fitness value. (Soeprijanto, A. 2012). Particles eventually shift toward the optima as result of their best location and the finest solution that the group has ever encountered.

3.3. Particle Speed

Current velocity is constrained by the limit. By specifying which areas will be searched between the current location and the target position, the parameter shows the resolution, or fitness, attained. Particles travel in greater steps as a result and, if it is really high, they may miss promising solutions. In contrast, if is too low, particles travel far before finding the necessary solutions. They run the danger of becoming trapped in local minimal solutions because of inadequate investigation (Taghikhani, MJ. 2019).

The advantages of PSO include a reduced individual number, ease of computation, and excellent resilience. The technology has been successfully applied across a wide range of fields, robot route programming, fuzzy system control, fuzzy system recognition, and neural network training are examples of these types of applications (Tajizadeh, A. Ehsan, H. 2017).

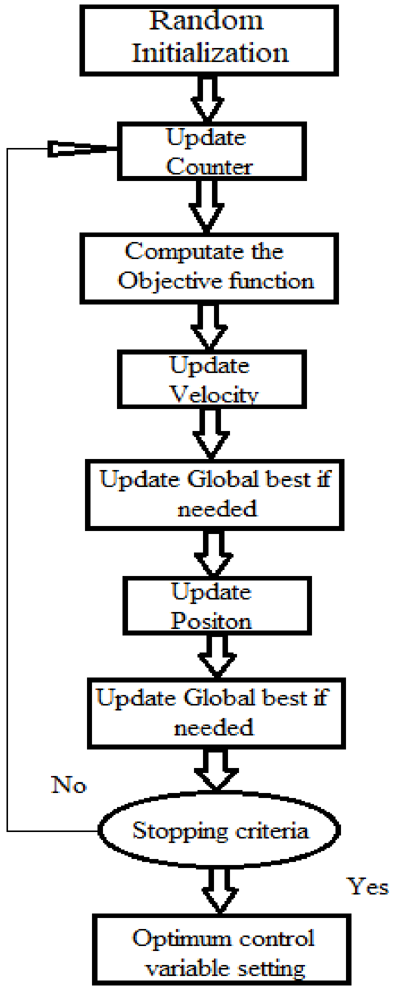

Figure 2. Flowchart of a basic Particle Swarm Optimization algorithm

3.4. Artificial Intelligent hybrid algorithm

GA and PSO have complementing abilities. When offspring arrive in GA, much essential information from the parents is overlooked. When compared to GA, PSO offers the advantages of ease, flexibility, and memorability. However, it falls short of GA in terms of global convergence. The research provides a hybrid algorithm that combines each benefit. During the hybrid algorithm search, some people use the PSO search strategy while others use the GA search strategy to get the best solution. Only those with a high level of fitness may be eligible for the following generation's optimization (Kai Zou, A P. Agalgaonkar, KM. Muttaqi, S. 2016). As a result, our technique inherits significant evolution information, improves particle swarm searching efficiency, and ensures algorithm global convergence (Ziari, NG. Platt, W. (2019).

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4. Results and discussion

4.1. Values for weights in a multi-objective function

The weights of a multi-objective function distributed differently depending on the designer's concern. This study focuses on actual power loss reduction since it may reduce total cost of operation while also increasing the efficiency of the power network. The other two aspects, however, are equally significant; taking this into account, research of the effect of weights on fitness should be conducted to find the ideal weights combination to use and achieve the multi-objective function.

- W_1 was between 0.5 and 0.7
- W_2 and W_3 were restricted between 0.4 and 0.1

This was done to guarantee that, as previously indicated, the real power loss reduction index receives a lot of attention, and having the multi-objective function take into account all three indices is also essential.

Table 1: The values for weights in a multi-objective function

Weight 1 (W1)	**Weight 2 (W2)**	**Weight 3 (W3)**	**Best Fitness**
0.5	0.1	0.4	0.909
0.5	0.2	0.3	0.910
0.5	0.3	0.2	0.909
0.5	0.4	0.1	0.910
0.6	0.1	0.3	0.910
0.6	0.2	0.2	0.909
0.6	0.3	0.1	0.909
0.7	0.1	0.2	0.91
0.7	0.2	0.1	0.910
0.8	0.1	0.1	0.909

Table 1 shows the results of the weight combinations chosen including, which combination gave the best fitness results at the minimum, the weights chosen $W_1 = 0.5$, $W_2 = 0.4$, $W_1 = 0.1$.

4.2. System Description

The American Electric Power System is represented in part by the IEEE-30 Bus Test Case (in the Midwestern US). In reality, the model places these buses at either 132 or 33 kV. The IEEE-30 bus test case does not have line limit.

Figure 3 shows a conventional IEEE 33-bus distribution power system illustrating the suggested method. The generally open tie switches are illustrated with orange lines, whereas normally closed switches, indicated by the green lines, are from s1 to s32. Using modified PSO, five of the thirty-three switches considered as being closed when, in fact, each considered as closed in the test system. Thus, five out of thirty-seven switches being considered as opened for the smallest loss configuration, each particle deals with five decision factors. Each variable (switch) in modified GA is represented by six bits, resulting in a chromosome with a length of sixty-four bits.

PSO performed for a predetermined number of iterations in the proposed technique, and the best solutions identified so far encoded into chromosomes and supplied as an initial population to GA. Then, for the rest of the iterations, GA is set to run. While anticipated that increasing the number of iterations would result in a better solution, the cost of computational resources is well thought out. To optimize optimization performance, it is necessary to fine-tune the number of particles and population size, the number of iterations and the inertia weight that are used in the method. The system solved for 200 times in a row to illustrate the resilience of the suggested method.

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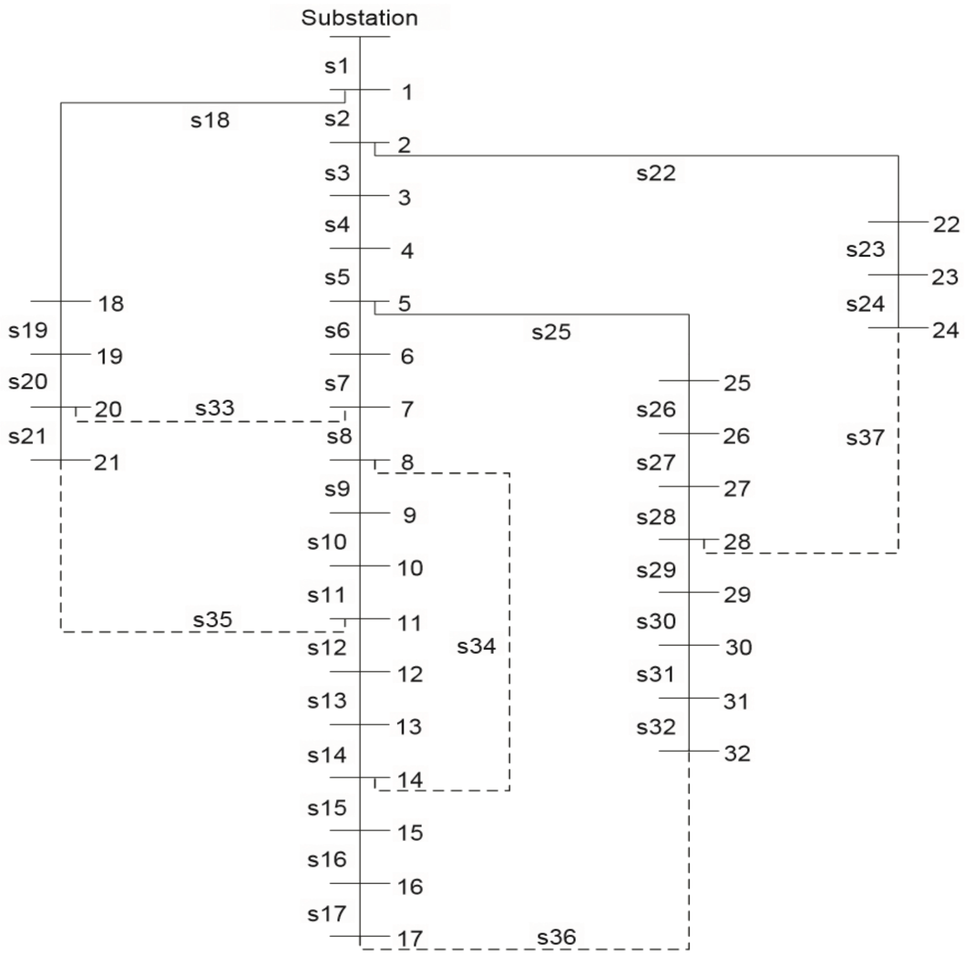

Figure 3. A 33-bus Test system used for testing the proposed techniques

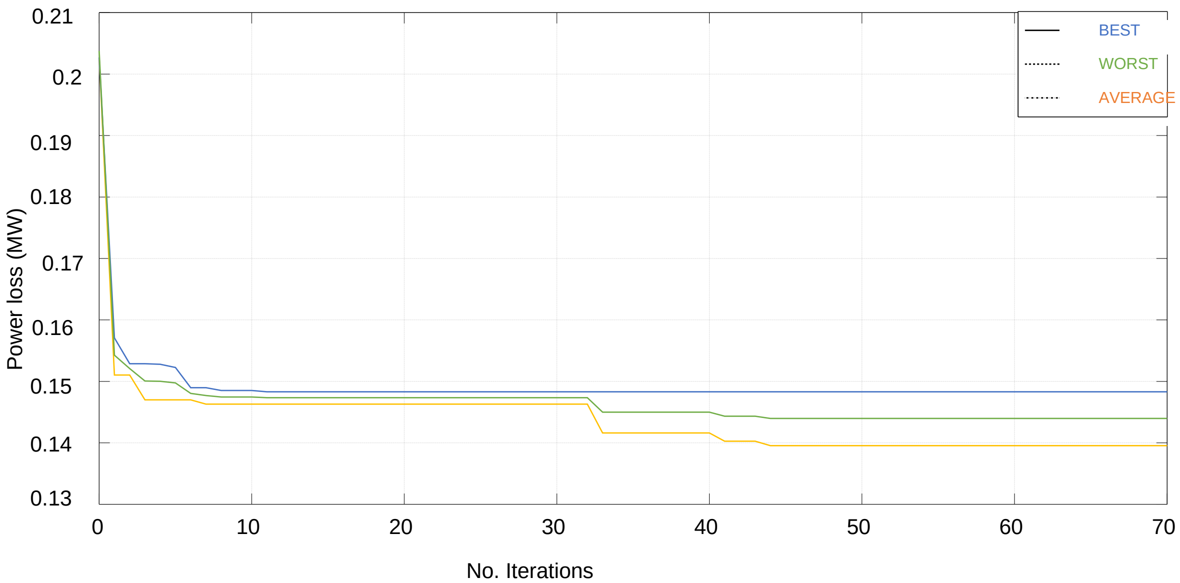

Figure 4. Convergence characteristics of proposed method

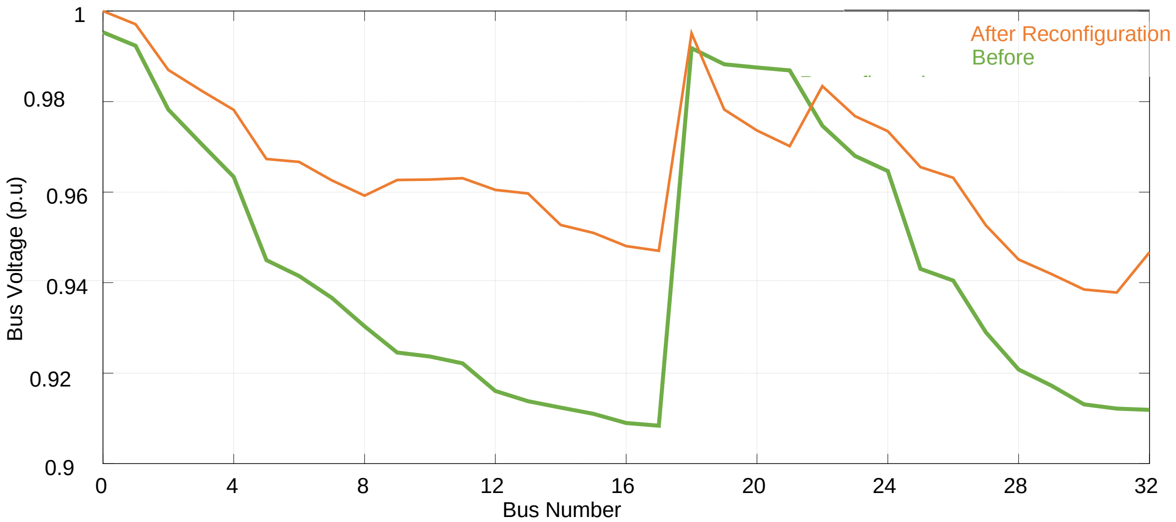

Figure 5. Magnitude of voltage after reconfiguration of each bus

As shown in Figure 4 and Figure 5, this hybrid technique exhibits convergence properties for both the best and worst cases of 200 independent runs, as well as an average of these two scenarios. Result of updating the PSO, the power loss decreased from 0.202 MW (starting value) to 0.114 MW after 25 iterations.

On the 44th iteration, GA achieves its global optimum (0.139 MW) by even further minimizing the loss. Using the suggested technique, 200 simulations were performed using various methods. By comparison, the resulting average loss reduction obtained using the recommended technique is higher than that achieved using GA and PSO as shown in table 2.

Table 2. Loss reduction and tie switch configuration

Configuration Algorithm	**Power Loss (MW) Best and Worst STD**	**Loss Reduction (%)**	**Min Voltage (p.u) (Best value)**	**CPU Time (s)**
Initial	0.20	-	0.91	-
GA	0.14	15.74	0.92	14.2
	0.01			
PSO	0.13	18.65	0.93	13.8
	0.19			
(HGAPSO)	0.13	30.63	0.93	**5.7**
	0.01			

5. Conclusions

For a more efficient, precise solution of the Distribution Network Reconfiguration issue, this research used a hybrid GA and PSO strategy. Several measures were employed in this strategy to maintain population diversity. In addition, the system applies a mending technique to meet the radial requirements for each PSO particle or GA chromosome, significantly reducing the solution space. By using the proposed method, a high rate of convergence was achieved, and the global optimum can be located without premature convergence. In terms of computing time, average loss reduction, and least standard deviation, the suggested hybrid technique outperforms other methods when it comes to searching for optimal solutions of multiple independent runs as HGAPSO loss reduction is higher than GA and PSO by 30.63 per cent, 18.65 per cent and 15.74 per cent respectively.

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An Ontology Based Knowledge Representation for Coordinated SS-bots

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Abstract
Collective behaviour empowers biological species to achieve remarkable swarm level results through distributed actions. For example, social spiders achieve coordinated activities that can lead to plausible outcomes such as preying, mating, or building webs. Developers of simulated swarm systems are increasingly moving away from insinuating individualistic robotic devices, gravitating towards collective swarms to achieve common goals. However, for this to happen, it is imperative to understand the principles that underpin successful simulated coordination of robotic devices in swarms. In this article, we investigate the principles behind artificial swarm systems built on the instinctive behaviours of simulated social spider-like devices (SS-bots). We classify these principles into six interconnected knowledge domains, including (a) environment, (b) SS-bot architecture, (c) SS-bot mission planning, (d) SS-bot communication, (e) SS-bot operators, and (f) metadata and swarm-level data. The key features of each domain are discussed, and an SS-bot ontology is proposed.

Keywords: SS-bot, SS-bot ontology, social spider

1. Introduction

Swarm intelligence is about large multi-agent systems demonstrating emergent behaviour beyond the scope and abilities of the individual swarm members. In this context, emergent behaviour is about the creation of swarm-level outcomes from the individual actions of the members of the swarm (Chibaya, 2014). This phenomenon is, commonly, observed in natural social groups such as herds, ant colonies, flocks, bee swarms, fish schools, or social spider swarms. Although it is desirable to harness the principles that govern swarm intelligence in different scenarios and interpret the individual-level actions of the swarm members into practical computational routines, we will firstly require scrupulous apprehension of the representation of such low-level actions and how they cause emergent behaviour. An understanding of the computational semantics and clear interpretation of the low-level actions of swarm members will valuably inform proper knowledge representation before we can solemnize swarm intelligence as a practical problem-solving approach. The quest to understand the basis of swarm intelligence in different contexts, pursuit to pinpoint the key vocabulary used by swarm members, as well as the desire to formalize knowledge representation in the context of swarm intelligence, are the key motivating factors for undertaking this study. Although this article focuses on a case study scenario of the understanding of social spider-like robotic devices (SS-bots) in swarms, we hope to contribute a methodology that can be mapped to the understanding of other forms of swarm intelligence systems.

Studies aimed at understanding the principles behind swarm intelligence, pinpointing the factors that cause emergent behaviour, and identifying the key factors in the formation of emergent behaviour are gradually gaining popularity (James et al., 2015; Cheraghu et al., 2021). Intriguing is the interest by researchers to investigate even the extension of such knowledge to the coordination of swarms of heterogeneous members (Saffre et al., 1999). Swarms of heterogeneous members can deal with complex mission too challenging for human to perform (Saffre et al., 1999; Tan and Zheng, 2013), tasks that may present a mammoth assignment to a swarm of homogeneous members (Abosaif and Elrofai, 2020). For example, what form of swarm intelligence can achieve a search and rescue mission in a collapsed mine? What

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form of swarm can be deployed to retrieve bodies in piles of rubble after an earthquake to search through the wreckage? Search mission in these circumstances may require heterogeneous swarms whose members are built from different perspectives. For example, such swarms may comprise ant-like members for robust and fault-tolerant search (Melaine et al., 2020), as well as bee-like members for a waggle-dance inspired recruitment (Cheraghu et al., 2021; Carrillo-Zapata et al., 2020) of other members when it becomes necessary. Swarms of heterogeneous members are better when homogeneous swarms or human may fail to endure (Abosaif and Elrofai, 2020) because such members' working efficiency may be much better (Carrillo-Zapata et al., 2020).

We understand heterogeneity to emanate from putting together several homogeneous swarms (Melaine et al., 2020). One way to achieve heterogeneity is by gradually building and integrating homogeneous perspectives. If we can create and formalize the representation of distinct categories of homogeneous swarms, emphasizing the key principles in each case, concepts, data, and meta-entities of the homogenous swarms, then heterogeneity can emanate. We refer to such formalized representation of swarm intelligence knowledge as a swarm intelligence ontology. Precisely, swarm intelligence ontologies capture the vocabulary, semantics, and the relationship between the actions of the individual swarm members which trigger emergent behaviour (Li et al., 2017; Bock, 2013). A swarm intelligence ontology, therefore, can vitally define the key components of a swarm system, including the knowledge shared, process through which swarm knowledge is generated, managed, used, and stored. It can define the diverse formats of the knowledge produced and how swarm members interpret the meanings of such knowledge. Additionally, a swarm intelligence ontology may enable logical use of knowledge to allow inferences, discoveries, and decision-making. It would potentially define the security aspects at individual member level, bringing about context awareness. A swarm intelligence ontology should, thus, reinforce internal state management, as well as tracking the influences of the actions of the individual members of the swarm on the emergent behaviour thereto. The overall goal of a swarm intelligence ontology is to therefore, eventually, and gradually, evolve into a swarm language (James et al., 2015; Saffre et al., 1999).

Hopefully, new swarm intelligence applications may ensue from the birth of swarm intelligence ontologies. Similarly, successful development of homogeneous swarm intelligence ontologies will, potentially, propel the growth of heterogeneity towards better interoperability and reusability in swarm systems.

1.1. Problem statement

Arriving at a swarm intelligence ontology for coordinating heterogeneous swarm members is an ambitious task. It involves understanding discrete swarm intelligence ontologies for coordinating homogeneous swarm members. For example, an arbitrary swarm of heterogeneous members could comprise ants, termites, bees, social spiders, fish, or birds. In that case we would need to understand an ontology for each type of swarm member before we merge the several homogeneous ontologies into a generic ontology that supports heterogeneity. This article is written with the hope of arriving at such an ontology in mind.

The behaviour of social spiders in nature is fascinating. As a starting point, we tackle the problem of creating a homogeneous swarm intelligence ontology for coordinating spider-like robotic devices, here referred to as SS-bots. The hope is that heterogeneity will ensue when, in future, new ontologies are added to this proposed body of knowledge.

1.2. Overview

We envision the collective behaviour of SS-bots as based on individual decision making and local interactions policies (James et al., 2015; Li et al., 2017; Bouriot and Chevrier, 2020). Collective behaviour is only visible at swarm level (Saffre et al., 1999; Abosaif and Elrofai, 2020) though it is generated at individual SS-bot level. Little has been documented on the nature of the low-level actions and the information SS-bots share. The mechanisms in which SS-bots share information, and the dynamics involved in their decision-making to cause emergent behaviour are blurred. In this case, coordination refers to cooperative actions and movements of SS-bots towards a goal (Melaine et al., 2020). Precisely, coordination in the context of SS-bots is about resolving a search problem (Bouriot and Chevrier, 2020).

Little is known about SS-bots' ability to emulate vibrations and emulate them through simulated

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communal webs (James et al., 2015). While the actions of SS-bots, such as decision-making, communication, interaction, and generation of vibrations are the key ingredients of the emergent behaviour thereto, how do we holistically represent SS-bots' knowledge in computational terms? How do we formalize such knowledge representation for reproducibility and further use?

This study seeks to pinpoint the component units of a swarm intelligence ontology for coordinating SS-bots. The proposed swarm intelligence ontology involves conceptualization of mission planning, SS-bots internal states, communication, and metadata issues. It involves the representation of SS-bot reasoning and their architectural design. Also, it entails abstracted representation of the environment in which SS-bots operate, depicting the environment as the shared memory for the swarm. Additionally, the ontology captures the representation of any uncertainty, incompleteness, and inconsistencies in the swarm information and knowledge. Consequently, global level policies such as global awareness, and any decision-making made at swarm level are also recorded in the ontology, defining SS-bot context reasoning. The aim of this work is to present an informed understanding of the prospective vocabulary of SS-bots to enhance practical use, application, and visibility of this knowledge domain in problem-solving. Hopefully, representation of the proposed SS-bots ontology creates new content in the field.

Section 2 presents related work in which attempts to understand the design of swarm intelligence are discussed. We focus on discussion emphasizing swarm member interactions, communication, and decision making. Section 3 identifies the key underlaying principles of SS-bot coordination. In Section 4, we further describe the identified knowledge domains of the SS-bots. In section 5, we highlight the contributions we make, as well as pointing towards the direction for future work.

2. Related Works

SS-bots inspired swarm systems function under uncertainty (Abosaif and Elrofai, 2020). They equally rely on the environment, SS-bots, data for decision-making, action planning, and interaction among the SS-bots. The key information needed by the SS-bots is created within the swarm by other SS-bots (St-Onge et al., 2020) or by prey. There have been ongoing efforts to formalize the design principles underlaying such swarms to then solemnize knowledge representation officially in this domain (Zhaoyu et al., 2020). However, we first require a concise understanding of the features of the environments, data and its storage, as well as an apprehension of the mechanisms in which shared memory emerges.

Representation of swarm knowledge using an ontology has been recommended (Li et al., 2017). In doing so, focus is commonly on pinpointing swarm characteristics, dominant design features, popular contexts, SS-bots interaction strategies, mission planning policies, and prevalent decision-making approaches. Notably, literature focuses on understanding swarm processes under uncertainty while noting common constraints and any gaps.

2.1. Related Ontologies

An ontology captures the creation, representation, storage, relationships, and access to knowledge (Bock, 2013). The task to create an ontology is a requirements elicitation exercise where we also stipulate the functional categories, properties, rules, policies, and the relationships between all the aspects of the ontology (Li et al., 2017; Bock, 2013). In swarm intelligence terms, an ontology emphasizes swarm capabilities, SS-bots abilities, and those environment features that influence the SS-bots' behaviours (Tan and Zheng, 2013).

Bids to create swarm intelligence ontologies are ongoing. For example, a multi-agent ontology-based system was combined with a business rule management system (Sadik and Urlker, 2014) and produced plausible distributed control solution to the cooperative manufacturing problem (Navarro and Matia, 2013). To do so, it treated the ontology as a conceptual tool to represent mutual understanding between manufacturing work entities (Carrillo-Zapata et al., 2020). Another ontology was created and merged with a support vector machine for data clustering (Li et al., 2017). In both cases, accurate feedback was noted.

Standardization of knowledge representation in robotics was also achieved using a core ontology for robotics and automation (CORA) (Navarro and Matía, 2013). Here, robotic devices required explicit knowledge representation (James et al., 2015). However, environment aspects were excluded from the key elements of the ontology (Bock, 2013). However, all other abstract representation of the SS-bots actions, interactions, events, and hardware were clear (Bock, 2013). Also, inferential procedures for operating on the

ISBN: 978-99949-0-888-2

data were commonly considered (Li et al., 2017). In addition, and in most cases, emphasis has been placed on improving SS-bots autonomy rather than enabling cooperation and coordination (Navarro and Matia, 2013). The focus has been, often, to enable simpler SS-bots interactions (Srikanth and Sridhar, 2020), enabling knowledge transfer between SS-bots and the environment, representing the key operations, mission planning policies, and detailing the architecture of SS-bots (St-Onge et al., 2020).

Other ontologies are mere references to collective behaviour (Melaine et al., 2020), providing models of systems and the environments thereof, supporting interactions between the system objects and the environment, and stipulating the behaviour of system objects which change the environment (Srikanth and Sridhar, 2020). A few other ontologies provided semantic formalization (Bock, 2013). However, application-specific ontologies are predominantly conceived as too specific and limited to cover generalized requirements. Such ontologies are regarded as too complex (Bock, 2013), which impedes use in generalized contexts (Li et al., 2017). Most ontologies in this category assume deterministic worlds that lack any possibility of uncertainty, incompleteness, or inconsistences in the data (Carrillo-Zapata et al.,2020; Bock, 2013).

Although discrete swarm intelligence ontologies exist, the inferred natural inspiration and the methods followed in their creation differ. Even though we cannot pinpoint a standard way of creating these ontologies, six principles are common. (1) Ontologies need clarity. This means that the terms of the ontology should be clear, independent, and objective. (2) Also, ontologies should be coherent. In this case, inferences should be consistent with the terms of the ontology. (3) Additionally, ontologies should be extensible. This refers to possibilities of scaling the ontology horizontally and vertically. (4) More so, an ontology should embrace modularity. This refers to an ontology being divisible into modules with relevant purposes. (5) Ideally, an ontology may bring about minimal bias. In this case, the description of terms should not rely on a specific encoding approach. (6) In all cases, minimal ontological commitment should be evident. This means that the ontology should support knowledge sharing with minimal constraints to allow flexibility.

We acknowledge the likelihood of diversity between the swarm intelligence ontologies discretely built from different inspiring social colonies. We thus seek to understand the various stand-alone homogeneous swarm intelligence ontologies as building blocks of the generalized versions. As a starting point, we investigate the aspects of a swarm intelligence ontology with which to coordinate swarms of SS-bots.

2.2. Modelling uncertainty

An aspect of swarm intelligence systems that is often ignored in most discussions is consideration of uncertainty (Li et al., 2017) and information incompleteness when SS-bots make decisions. However, ontologies that consider information ambiguity, randomness, vagueness, inconsistency and fuzzy are noticed in the literature (Evangeline and Abirami, 2019). Often, mathematics theories are used to handle such uncertainty through fuzzy logic, Bayesian networks, or Markov networks. Vagueness is better handled using fuzzy logic (Li et al., 2017; Cuevas et al., 2013). On the contrary, randomness, inaccuracy, and incompleteness are best tackled using probabilistic views (Li et al., 2017). However, mathematical approaches focus on annotation (Li et al., 2017), and not resolution of the problems in uncertain contexts. As such, approaches to annotate and support reasoning under uncertainty are still upcoming. IN proposing the SS-bot ontology, we keep the need for reasoning under uncertainty in mind.

2.3. Modelling swarm context

In this case, the term context is synonymous with the environment. A swarm intelligence ontology should include the environment, SS-bots, actions, and interactions between SS-bots (Cheraghu et al., 2021; Bouriot and Chevrier, 2020). Although contexts are often domain-dependent (Melaine et al., 2020), they are all modelled as grids with rows and columns that intersect to form positions (Saffre et al., 1999). For SS-bots, the web is a key component of the context (James et al., 2015). In nature, a web is a non-geometrical network of silk lines that form a horizontal hammock (Saffre et al., 1999). A web represents the plan (Tan and Zheng, 2013) followed by the swarm. The positions on the web represents feasible solutions to the optimization problem (James et al., 2015). SS-bots can move freely on the web. Each SS-bot holds a position, and the quality of the solution pursued is based on the objective function

ISBN: 978-99949-0-888-2

represented by the potential to find the goal (Melaine et al., 2020). SS-bots cannot leave the web because positions outside the web are infeasible. Consequently, the web forms the shared memory for the swarm.

2.4. Modelling the SS-bot

The design and capabilities of the SS-bot are essential. Most designs of robotic devices imitate social colonies (Abosaif and Elrofai, 2020). For example, ant colony systems mimicked the foraging behaviour of ants (Li et al., 2017). Work on SS-bots, in the past, imitated social spider walking pattern (James et al., 2015). In most cases, simulations aim explain the behaviour exhibited at individual levels that causes swarm-level behaviour (James et al., 2015). Concern is mainly on the "how?" aspect and not the "why?". However, what are the required behavioral elements of SS-bots sufficient to explain the swarm intelligence that emanates. What are the low-level activities of SS-bots which causes emergent behavior? How does an SS-bot communicate, decide, generate information, represent, and store related knowledge? How can we mimic SS-bots in computational terms?

An understanding of SS-bots knowledge, and apprehension of the relationship between SS-bots and their contexts can allow the formalization of an SS-bots ontology. The notion that SS-bots complete tasks with limited perception inspire us (James et al., 2015). Knowledge that SS-bots make probabilistic choices with little knowledge of the context is compelling (Saffre et al., 1999). We notice that most decisions are based on the information held in the environment, bringing about stigmergic swarm coordination (Tan and Zheng, 2013; Cheraghu et al., 2021). There is no global organization. All SS-bots are homogeneous simple and autonomous (Melaine et al., 2020). These SS-bots features are elaborated below.

2.4.1 Structural design

SS-bots are classified by gender (James et al., 2015; Carrillo-Zapata et al., 2020; Navarro and Matía, 2013). Male and female SS-bots co-exist (Navarro and Matia, 2013). Female counterparts often outnumber the male by about 70%. Male SS-bots are separated into dominant and non-dominant (Cuevas et al., 2019). Dominant male SS-bots have better fitness and can reproduce by mating with the female neighbours (Melaine et al., 2020). Non-dominant male SS-bots remain close to other male, relying on the dominant males for nutrition (Srikanth and Sridhar, 2020; James et al., 2015; Cuevas et al., 2013). Female SS-bots can attract or repel the male counterparts (Abosaif and Elrofai, 2020). Eventually, emergent behaviour arises, such as weaving (Bouriot and Chevrier, 2020), preying (Abosaif and Elrofai, 2020), homing, or mere searching (Bouriot and Chevrier, 2020). Emergent behaviour results from the activities of the individual SS-bots that contribute to the creation of the shared memory on the environment (Abosaif and Elrofai, 2020).

Each SS-bot has a weight assigned to it based on its fitness (Cuevas et al., 2019). Weights are compared to determine the best fir SS-bot around (Kamath et al., 2018). The worst counterparts are noted (Kamath et al., 2018). Also, every SS-bot has a position and can generate vibrations. Positions are candidate solutions. Therefore, a female SS-bot’s next step is influenced by the nearest best, context, and the global bests SS-bot in the swarm.

2.4.2 SS-bots communication

A specific population of SS-bots is initialized in the environment (James et al., 2015; Tan and Zheng, 2013). Socialization between SS-bots is an ingredient for cooperation and convergence. Vibrations are SS-bots’ mode of communication (Carrillo-Zapata et al., 2020; Cuevas et al., 2013). Each SS-bot seeks to get information about the positions of other SS-bots based on the vibrations it receives. The web is the communication channel (Cuevas et al., 2013; Talamala et al., 2020). Movement around the web is triggered and orientated by vibrations. Information about the location of preys or mating possibilities are communicated through the web (Perez et al., 2016). The intensity of the vibrations is important. It depends on the distance of the source (Navarro and Matía, 201; Zhao et al., 2021), the curiosity of the vibration source, and vibration attenuation over the distance. Thus, every individual SS-bot actively performs local and global searches using vibration sensation (Zhao et al., 2019).

SS-bots do not have a full view of the environment (Carrillo-Zapata et al., 2020; Wignall and Herberstein, 2013). They cannot perceive the complete historic events (Melaine et al., 2020). Thus, SS-bots have limited perception of the environment (Otor et al., 2019; Talamala et al.,

ISBN: 978-99949-0-888-2

2020), emphasizing locality. This defines three types of vibrations (Cuevas et al., 2019), namely, vibration generated when SS-bots move, vibration by the fittest SS-bot, and vibration from the prey. SS-bots can distinguish between these different vibrations and act accordingly. The actions thereto are guided by the received information, including uncertainties and constraints (St-Onge et al., 2020; Navarro and Matía, 2013).

2.4.3. SS-bot mission planning / decision making

SS-bots decisions shape their behaviour. SS-bots commonly trigger such decisions based on their internal states (Cheraghu et al., 2021; Cuevas et al., 2013). One prevalent decision is to move (James et al., 2015 ; Cheraghu et al., 2021; Saffre et al., 1999; Cuevas et al., 2013). Although movement may be random, the choice of where to go is based on the predetermined goal, vibrations, and the shared memory (James et al., 2015). In addition, the gender of the SS-bot also shapes the walk (Cuevas et al., 2013; Zhao et al., 2021). Gender upholds that the female SS-bots move towards stronger vibrations while male SS-bots move towards the nearest female. Female SS-bots are also attracted to gender-neutral SS-bots (Cuevas et al., 2019). Giant female SS-bots are favoured because they create potent vibrations. However, although other factors such as curiosity and reproduction influence like/dislike decisions (Evangeline and Abirami, 2019; Otor et al., 2019)], the final decision SS-bot choice remains stochastic (Cuevas et al., 2013; Zhao et al., 2019).

2.4.4. High level operations

A swarms should maintain a strong community to improve exploration. This is achieved by getting rid of weaker SS-bots on poor fitness grounds (James et al., 2015; Cuevas et al., 2013). The work of Zhao et al. (2019) proposed replacing wort members after each iteration. On the other hand, Cuevas et al. (2019) proposed replacement of the worst fit, replacing these with the offspring from mating best fit members of the swarm. This is an essential swarm level operation that binds the swarm together.

2.4.5. SS-bots constraints

The primary constraint in most swarm intelligence models is lack of inclusion of the time model in the environment. SS-bots movements are, thus, strictly modelled as one single time step per iteration regardless of the fitness value carried, position, or the neighbourhood thereof. It would be ideal to improve aspects of understandability and conciseness in the behaviour of SS-bots. In this vase, understandability suggests that a swarm intelligence ontology would be understood by all stakeholders, other ontology developers, swarm intelligence experts, and even swarm intelligence systems operators. Conciseness, on the other hand, means that a swarm intelligence ontology would consist of a minimal vocabulary to describe the swarm of homogeneous SS-bots. The desire to capture all these aspects in the context of swarms of spider-like robotic devices is the gap this study seeks to fill in the body of knowledge.

3. Methods

An SS-bot ontology can be characterized by six aspects. The core and central aspect is the swarm knowledge. In swarm knowledge, we define the global context of the swarm. This is where data about the other five aspects is synchronized. The environment is another key component of the SS-bot ontology which defines the context in which SS-bots operate. This aspect captures data about the web, its boundaries, structure, the shared memory and any stigmergic factors for SS-bots during their stay on the environment.

Mission planning and related parameters is another rich aspect of the SS-bot ontology. It entails the tools for SS-bot reasoning, design of internal state, meanings of vibrations, parameters that characterize neighbour SS-bots, as well as the triggers to stochastic SS-bot movement decisions. Precisely, mission planning summarizes how path planning and movements are driven (Cheraghu et al., 2021; Cuevas et al., 2013). In SS-bots mission planning, explicit definition of gender plays a key role (Cuevas et al., 2019) towards most decision-making processes (Zhao et al., 2021).

Another key aspect of the ontology is the SS-bot architecture. This aspect considers four SS-bot features, namely, gender, memory, sensory skills, and weights. In addition, SS-bots communication is equally important. This aspect captures the media of communication and the attributes of the medium. In this case, vibrations are characterized with respect to how frequency and the amplitude of a vibration are related to some position on the web, as well as how a vibration is associated with the gender of the SS-bot at its source. Also, the relationship between a vibration, weight, source, amplitude, distance, attenuation, and the gender of

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the SS-bot is established. The web is the medium through which vibrations are transmitted.

The last aspect of an SS-bot ontology captures the operator and meta-knowledge of SS-bots. In this case, memory about the prey, as well as recalling the frequency of prey vibrations are key triggers of curiosity, mating, or following others. The proximity of prey overrides all other operations in favour of attacking the prey. Thus, most decisions made by SS-bots are based on the different vibrations it receives.

4. Integration of SS-bot ontology aspects

Figure 1 presents the six aspects of an SS-bot ontology. Swarm knowledge is central. This is where the goal of the swarm is defined (mating or preying). Also, this is where initialization of swarm population and other parameters is done, such as setting up gender roles, marking targets, and setting the conditions for achieving the goal.

Figure 2 expands the environment aspect to depict its four parts: the web, its boundaries, and the occupants (SS-bots and prey). SS-bots cannot go to infeasible positions outside the web. SS-bots understand the structure of the web. On the other hand, the web creates a shared memory for the swarm. Both the prey and SS-bots have precise positions on the web. Prey generate unique vibrations attractive to SS-bots. Contrary, SS-bots generate vibrations of different intensity based on gender, weight, and position in the web.

Figure 3 summarizes SS-bot mission planning, depicting four entities. First, an SS-bot's internal state is central in this aspect. It holds the goal of the SS-bot, target, and the resources for achieving the goal. Internal states are influenced by the behaviour of other SS-bots in the neighbourhood, their gender, and other random stochastic actions of the neighbours. Neighbour SS-bots occupy precise positions on the web. They broadcast gender-based vibrations in different intensities. On one hand, male counterparts follow behind the female foils to mate. Only dominant male SS-bots can mate. Non-dominant male SS-bots are meant to balance the population ratio of the swarm.

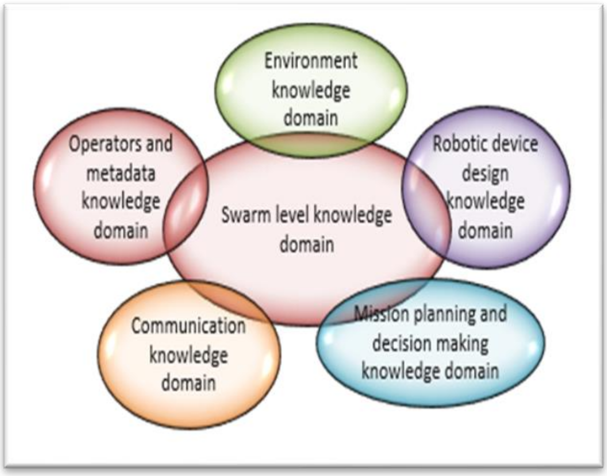

Figure 1. Level 0 ss-bots ontology

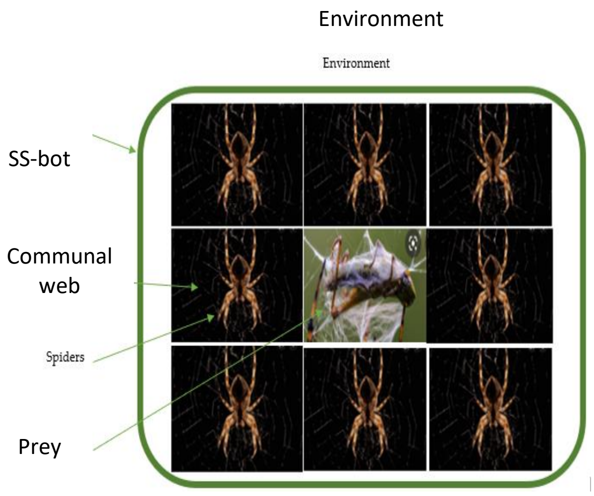

Figure 2. The environment

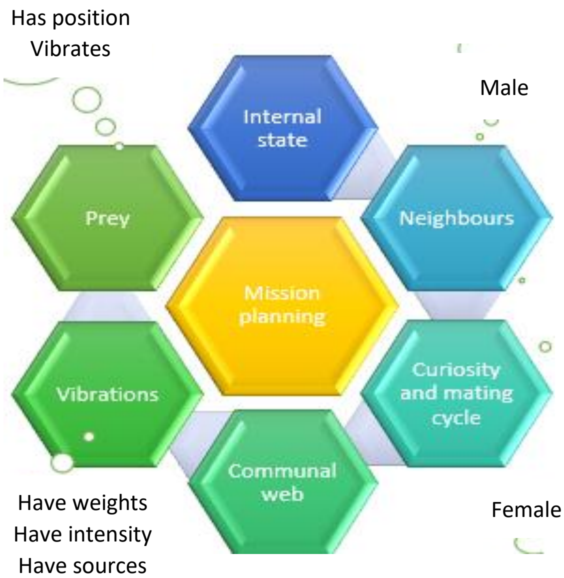

Figure 3. Mission planning in nanites

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The female SS-bots exert curiosity and anxiety to mission planning SS-bots. Vibrations originate from prey or other SS-bots in the swarm. The decision by an SS-bot to move is, therefore, triggered by other SS-bots around, the vibrations they generate, prey, and all other mission planning factors such as vibration weight, intensity, source, and the gender of the source SS-bot.

Two entities stand out under the communication aspect. These are the web and vibrations (see Figure 4). While the web is a communication medium, vibrations are the signals transmitted via the web. Vibrations are generated at various sources with specific frequencies, intensities, and attenuations. Sources of vibrations are the SS-bots or prey. These sources have specific positions on the web. The intensity of the vibration depends on the distance of the source, gender, curiosity, and the weight. Prey generated vibrations are stronger than those generated by SS-bot. Vibrations from nearby sources are relatively stronger than those from a distance.

The architecture of an SS-bot connotes four parts (see Figure 5). SS-bots have memory, sensory abilities to detect vibrations, gender to stipulate the role, and weight.

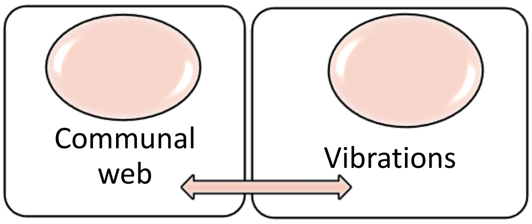

Figure 4. Communication knowledge

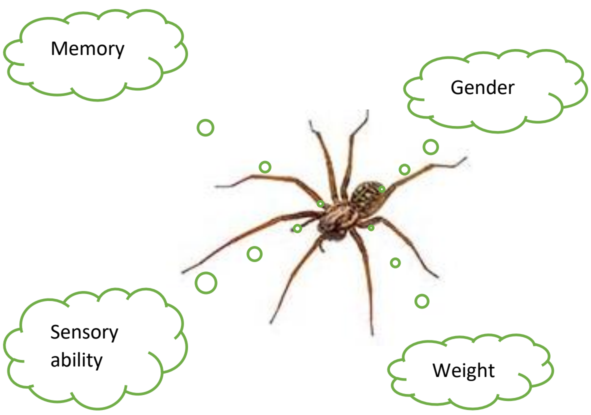

Figure 5: SS-bot design

A collection of operators and metadata define the last aspect of an SS-bot ontology. This is where we keep knowledge about best fit members, worst fit members, and their positions. Although the key decisions are based on the vibrations and other implicit metadata such as the ability of SS-bots to distinguish between vibrations from prey, male, and female SS-bots, these attributes aid decision making in SS-bots and in the entire swarm. Thus, the survival of a swarm depends on the strength of the community of fitter members. Eventually, weak members would be replaced by the offspring of fitter members, updating the shared memory of the swarm with data about fitter members.

Between the distinct aspects of the ontology there is transfer of vital swarm knowledge. For example, vibrations are shared through the web to be used by SS-bots to generate knowledge that influence decision making and internal state. The ability of SS-bots to distinguish vibrations from the prey from those from other SS-bots change SS-bots' features in every movement step (such as weight, position, curiosity, anxiety).

5. Conclusion

We have formalized the representation of SS-bots knowledge in the form of an ontology. Unfolding the elements of such an ontology together with the entities and relations associated with such swarms is essential for providing a detailed modelling space that can be applied to other swarm intelligence contexts. In fact, explaining this goal-orientated ontology and presenting its design can propel related application-specific modelling.

5.1. Contributions

Three contributions characterize this study as follows:

- The paper presented a formal understanding of the key entities key in the design of an SS-bot ontology. This literature extends content.
- This work gives a baseline upon which other studies aimed at understanding knowledge representation in other swarm contexts will be built. Representing swarm knowledge in the form of an ontology creates the building blocks for heterogeneous swarm ontologies.
- Although the focus was on understanding the elements of an ontology for coordinating homogeneous SS-bots, the work presents a new method for describing swarm systems.

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5.2. Future Work

Four ambitious directions for future work noted as follows:

- An experiment to corroborate this knowledge representation approach is pending.
- The SS-bot ontology could be extended by incorporating applicable knowledge domain to cover certain use cases. Precisely, the SS-bot ontology should be assessed further for applicability, extensibility, and expandability.
- Integrating the SS-bot ontology with other swarm intelligence ontologies to, eventually, create a heterogeneity is pending.
- More knowledge domains can be considered for the SS-bot ontology to include mission planning under uncertainty, dealing with incomplete data, managing vague, inaccurate, inconsistent, and imprecise situations.

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Clustering of the West African Starchy Roots and Tubers using Nutritive Value

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Abstract
The objective of this study was to sub-group the West African starchy roots and tubers' food sources according to their nutritive values. The *k*-means algorithm was deployed on a dataset consisting of starchy roots and tubers food items extracted from the West African Food Composition Table. Various measures of evaluating clustering validity were employed and the results showed that the clustering was valid. Three clusters were extracted, each consisting of food sources that are very similar in nutritive value. Findings prove that in terms of nutritive value, some kinds of yam and cassava could be classified together, while some kinds of sweet potato and cocoyam could also be classified together, and so on. The clusters can be explored by nutritionists, dieticians, food processing enterprises, and food scientists to find alternative food sources when their original choices are unavailable. Though clustering validation showed that food sources within the same cluster are significantly similar on a general note, a future study is required to research on the extent to which food sources within the same cluster are similar to each other at a granular level.

Keywords: Starchy roots and tubers, nutritive value, West African food composition table, *k*-means clustering, clustering validation

1. Introduction

Starchy roots and tubers include all plants that store edible starch material in roots, subterranean stems, rhizomes, corms, and tubers. Some examples include yam, cocoyam, cassava, sweet potato, and taro. Starchy roots and tubers are valuable food sources with carbohydrates as the major nutritive content and energy source (Chandrasekara & Kumar, 2016; Ugwu, 2009). Cassava, sweet potato, and potato form up to 90 per cent of the global cultivation of roots and tuber food sources (Chandrasekara & Kumar, 2016).

The data from the West African Food Composition Table (WAFCT), authored by the Food and Agriculture Organization of the United Nations (FAO), indicate that eight types of starchy roots and tubers are cultivated across the West African subregion (FAO, 2012). These are cassava, cocoyam, potato, sweet potato, taro, tiger nut, water yam, and yam. Information is provided regarding the nutritional content of these food sources both in the raw forms and their products such as flour, boiled without salt, as well as in dried forms. Apart from nutritional values per edible portion, energy, water, protein, fat, carbohydrate, fibre, and ash, information is provided with respect to the content of mineral nutrients such as calcium, iron, magnesium, and so on (Atsa'am et al., 2021; FAO, 2012).

It is important to point out that though these food sources belong to the same class of starchy roots and tubers, their nutritive values are not similar across the board. For instance, it is possible for a certain variety of cassava to exhibit more similarities to a certain variety of yam than to another variety of cassava. However, the criteria adopted for classification in WAFCT is very rigid, such that starchy roots and tubers have been categorized into static classes based on crop type. The classification did not contemplate the similarities among food sources of different crops. Against this backdrop, the objective of this study was to deploy an unsupervised machine learning method to establish segments among the West African starchy roots and tubers. Specifically, the study employed *k*-means clustering (Morissette & Chartier, 2013; Slonim, Aharoni, & Crammer, 2013; Tzortzis & Likas, 2014; Xu & Wunsch, 2009) to subgroup starchy roots and tubers and their products into clusters according to inherent similarities in nutritional and mineral contents. The results of the study could be useful in the selection of raw materials for food processing, and in the formulation of dietary and nutritional guidelines.

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The rest of the paper is structured as follows: Section 2 reviews existing literature where clustering was employed in food science research; Section 3 presents the research data, modeling tool, and the analytical approach; Section 4 presents the experiments conducted to extract clusters from the research data and the results; Section 5 evaluates and discusses the clustering results; and Section 6 concludes the paper.

2. Related Works

Previous studies have employed clustering for research in food science and technology. A review study by Balakrishna, Manda, Mwambi and van Graan (2022) examined existing literature that employed statistical methods in the analysis of Food Composition Databases (FCDB). The research found that 37.5 per cent of the research in this area employed cluster analysis to subgroup similar food items (Balakrishna et al., 2022).

A study by Windham, C., Windham, M., Wyse, and Hansen (1985) used clustering to subgroup foods based on nutrient content. Dairy, grain, and fat food sources were clustered using similarity in nutrients such as vitamin B-6, calcium, iron, and magnesium. Furthermore, natural cheese and whole milk were clustered based on nutrient, fat, and sodium content. On the other hand, whole wheat breads, pumpernickel bread, and pancakes were clustered based on nutrient, cholesterol, sugar, fat, and sodium content (Windham, et al., 1985).

In another study, Atsa'am et al., (2021) deployed *k*-means cluster analysis to extract six clusters of cereals food sources from the West African subregion. Clustering was done based on similarity in energy, carbohydrate, protein, fat, fibre, and so on. Furthermore, a cross-sectional study by Guiné et al., (2020) extracted three clusters from a sample of 6,010 participants. The study was to evaluate the knowledge level of the participants on the benefits of dietary fibres. The clusters include (i) those that had good knowledge about the sources and health benefits of dietary fibres, (ii) those with a good knowledge about the sources, but a poor knowledge about the health benefits of dietary fibres, (iii) those with a poor knowledge about both the sources and health benefits of dietary fibres.

A study by O'Hara, O'Sullivan and Gibney (2022) deployed *k*-means clustering on the 2008–2010 Irish National Adult Nutrition Survey (NANS) data to segment the participants based on the commonly consumed meals. Clusters were established indicating similarities in nutritional content and portions of foods consumed both at the individual and population levels. Three clusters were extracted, namely, high, adequate, and low, reflecting the nutritional quality of the meals often consumed (O'Hara et al., 2022).

It could be observed that though cluster analysis has previously been conducted in food science research, no specific research has covered starchy roots and tubers food sources from the West African subregion. The present study sought to address this gap.

3. Methodology

The research data and modeling tool are described in this section. Further, the analytical approach and procedures followed in data preprocessing are presented.

3.1 Data on starchy roots and tubers from the WAFCT

The WAFCT is made up of food sources found across nine West African countries. The data were generated from academic papers, theses, dissertations, and food composition tables of individual West African countries (FAO, 2012). The data used in this study are a subset of the WAFCT which consists of information on starchy roots and tubers and their products. A total of 102 records containing the nutritive values of raw cassava, cocoyam, potato, sweet potato, taro, tiger nut, water yam, yam and their products make up the research data. The data variables, which are basically nutrients, are shown in Table 1. The values entered for each variable are average values per 100g edible portion.

Table 1. Data variables (FAO, 2012)

Nutrient	Unit	Nutrient	Unit
Edible portion	ratio	Zinc	mg
Energy	kj, kcal	Copper	mg
Water	g	Vitamin A	mcg
Protein	g	Retinol	mcg
Fat	g	Beta-carotene equivalents	mcg
Carbohydrate	g	Vitamin D	mcg
Fibre	g	Vitamin E	mg
Ash	g	Thiamin	mg
Calcium	mg	Riboflavin	mg
Iron	mg	Niacin	mg

ISBN: 978-99949-0-888-2

Magnesium	mg	Vitamin B6	mg
Phosphorous	mg	Folate	mcg
Potassium	mg	Vitamin B12	mcg
Sodium	mg	Vitamin C	Mg

3.2 Modeling tool

The R programming software, version 4.1.3, was utilized in this study for modeling. The *kmeans* function, available in the *cluster* package, was deployed for assessing the optimal number of clusters and cluster extraction. Further, the *tidyverse* and *factoextra* packages in R were used for efficient data manipulation and visualization.

3.3 Data preprocessing

The observations, with a missing value in any of the variables shown in Table 1, were eliminated during data cleaning. A total of 34 records were retained for clustering. Further, the cleaned data was normalized using min-max normalization (Atsa'am, 2020; Bodur & Atsa'am, 2019) where all data points were transformed to a uniform scale with values ranging between zero and one (Jain, Shukla, & Wadhvani, 2018; Pandey & Jain, 2017). It was necessary to normalize the research data because of the disparity in the measurement units and the presence of outliers in some variables such as energy, water, and carbohydrate. For instance, the unit of edible portion is ratio, energy is recorded in kilojoules (kj) and kilocalories (kcal), protein is recorded in gram (g), while the mineral elements are recorded in either milligram (mg) or microgram (mcg). Data normalization effectively converted all units into the same scale to enhance clustering accuracy.

3.4 Optimal number of clusters

Prior to cluster analysis proper, the elbow method (Marutho, Handaka, & Wajiya, 2018; Shi et al., 2021) was deployed on the normalized data to ascertain how many clusters to extract from the data. The elbow method executes the *k*-means algorithm on a given dataset for different *k* values and then plots the within-cluster sum of squares corresponding to each *k* on a curve (Marutho et al., 2018). The *k* value where an elbow is located on the curve determines the optimal number of clusters (Atsa'am & Wario, 2022; Atsa'am, Wario, & Okpo, 2020; Marutho et al., 2018). The elbow plot on the research data is shown in Figure 1.

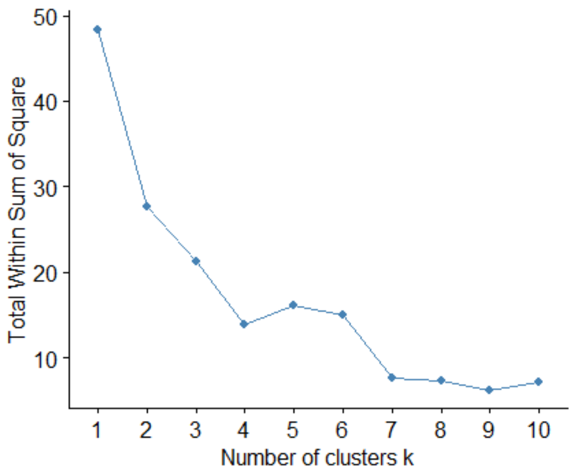

Figure 1. Elbow plot of optimal number of clusters

4. Experiments and Results

From Figure 1, it could be observed that 3 or 4 might be the suitable sizes of *k* to extract from the experimental data. Consequently, two experiments were separately conducted using $k = 4$ and $k = 3$ and the results were examined.

The *kmeans* function in the R *cluster* package was invoked, setting *k* to 4. Four clusters were generated, yielding the cluster plot shown in Figure 2.

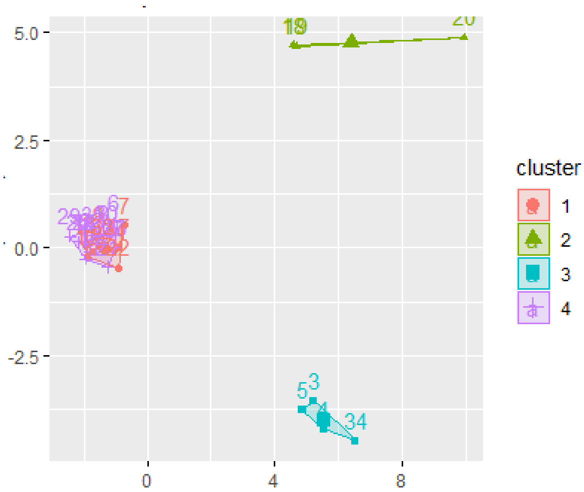

Figure 2. Cluster plot for four clusters

From Figure 2, it could be observed that setting $k = 4$ did not produce a good clustering, as clusters 1 and 4 are not well separated from each other. A valid clustering requires that any two clusters must be well separated from each other, which is an indication of a maximized inter-clusters dissimilarity (Atsa'am et al., 2020). Following the invalidation of the clustering with $k = 4$, *k* was set to 3 and the clustering procedure was repeated, generating the cluster plot in Figure 3.

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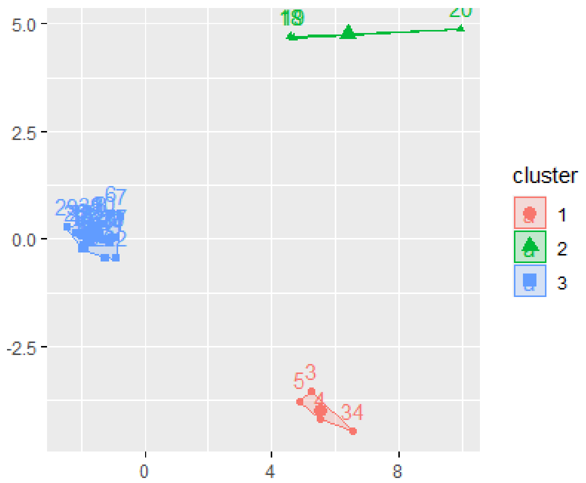

Figure 3. Cluster plot for three clusters

The clustering result in Figure 3 shows that the three clusters are well separated from each other, thus validating an optimal inter-clusters dissimilarity. Consequently, clustering of the starchy roots and tubers food sources was established with three clusters. The distribution of the food sources across the three clusters is shown in Table 2.

Table 2. Food sources distribution across clusters

Cluster 1		
S/No	**WAFCT Code**	**Food source**
1	02_002	Cassava, tuber, dried
2	02_021	Cassava sweet, tuber, dried
3	02_004	Cassava flour
4	02_036	Yam, tuber, flour
Cluster 2		
S/No	**WAFCT Code**	**Food source**
5	02_024	Tiger nut, tuber, raw
6	02_025	Tiger nut, tuber, boiled - without salt
7	02_026	Tiger nut, tuber, dried
Cluster 3		
S/No	**WAFCT Code**	**Food source**
8	02_001	Cassava, tuber, raw
9	02_003	Cassava, tuber, boiled - without salt
10	02_005	Cocoyam, tuber, raw
11	02_006	Cocoyam, tuber, boiled - without salt
12	02_009	Potato, raw
13	02_010	Potato, boiled - without salt
14	02_022	Sweet potato, pale yellow, raw
15	02_023	Sweet potato, pale yellow, boiled - without salt
16	02_013	Sweet potato, yellow, raw
17	02_014	Sweet potato, yellow, boiled - without salt
18	02_011	Sweet potato, deep yellow, raw
19	02_012	Sweet potato, deep yellow, boiled - without salt
20	02_015	Taro, tuber, raw
21	02_016	Taro, tuber, boiled - without salt
22	02_017	Water yam, tuber, raw
23	02_018	Water yam, tuber, boiled - without salt
24	02_019	Yam tuber, raw
25	02_020	Yam, tuber, boiled - without salt
26	02_027	Yam, tuber, Isu akoko, raw - Nigeria
27	02_028	Yam, tuber, Isu oko, raw - Nigeria
28	02_029	Yam, tuber, Amara, raw (Nigeria)
29	02_030	Yam, tuber, Chika, kundu, raw - Nigeria
30	02_031	Yam, tuber, Isu Abuja, raw - Nigeria
31	02_032	Yam, tuber, Pepa, raw - Nigeria
32	02_033	Yam, tuber, Giwa, raw - Nigeria
33	02_034	Yam, tuber, combined cultivars, raw - Nigeria
34	02_035	Yam, tuber, combined cultivars, boiled - without salt (Nigeria)

The implication of the clusters shown in Table 2 is that all the food sources within the same cluster have a similar nutritive value. Conversely, all the food sources in different clusters are dissimilar in nutritive value.

5. Evaluation and discussion

The validity of the clustering was evaluated using several measures. In Table 3, the variability (Atsa'am et al., 2021) of the nutritive values of the food sources in different clusters were validated using mean squares and F tests.

ISBN: 978-99949-0-888-2

Table 3. Clustering validation with variability

Nutrient	**Mean Square**	**F**	***P***
EdiblePortion	0.765	4.050	0.027
Energy	0.960	160.116	0.000
Water	1.407	168.492	0.000
Protein	0.493	30.937	0.000
Fat	0.731	214.255	0.000
Carbohydrate	1.068	169.628	0.000
Fibre	0.312	11.287	0.000
Ash	0.843	74.352	0.000
Ca	0.760	59.633	0.000
Fe	0.600	70.138	0.000
Mg	0.718	198.689	0.000
P	0.805	115.992	0.000
K	0.117	4.459	0.020
Na	0.964	24.661	0.000
Zn	0.341	25.186	0.000
Cu	0.236	9.961	0.000
VitE	0.986	85.958	0.000
Thiamin	0.292	2.522	0.007
Riboflavin	0.595	11.420	0.000
Niacin	0.781	34.877	0.000
VitC	0.256	4.916	0.014

As could be observed from Table 3, each nutrient yielded a value of $P < 0.05$, indicating that food sources within the same cluster have significantly similar nutritive values, while food sources within different clusters have significantly dissimilar nutritive values across all the nutrients. Furthermore, the final cluster centers were plotted on a bar chart to examine the validity of clusters' separation – see Figure 4.

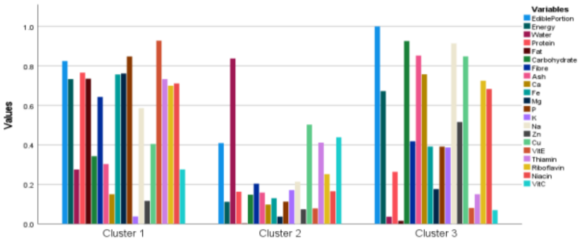

Figure 4. Bar chart of final cluster centers

Figure 4 indicates that the mean value for each nutrient in all the clusters are dissimilar. This proves that the clusters are well separated (Atsa'am et al., 2020).

Some common characteristics of the food sources across the three clusters were deduced as follows:

Energy: Food sources in cluster two contain a higher amount of energy, followed by those in cluster one, while food sources in cluster three contain a comparatively least amount of energy.

Water: Cluster three food sources contain a relatively higher amount of water, followed by those in cluster two and the least in cluster one.

Protein: Cluster two food sources contain a relatively higher amount of protein, followed by those in cluster two, while those in cluster three contain a lower amount of protein.

Carbohydrate: Food sources in cluster one contain a relatively higher amount of carbohydrates, followed by those in cluster two, and the least amounts by those in cluster three.

Fibre: Cluster one food sources contain a relatively higher amount of fibre, followed by those in cluster two and lastly, those in cluster three.

Ash: Food sources in cluster one contain a relatively higher amount of ash, followed by those in cluster two and lastly, the cluster three food sources.

The clustering in this study has practical implications in food labeling, nutritional and dietary guidelines, raw materials, and specimen selection. For example, a food processing factory that depends on a particular raw material because of its carbohydrate content could conveniently find another alternative in cluster one when their primary choice is not available or unaffordable. Furthermore, the findings of this study have added another dimension to how starchy roots and tubers can be classified. The WAFCT categorized these food sources into static classes as cassava, cocoyam, potato, sweet potato, taro, tiger nut, water yam, and yam. The present study has proved that when it comes to nutritive value, some kinds of yam and cassava could be classified together, while some kinds of sweet potato and cocoyam could be classified together, and so on – see Table 2. This has effectively eliminated the static taxonomy where cassava food sources were strictly classified under cassava, and yam food sources were strictly classified under yam, and so on.

6. Conclusions

The WAFCT classified starchy roots and tubers into static classes based on crop type, without considering the similarities between food sources of different crops. This study exploited the differences that exist in the nutritive values of food sources from the same crop type on the one hand, and the similarities among nutritive values of food sources from different crops, on the other hand, to develop a new classification. Three clusters were extracted, each consisting of food sources with similar nutritive values irrespective of crop type. The findings from this study show that it is not true that all food sources from the same crop will always be classified together. This is because a food source from a certain crop could exhibit similarities to a food source from another crop, more than those from the same crop. The clusters can be explored by nutritionists, dieticians, food processing enterprises, and food scientists to find alternative food sources when their original choices are unavailable. Clustering validation showed that food sources within the same cluster are significantly similar, generally. In a future study, the extent to which food sources within the same cluster are similar to each other should be researched at a granular level.

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A Comparative Study of Wind Energy Conversion System incorporating the Doubly Fed Induction Generator and the Permanent Magnet Synchronous Generator

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Abstract
The renewable energy power producer (RPP) sector is growing rapidly to become an important source of power in South Africa and in nations across the globe. Companies within this sector provide a variety of clean energy sources. Despite its ability to support the power system and conserve the environment that sustains life, the rising usage of renewable distributed generators (RDGs) poses power quality problems in the overall distribution network, such as the voltage instability at buses, the increase in voltage/current harmonic distortions, etc. Furthermore, RDGs are required to remain connected to the electrical power network during grid faults and provide system support by injecting reactive current when required, depending on the nature of the fault. This study provides a dynamic performance analysis of a doubly fed induction generator (DFIG) based wind energy conversion system (WECS), and permanent magnet synchronous generator (PMSG) based WECS. The potential fault ride-through capability solutions in grid code power generation and injection of reactive power are taken into account, and the application results of both systems are shown under similar working conditions. From the simulation results, it is found that the DFIG based WECS topology performed well compared to the PMSG based WECS topology.

Keywords: Fault-ride through capability, doubly fed induction generator, permanent magnet synchronous generator, wind energy conversion system.

1. Introduction

In this contemporary region, the contribution of thermal power plants to environmental pollution and global warming has become a serious economic issue. This has led academics to look for ways to generate electricity without using carbon as an alternative to the ways that are currently used (Qazi et al., 2019), (Olson-Hazboun, 2018). Wind energy conversion systems (WECS) are one of the most enticing renewable distributed generators (RDGs) due to their broad availability and the financial benefits associated with high power generation (McKenna et al., 2022). This RDG can be categorized into two technologies: doubly fed induction generator (DFIG)-based WECS, or permanent magnet synchronous generator (PMSG)-based WECS (Gupta & Shukla, 2022), (Ouyang et al., 2019), (Nadour et al., 2020). The increasing use of RDGs poses power quality problems in the overall distribution network, such as the voltage instability at buses, the increase in voltage/current harmonic distortions, etc., despite their ability to support the power system and preserve the environment that sustains life. The standard grid code defines the technical standards for connecting RDGs to the power system to assure the safety, security, and proper operation of the entire power system. Grid code specifications include the limit of voltage variations (i.e., +/-1 pu), the limit of frequency variations (i.e., +/-5%), the limit of current/voltage harmonic distortions (i.e., total harmonic distortion voltage (THDv) of 0.1% and total harmonic distortion current (THDi) of 5%), and the limit of power factor (i.e., Pf = 0.9-0.95), (Voglitsis et al., 2016).

In the past, if there was a problem with the power grid, RDGs could be disconnected from it avoid serious damage. Nevertheless, in the present day, RDGs are expected to remain connected during grid failure and provide grid support. Grid code requirements are used to effectively describe the technical details of RDGs that are connected to the power system (Sewchurran & Davidson, 2016). In accordance with South Africa technical grid-code regulations, RDGs are obliged to inject reactive current during voltage instability to aid in voltage recovery and maintain a continuous real power supply (Akinyemi et al., 2022), (Chapagain et al., 2021).

RDGs are mandated to take reactive power from the grid whenever there is a system-wide rise in reactive power. The three most important standard grid codes are the ability to ride through low voltage, the ability to control frequency, and the ability to control voltage (Tarafdar Hagh & Khalili, 2019), (Mohseni & Islam, 2012). This paper is organized as follows: Section 2 contains results and analysis, and Section 4 contains a conclusion of results work.

2. System Modelling of Wind Energy Conversion System

The power generated by a wind turbine is related to the size of the blades diameter as they move through the wind (Yossri et al., 2021). Furthermore, the output power of a wind turbine is precisely related to the cube of wind speed. Federal law prohibits wind turbine generators from having an efficiency greater than 59.9 percent (Newman, 1986), (Raju & Pillai, 2015). The following formulas demonstrate the mechanical power and rotational force that can be generated by a wind energy conversion system. The power coefficient (C_p) represents the quality of available wind energy:

$$C_p = 0.22\left(\frac{11}{\gamma} - 0.4\beta - 5\right) - \ell^{\frac{116}{\gamma}} \tag{1}$$

Where β denotes the pitching angle and γ denotes the tip speed ratio.
Mechanical Energy is generated by wind turbines in the following ways:

$$P_m = \frac{1}{2} * p * a * v^3 * c_p(\lambda * \beta) \tag{2}$$

Where p is the air density, v is the wind speed, a is the rotor blade area, and C_p is the power coefficient. The following equation gives the mechanical torque of the wind turbine:

$$T_m = \frac{P_m}{\omega} \tag{3}$$

2.1 Modeling of DFIG-based WECS

The WECS power converter consists of a rotor converter for controlling the generator's speed and a grid converter for injecting reactive current into the grid. The grid- connected DFIG based WECS is depicted in Figure 1.

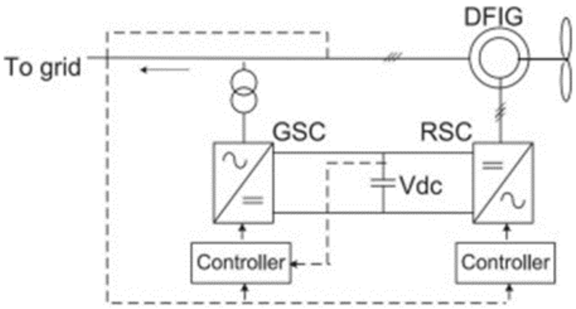

Figure 1. DFIG-based WECS(Ntuli et al., 2022).

Figures 2 and 3 show how to use a d-q reference frame to show the traditional ABC form in a DFIG.

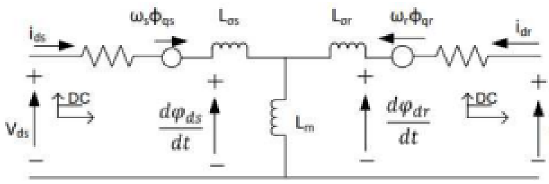

Figure 2. d-axis model of a DFIG(Ngom et al., 2018).

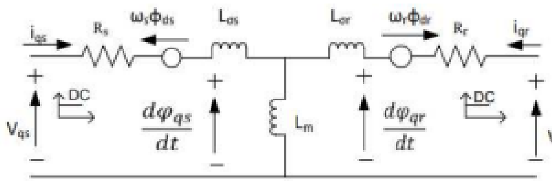

Figure 3. q-axis model of a DFIG(Ngom et al., 2018).

As depicted in figure 4, the RSC is achieved within a rotating d-q axis frame with the d-axis lined up with the position of the fixed coil flux vector.

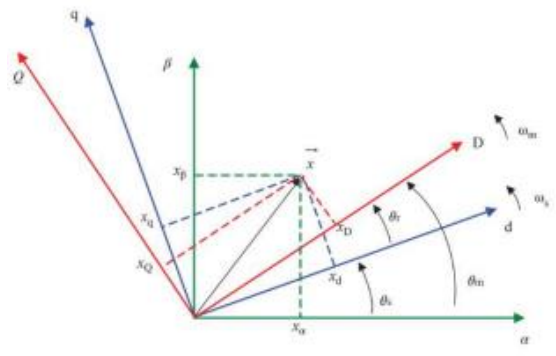

Figure 4. Three non-identical revolving reference frames(Al Zabin & Ismael, 2019).

The dynamic equations for the voltages and flux connections in a three-phase DFIG can be expressed as follows in a synchronously rotating direct-quadrature (d-q) reference frame

$$v_{ds} = r_s i_{ds} + \frac{d}{dt}\varphi_{ds} - \omega_s \varphi_{qs} \tag{4}$$

$$v_{dqs} = r_s \left| i_{qs} + \frac{d}{dt}\varphi_{qs} + \omega_s \varphi_{ds} \right. \tag{5}$$

$$Q_s = \frac{3}{2}(V_{sq} * i_{sd} - V_{sd} * i_{sq}) \tag{6}$$

$$P_s = \frac{3}{2}\left(V_{sd} * i_{sd} + V_{sq} * i_{sq}\right) \tag{7}$$

Due to the constant stator voltage, Iqr and Idr govern the stator's active and reactive power, respectively. The rotor voltages can be expressed as a function of the rotor currents, resulting in the following formulas:

$$V_{dr} = R_r I_{dr} + \frac{d}{dt}\varphi_{dr} - \omega_r \varphi_{dr} \tag{8}$$

$$V_{qr} = R_r I_{qr} + \frac{d}{dt}\varphi_{qr} + \omega_r \varphi_{dr} \tag{9}$$

$$\varphi_{dr} = l_m * i_{ds} + l_r * i_{dr} \tag{10}$$

$$\varphi_{qr} = l_m i_{qs} + l_r i_{qr} \tag{11}$$

Where Vds denotes direct-axis stator voltage, Vqs denotes quadrature-axis stator voltage, and Ids denotes direct-axis stator current. Iqs denotes the current flowing through a quadrature-axis stator. Lds represents stator inductance along the direct axis, Lqs represents stator inductance along the quadrature axis, and Lm denotes mutual inductance between the stator and rotor. Rs is the resistance of the stator, and ω_s is its rotational frequency.

2.2 Permanent Magnet Synchronous Generator

Figure 5, depicts a grid-connected permanent magnet synchronous generator. To create a computational formula for the PMSG, the following assumptions must be made: The PMSG conductivity at zero, sinusoidal induced electromotive force, power losses at a minimum, and zero field dynamics. Nonetheless, during power system disturbances, PMS-based WECS exhibits higher DC-link voltage (Van & Ho, 2016). The following are the mathematical voltage equations:

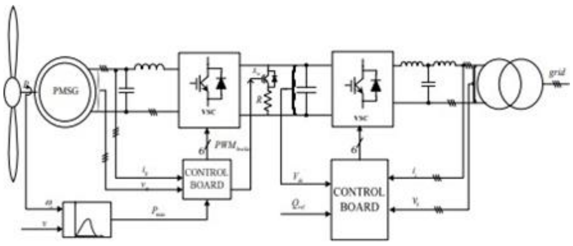

Figure 5. PMSG-based WECS(Li et al., 2010).

$$v_{ds} = -R_s i_{ds} + w_r L_q i_{qs} - L_d p i_{ds} \tag{12}$$

$$v_{qs} = -R_s i_{qs} - w_r L_d i_{ds} + w_r \lambda_r - L_q p i_{qs} \tag{13}$$

3. Simulation results and analysis

This section provides a comparative analysis of the two WECS topologies: i.e. the PMSG-based WECS and the DFIG-based WECS. The simulation is conducted using the MATLAB/SIMULINK. When comparing the two topologies, a single line-to-earth fault was simulated on the middle phase (white phase) of the grid transmission network for duration of 1.5 seconds. This was undertaken to compare the performance of these technologies, as the RDGs are designed to inject reactive current under unbalanced grid voltages. Figure 6 depicts the wind velocity employed in this model. The wind farm system consists of three 1.5 MW wind turbines. Both systems are shown under identical settings. The simulation for both systems was run for 12 seconds under changing wind conditions.

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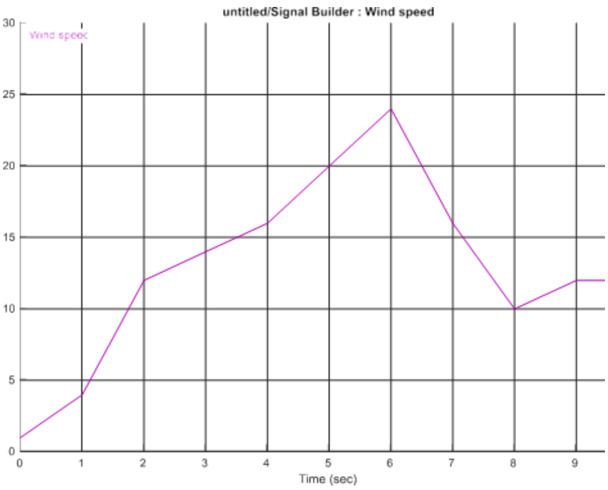

Figure 6. Wind speed signal.

Figure 7 clearly shows that there were oscillations on the active power at the startup of the PMSG. However, the overshoot was kept to a minimal. The active power in the grid was reduced to practically nil during the grid fault. As a result, it was reduced. At 5 seconds, the active power was practically at its maximum.

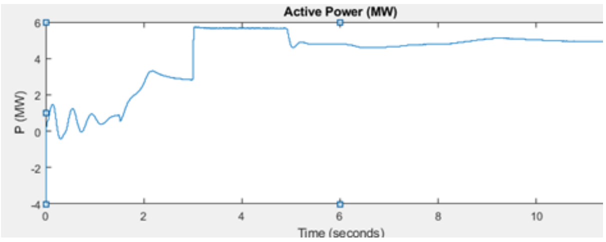

Figure 7. PMSG Active Power.

Figure 8 clearly shows that there were oscillations on the dc link voltage at initialization of the PMSG, and the increase in voltage magnitude about quadrupled the rated DC voltage. After the fault was cleared, the DC voltage was restored to its nominal value.

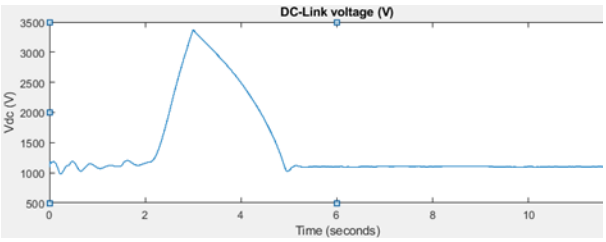

Figure 8 DC Voltage for PMSG..

Figure 9 depicts the voltage dips on the grid that were half the nominal value.

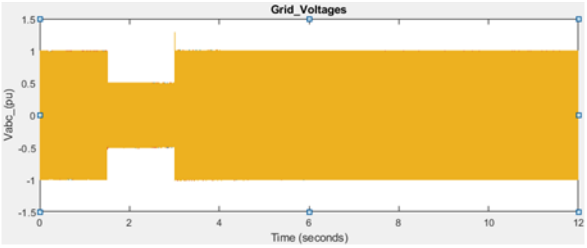

Figure 9. Grid voltage in PMSG based WECS.

Figure 10 depicts the pitch angle of the pmsg wind turbine. The pitch angle control is shown to have begun in the first 1.8 seconds of the experiment.

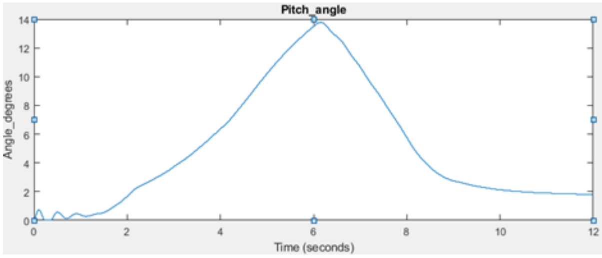

Figure 10. Pitch angle of PMSG based WECS.

Figure 11 depicts how reactive power was introduced into the grid during the fault incident. After the issue was resolved, the reactive power was reduced from 3.8 to 5 seconds of simulation time. However, after 5 seconds, it dropped below zero, suggesting grid absorption of reactive power.

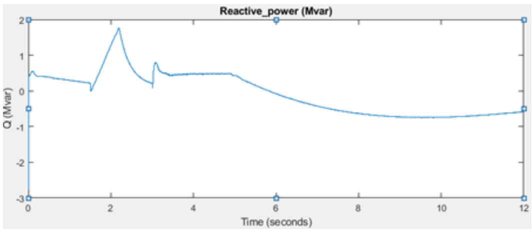

Figure 11. Reactive Power of PMSG based WECS.

Figure 12 shows that the pmsg rotor speed increased to nearly double the rated rotor speed. After 9 seconds of simulation, it was reset to its original value.

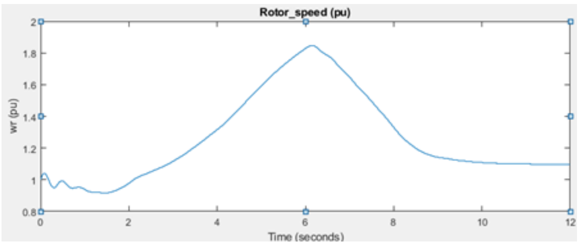

Figure 12. Rotor speed of PMSG.

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Between two and five seconds, the stator voltages of the PMSG rises by one pu. And the capture results are shown in Figure 13.

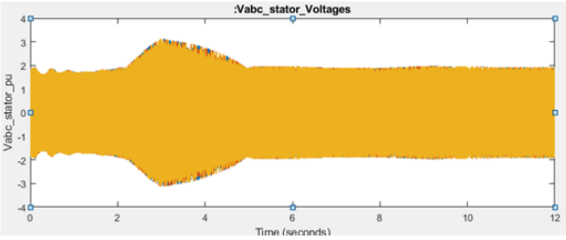

Figure 13. Stator voltage of PMSG.

Figure 14 shows that when there is a fault, the real power goes down to almost zero. Once the fault is fixed, the active power goes back to its nominal values. The optimal active power was reached in 8 seconds, and the wind farm system was working at full capacity.

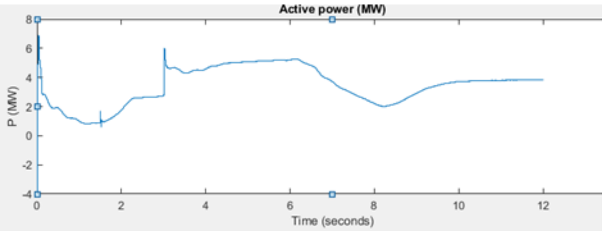

Figure 14. DFIG active power.

Figure 15 depicts the voltage dips on the grid that were half the nominal value.

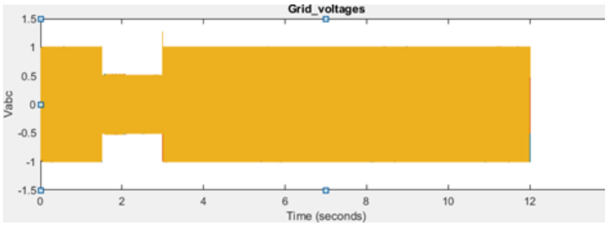

Figure 15. Grid voltages for DFIG based WECS.

Figure 16 indicates that the pitch angle control began shortly after the rotor speed exceeded its rated value and that it was disabled after 8 seconds because the DFIG was running at its optimal speed (rated speed).

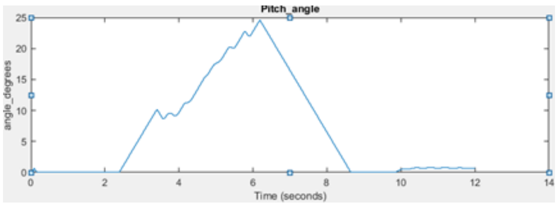

Figure 16. Pitch angle control for DFIG based WECS.

The fault-ride-through capability of the DFIG-based WECS is illustrated in figure 17. The model was capable of injecting the reactive power needed to return the power system to normal operating conditions. DFIG was able to retain zero reactive power when the fault was rectified.

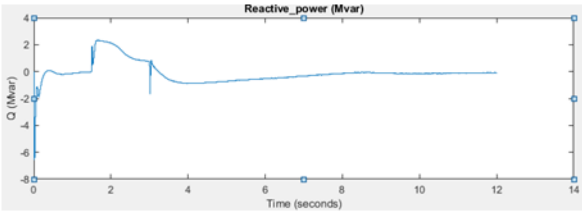

Figure 17. DFIG reactive power.

The rotor speed drooped during the grid failure, and after the fault was cleared, the rotor speed began to alter with the change in wind speed, as seen in Figure 18. The dfig was running at full speed after 10 seconds.

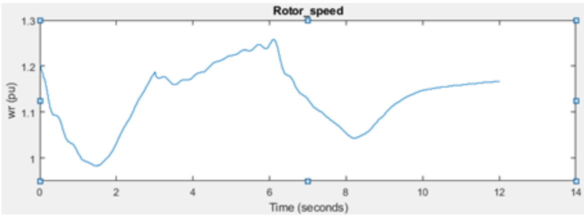

Figure 18. DFIG rotor speed.

During the fault occurrence, the DC link voltage was temporarily disrupted. It was, nevertheless, kept within the rated value as shown through Figure 19.

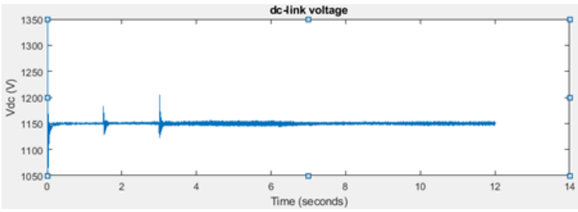

Figure 19. DFIG DC Link voltage.

Figure 20 depicts the voltage dips on the stator of DFIG that were 75 per cent the nominal value.

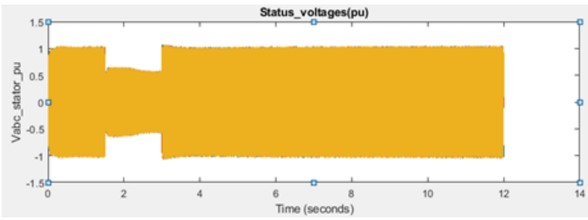

Figure 20. DFIG stator voltage.

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3.1 summarized results

This section provides an analysis of the dynamic performance of a DFIG-based WECS against a PMSG-based WECS. The capability solutions for grid-coded power generation have been analyzed, and the application results of both systems have been shown under identical working conditions. The results indicate that the DFIG-based WECS topology outperformed the PMSG-based WECS topology. Table 1 compares the two topologies.

Table 1.Summarized results.

Model Type	**DC-Link Voltage**	**Reactive Power (Mvar)**	**Active Power (MW)**
DFIF-based WECS	It enables robust management of DC-link voltage during grid disruptions in terms of overshoot. As a result, generator rotor damage is prevented.	By injecting reactive power, the model excels at bolstering the grid during faults. In addition, once the problem has been rectified, the system can operate at about 0 Mvar, as required by standard grid code.	During grid faults, the active power of the system was drastically decreased, but once the fault was resolved, the system resumed normal operation. Consequently, active power has a significant impact on power system frequency.
PMSG-based WECS	The DC-link voltage is approximately three times the reference voltage. This could lead to system destruction. It also requires additional precautions.	The model can handle the reactive power needs of the grid. However, once the fault has been rectified, it cannot operate at 0 Mvar as per grid code regulations.	In terms of active power supply, the model is more resilient than the recommended method. The performance of DC-link voltage and reactive power, however, makes the DFIG-based WECS superior to the PMSG-based WECS.

4. Conclusion

This research work is dedicated to study the impact of grid disturbance on PMSG and DFIG systems. The various parameters, such as active power, DC link voltage, grid voltage, reactive power, stator voltages of PMSG and DFIG are shown in the event of the disturbance and the system results are shown for PMSG and DFIG. As a result, it is concluded that DFIG is more effective as a wind turbine generator in comparison to PMSG for a particular disturbance. The contrast can be summarized by saying that DFIG injected enough reactive power during the fault and maintained zero reactive power at the steady state condition. Furthermore, DFIG demonstrates a high level of capability in regulating DC link voltage to its nominal value when matched with PMSG under the same operating conditions. This indicates that DFIG is more stable than PMSG in the presence of varying wind speeds and, in the event of grid faults; hence it can be concluded that DFIG is more suitable and robust for wide wind speeds and for grid disturbances.

5. References

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An Hybrid Part of Speech Tagger for Setswana Language using a Voting Method

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Abstract
Part-of Speech (PoS) tagging is a corpus linguistics that deals with assigning appropriate lexical categories to each word in a sentence. To effectively address challenges associated with PoS tagging, several Natural Language Processing (NLP) tasks modelling techniques have been employed, including Conditional Random Fields (CRF), Support Vector Machines (SVM), and Decision Trees in diverse languages. These PoS taggers implement the process of associating the correct PoS (nouns, verbs, adjectives, adverbs, etc.) with each word in a sentence. However, creating language resources is an expensive process for many languages, including the indigenous languages of South Africa that are classified as resource-scarce. Therefore, using Setswana as a language with limited resources, this study explores and applies methods to increase the utilization of existing resources and tagger accuracy. This is done using Setswana's two PoS taggers: a Maximum Entropy (MaxEnt) and an SVM, which achieved an accurateness of 94.4 per cent and 95.59 per cent respectively. To find errors in the taggers, an error analysis is carried out. The Setswana PoS Tagger was then built using a voting algorithm to improve results and attain 97.06 per cent accuracy. The combination of taggers reduces the error rate by up to 2.01 per cent.

Keywords: PoS tagging, SVM, MaxEnt, Setswana, voting method

1. Introduction

PoS tagging is a process of assigning each word in the text with an appropriate lexical category. Words can have more than one lexical category which causes ambiguities, therefore PoS taggers are used to resolve this issue. There are several approaches for PoS tagging that have been proposed and successfully implemented for various languages such as Indo-European and Asian languages. However, African languages, which make up 30.2 per cent of the world's languages (Ayogu et al., 2017), with notable exceptions to other recent work on languages such as Arabic, Yoruba, Zulu, and Igbo, have not yet received much computational linguistics research.

Setswana is one of the eleven official languages of South Africa, spoken by 4,798,356 million people, which makes up 8.8 per cent of the population. Setswana is also spoken in other neighboring countries such as Botswana and Namibia (Kasieczka et al.,2019). Setswana is a resource scarce language with a disjunctive writing system. It is an agglutinative language where some words can be formed by adding suffixes and prefixes to the root word. (Dibitso et al.,2019). As with any other language, the main problem of Setswana PoS tagging is the ambiguities that may appear at different levels.

Despite the widespread use of the indigenous languages of South Africa, there is less research attention to enhancing the potential of those indigenous languages. Therefore, this study aims to enhance the tagging accuracy of PoS taggers in Setswana. A common technique to improve tagging accuracy is tagger combination (Kasieczka et al., 2019) and (Amri et al., 2017). This approach combines different taggers to take

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advantage of each tagger's unique properties and reduce errors. According to (Popović, 2018), the result of a combined classifier outperforms any of its constituent classifiers. Based on this finding, the combined part or phonetic tagger is expected to provide better accuracy than the single first-level word part tagger of which it is composed.

In this study, a CombiTagger, a language, and a target dataset, which is simply termed a tagset, is used to design and assess composite taggers. The considered algorithm uses the weighted voting technique to allow the hybrid algorithm to be used to enhance the performance of the proposed system (Henrich et a., 2009).

The remaining sections of this paper are arranged as: related works, The Setswana language, Data and Tagset, the approach used, experiment and results, and conclusion.

2. Related Works

Part of Speech (PoS) tagging is the process of assigning an appropriate lexical category to each word in a text. These lexical categories (also known as tags) carry grammatical information, and they are assigned to words to indicate the PoS concerning their use in a text (Alayiaboozar et al., 2019). The advantages of PoS tagging can be realized at three levels:

- Lexical level – identifies and analyses how words are structured and labeled at their external level (Zhang & Lin, 2021),
- Syntactic level − allows identification of syntactic-grammatical functions of words to assign their PoS entities accordingly (Song, 2019), and
- Orthographic level – this level distinguishes homographs used in the same or other similar texts to clarify their semantic functions

PoS tagging has gained much attention in the past, achieving great success, with many algorithms being developed. Before PoS tagging, assigning PoS tags to each word in a sentence was performed manually. This was time-consuming, laborious, and costly, hence a widespread interest in automating processes. Consequently, automated PoS tagging is a method for automatically annotating lexical categories. The procedure accepts a word or a sentence as input, assigns it with the correct tag, and produces the tagged text (Mohammed, 2020) and (Demilie, 2020). PoS tagging was first investigated during the sixties by (Harris, 1962) and (Klein & Simmons, 1963) using hand-written rules. Then in the seventies, (Greene & Rubin, 1971) implemented a TAGGIT tagger, which was originally used to tag the Brown corpus. Various approaches exist for applying PoS tagging techniques, and Figure 1 demonstrates some of them which are either supervised or unsupervised.

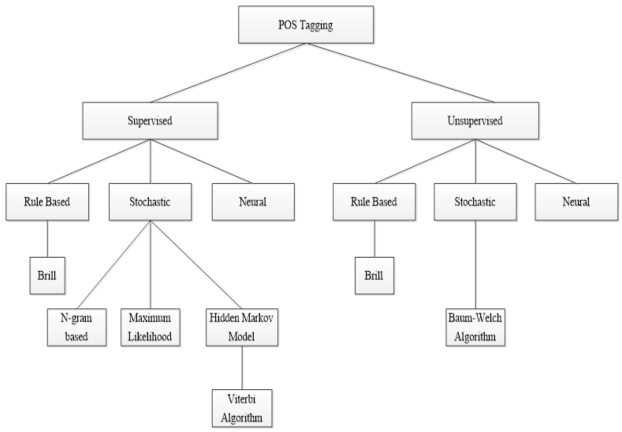

Figure 1. Classification of PoS tagging models (Latha, 2017)

In (Halteren et al., 2001), a comprehensive study was presented in which a full overview of prior combination attempts was provided, mostly utilizing machine learning techniques using the same corpus. After comparison, a variety of voting techniques and second-stage classifiers were used to aggregate their outputs. Every combination tagger performs better than its best component.

A closer look at the work done by (RamaSree & KusumaKumari, 2007) for the Telugu PoS tagger where they employed rule-based, Brill tagger, and maximum entropy techniques. The performance matrix adopted (accuracy) yield was 98.016 per cent, 92.146 per cent, and 87.818 per cent concerning the three adapted technique in their order of presentation. The taggers were trained using a corpus of 12000 words that had been annotated. When these techniques are compared with baseline machine learning, it was observed that overall error was decreased by 3 per cent for machine learning, and for Telugu rule-based, is recorded at 0.75 per cent.

In (Sjobergh, 2003), several PoS taggers were trained and tested on Swedish texts. These methods include voting, which allows taggers to change the contribution of votes based on their confidence and use the tagger's output to train new second-level classifiers. The Stockholm-Ume°a

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corpus (SUC), with 150 tags, was utilized as a dataset. The following taggers were put to the test: TreeTagger, Trigram HMM-tagger, Memory-based Tagger, Maximum Entropy Tagger, Transformation-based Tagger, and Stomp (Sjobergh, 2003). The combination of these tags has improved tagging accuracy, even when a simple method is used. In these tests, a 15 per cent to 18 per cent reduction in error was attained.

All these studies reach the same conclusion that, by integrating different learning systems, the machine learning field comes up with the idea of mixing classifiers to improve the accuracy of PoS tagging. These studies also demonstrated how to combine existing, openly accessible taggers, so that the combined taggers' accuracy exceeds that of their best solo counterparts.

3. The Setswana language, Data and Tagset

A. Setswana Language

Setswana belongs to the Sotho-Tswana subfamily group, which is related to Southern Sotho and Northern Sotho. These languages share similar dialects, beliefs, and social organizations (Berg et al., 2013). Setswana is also the national language in neighboring countries such as Botswana and Namibia.

As with any other language, Setswana contains words, phrases, and sentences that are ambiguous. Ambiguity refers to a word, sentence, or utterance that has more than one meaning, rendering what is meant unclear. In isolation, many words are vague, yet they have a strong contextual meaning making it difficult or impossible to understand without some extra context. For example, the following Setswana sentence example:

- tshela metsi

The above sentence is ambiguous because the word tshela can mean either pouring or jumping. Therefore, the sentence can either mean that he/ she is pouring water, or he/she is jumping the water. Another example of ambiguities is grammatical ambiguity (also known as syntactical ambiguity). This is the existence of more than one alternative meaning within a single sentence or sequence of words. For example, the following Setswana sentence.

- O ragile kgamelo

The sentence above can mean that the person has metaphorically ‘kicked the bucket’, meaning that he or she has died, or has literally kicked a bucket with a foot. Therefore, the context has an important influence in resolving ambiguities.

An annotated Setswana corpus that contains about 65784 tokens was used for this study. The corpus was sourced from government websites and documents (magazine articles, scientific articles, news articles, and prose articles). As reported in (Eiselen & Puttkammer, 2014) additional pre-processing was performed and verified using a spell checker, and thereafter reviewed by the language experts.

B. Data and Tagset

For the Setswana corpus, the Tagset used for annotation consisted of 128 tags, which were developed with the degree of granularity and refinement, guided by the EAGLES and Taljard & Bosch, (2006). The annotation was performed on token, morphosyntactic, and orthographic layers. Within the token layer, the corpus is then divided into sentences, paragraphs, words, etc. to ensure that the corpus is error-free, while the orthographic layer was used to make corrections. The morphological and morphosyntactic components were annotated using lemmatization techniques and these were done using available data provided by the score of South African research institutes/ universities (Eiselen & Puttkammer, 2014).

4. Our approach

This section outlines the specific methods such as SVM, MaxEnt and CombiTagger adapted within this work.

A. Support Vector Machine tagger

SVM is a common machine learning approach to supervised learning due to its robustness, powerful generalization capabilities, and unique global optimal solutions. Nonlinear algorithms, invented by (Cortes & Vapnik, 1995for classification and regression, can be tailored to a wide range of nonlinearities. Similar to neural networks, SVMs have demonstrated their effectiveness in several prediction and classification applications, which encourages researchers to further adapt these techniques to improve existing systems (Murthy & Bethala, 2021). Support vector machines were introduced in the late 1970s. According to (Vapnik & Izmailov, 2017), a typical model of learning consists of three central components: a generator of input vectors, a supervisor, and a learning machine.

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The primary goal of SVM is to partition the training set into different classes using a surface that maximizes the distance between them. The decision boundary between the two classes is optimized during the SVM classification training, which optimally creates a linear hyperplane within the two classes or objects, and this is defined within the feature space of the dataset. The SVM then uses this hyperplane to predict the new class of data objects presented by the feature vector (Cervantes et al., 2020).

Considering several arbitrary points, x within the domain of $y_i \in \{1, -1\}$, the two-dimensional space can be modeled with the hyperplane $\mathcal{H}$ as $\boldsymbol{w} \cdot \boldsymbol{x} = \boldsymbol{0},$ where $\boldsymbol{w}$ is perpendicular to the hyperplane. Figure 2 presents the pictorial representation of affirmational mathematical expression.

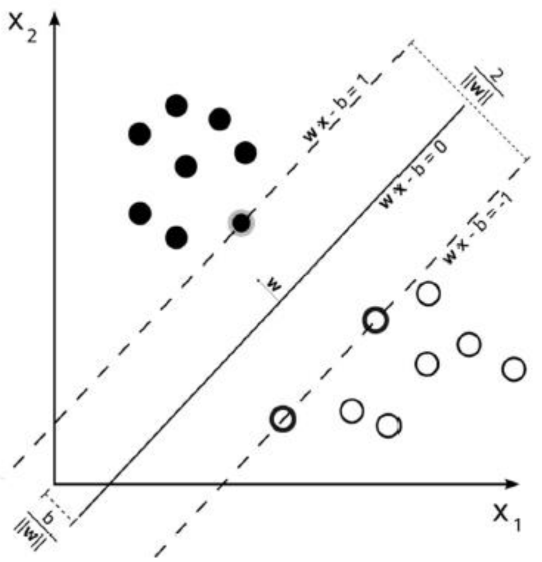

Figure 2. Maximum-margin hyper lane and margins for SVM (Deng & Wu, 2018).

For any arbitrary point represented by a vector $\boldsymbol{u},$ which could be on either side of the hyperplane $\mathcal{H}$, projection $\boldsymbol{u}$ onto $\boldsymbol{w}$ such the $\boldsymbol{w} \cdot \boldsymbol{u} \geq c$ and defining $c = -b$ gives the following decision rule:

$$\boldsymbol{w} \cdot \boldsymbol{u} + b \geq 0, +ve \tag{1}$$

Where $+ve$ are characterization.

Data classification is determined by the type of data separation. It can be both linearly separable data and non-linear data. SVMs require maximum boundary identification hyper traces when linearly separating classes. Confidence rises with increasing interclass distance when the intraclass variation classification is constant. The former is the simplest SVM because linear separations are easy to find.

The set of training vectors for the two classes in this instance can be separated non-linearly. The SVM literature proposes two further extensions to address hard-to-separate linear spaces: (1) by using soft margins, and (2) by transforming using kernels. The soft margin SVM by (Cortes & Vapnik, 1995) introduces an additional "slackening", where instance $\xi i \geq 0$ can be considered misclassified instances, and 0 otherwise (Yoon, 2018). Next, the optimization problem is rephrased as follows:

$$\min \frac{1}{2} ||\mathrm{w}||^2 + \mathrm{C} \sum \xi_\mathrm{i} \tag{2}$$

subject to:

$$\mathrm{y_i}(\mathrm{w} \cdot \mathrm{x_i} + \mathrm{b}) \geq 1\text{-}\xi_\mathrm{i} \tag{3}$$

Thus, the duality property of Eq. 3 provides the same solution to the problem at hand. It also indicates the optimization solution for the dot product $x_i, \cdot x_j$.Thus, we have the decision rule for any $\mathbf{u}_i$ that:

$$sgn(f(x, w, b)) \tag{4}$$

Considering $\xi \geq 0$, and where $C \sum \xi_i$ serves as a penalty for Eq.5. Then given a new instance x_i, the classifier $f(x) = sign(\boldsymbol{w} \cdot x_i + b)$.

The Lagrangian equivalent:

$$\mathrm{L} = \frac{1}{2} ||\mathrm{w}||^2 + \mathrm{C} \sum \xi_\mathrm{i} - \sum_{\mathrm{i}=1}^{\mathrm{n}} \alpha_\mathrm{i} [\mathrm{y_i}(\mathrm{w} \cdot \mathrm{x_i} + \mathrm{b}) - 1 + \xi_\mathrm{i}] - \sum \beta_\mathrm{i} \xi_\mathrm{i} \tag{5}$$

where the constraint $\sum \beta_i \xi_i$ is counted due to the non-negative constraint on $\xi \in [0, \infty]^n$.

The dual problem is shown as:

$$\max \sum_{i=1}^{n} \alpha_i - \frac{1}{2} \sum_{i,j=1}^{n} \alpha_i \alpha_j y_i y_j (x_i \cdot x_j) \tag{6}$$

subject to:

$$\sum \mathrm{a_i y_i} = 0, \text{and } \mathrm{a_i} \in [0, \mathrm{C}] \tag{7}$$

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and, such a quadratic programming problem has a strong duality, so solving this duality gives the same solution as the main problem. However, it is important to note here that the dual shows that the optimization problem essentially depends on the inner product (the inner product of the data vectors), $x_i, \cdot x_j$. Thus, we have the decision rule for any $\mathbf{u}_i$ that:

$$\sum \mathrm{a_i y_i x_i . u_i + b \geq 0 \text{ then } + ve} \quad (8)$$

This results in a “kernel trick”, using kernel functions to transform the original data points.

B. Maximum Entropy tagger
Apache OpenNLP is a Java open -source library that is utilized for Natural Language Processing (NLP), which uses the maximum entropy principle (Darwish et al.,2018). MaxEnt probability models provide a clear method for combining several pieces of contextual evidence and calculating the likelihood that a particular linguistic class will occur in a particular linguistic context with a contextual prediction as a function of:

$$\mathrm{cp: B \rightarrow \{true, false\}} \quad (9)$$

which return $true\, or false$, according to the occurrence or absence of a history $b \in \mathcal{B}$.

Assume a training set is represented by $\mathcal{T} = \{(a_1, b_1) \ldots (a_N, b_N)\}$, which is a large set of contexts $b_1 \ldots b_N$ that have been annotated with the correct classes $a_1 \ldots a_N$. One way to combine evidence is to “weight” the features by using them in a log-linear, or exponential model:

$$p(a|b) = \frac{1}{Z(b)} \prod_{j=1}^{k} a_j^{f_j(a,b)}$$
$$Z(b) = \sum_a \prod_{j=1}^{k} a_j^{f_j(a,b)} \quad (10)$$

Where $Z(b)$ is a normalization factor to ensure that $\sum_a p(a|b) = 1$, and k is the number of features. Each parameter a_j, where $a_j > 0$ corresponds to one feature f_j, can be interpreted as a weight for that feature. The probability $p(a|b)$ is then a normalized product of those features that are “active” on the (a, b) pair. The weights $a_1 \ldots a_k$ of the probability distribution p^* that best fit the training data can be obtained with the maximum likelihood estimation:

$$\mathrm{Q = \{p \mid p(a|b) = \frac{1}{Z(b)} \prod_{j=1}^{k} a_j^{f_j(a,b)}\}}$$
$$L(p) = \sum_{a,b} \tilde{p}(a,b) \log p(a|b)$$
$$p^* = \arg\max_{q \in Q} L(q) \quad (11)$$

where Q is the number of log-linear forms, $\tilde{p}(a,b)$ is the probability of seeing a, b in T that is the training dataset, the conditional log-likelihood of T is represented by $L(p)$, and p^* is the probability distribution. The entropy distribution p is then defined as:

$$H(p) = - \sum_{a \in \{x,y\}, b \in \{0,1\}} p(a,b) \log p(a,b) \quad (12)$$

C. CombiTagger
CombiTagger is implemented in Java with SWT-Toolkit2. This program's primary function is to receive data files produced by various taggers and utilize them to generate combined taggers following a predetermined algorithm. CombiTagger supports all taggers and requires more than one tagger output file (Henrich et al.,2009).

Cascading, voting, and boosting are some of the well-known combination techniques. Voting is perhaps the simplest method that can be used to combine classifiers for natural language processing out of the ones listed above. This paper employs voting and has a basic implementation. Simple voting and weighted voting are the two most common voting methods:
1. Simple voting: in this method, the classifiers are all given the same weight (Lin et al., 2003).

2. Weighted voting: In weighted voting, each vote in a first-level classifier is multiplied by the weight assigned to that classifier. A candidate receives the classifier's weight as a confidence score when they receive a first-level classifier's vote in favor of them (Halteren et al.,2001).

5. Experiment and Results
In this section, we outline our experimental settings and discuss the findings obtained.

SVM-based tagger setup
Given a training set of Setswana annotated corpus, it is liable for the preparation of a bunch of SVM classifiers. This was done by utilizing the SVM–

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light7 library that is developed by (Joachims, 1999) in his work titled "SVMlight Support Vector Machine" as detailed. The Setswana corpus, which was discussed in Section 3, is split into three sets (training, testing, and evaluation). Eight various tests were performed. The models are then tested with the test data using cross-validation. The model performance was evaluated in terms of accuracy using the predicted tagging output and the corresponding gold-standard data to produce a brief report.

MaxEnt-based tagger setup

To conduct the PoS tagging tests, Apache OpenNLP MaxEnt tool was utilized, which is a machine-learning-based Java open-source library used for processing natural language. The Setswana corpus, which was discussed in Section 3, was used, which was split into three sets (training, testing, and evaluation). Eight different tests are performed using different portions of the training set from 10 per cent of the training datasets to observe the learning curve. The corpus is incremented by 10 per cent each time until it reaches 80 per cent. Every time the tagger is trained its performance is measured on the testing set.

CombiTaager setup

The CombiTagger, which uses a voting method to choose the tag that obtains the most votes, was utilized to enhance the PoS tagger's accuracy (Zhang & Lin, 2021). The data files (PoS tagger outputs) that were generated by the individual taggers of Setswana are used to create a combined tagger. It should be noted that CombiTagger supports all taggers, as it uses the output file, but not the tagger itself.

First, the tagger tries to see if there is a maximum number of tags behind a single tag, then the tag is chosen. The processor will use the tiebreaker approach when two or more equally sized groups of taggers disagree. The group whose tag has the highest priority, which is measured by accuracy, is chosen by popular vote. Therefore, the most exact accuracy has the highest priority, followed by the second most accurate, and so on.

Eight different tests were conducted for both proposed SVM and MaxEnt-based taggers using the same dataset that was split into different portions to assess the accuracy of the tagger. The performance results, in terms of accuracy, precision, recall, and F1 score obtained for both taggers, are shown in Table 1. The training was performed by using the training set. After the taggers were trained, their performances were measured on the testing set. Having got a low performance when the taggers were trained on the 10 per cent of the training set, the training data set was added by 10 per cent until it reached 80 per cent, and as a result produced desired performance.

Table 1. MaxEnt and SVM Tagger performances

	MaxEnt				**SVM**			
Data %	**Accuracy**	**Precision**	**Recall**	**F1 Score**	**Accuracy**	**Precision**	**Recall**	**F1 Score**
10	83.69	48	38	42	85.36	51	47	49
20	87.92	51	43	47	86.27	54	47	51
30	89.25	50	44	48	88.9	56	50	53
40	91.28	55	46	50	90.01	57	50	53
50	92.71	56	48	51	92.55	61	55	57
60	94.4	57	49	53	95.59	64	56	60
70	95.08	58	51	54	97.61	64	59	61
80	96.73	59	53	56	98.5	77	73	75

Figure 3 shows the performance of the taggers measured from the learning curve with almost constant values from 50 per cent of the training set, regardless of the training data added for training the system. The curve shows that the available training set is almost sufficient, despite the lack of an already tagged corpus.

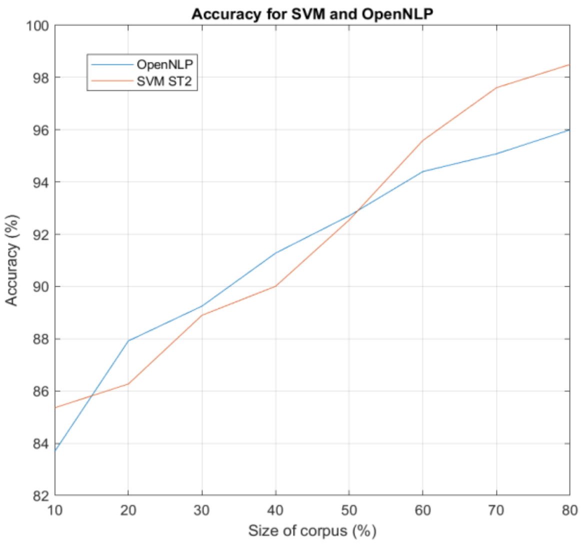

Figure 3. Tagging accuracy for different techniques used

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However, the SVM model outperformed the MaxEnt model, achieving higher accuracy, precision, recall, and F1 score of 98.5 per cent, 77 per cent, 73 per cent, and 75 per cent, respectively. During 20-50 per cent of training data, the MaxEnt model achieved higher accuracy than the SVM model, with 87.92 per cent, 89.25 per cent, 91.28 per cent, 92.71 per cent and 92.71 per cent, respectively; with margins of 1.65 per cent, 0.35 per cent, 1.27 per cent, 0.16 per cent. The results demonstrate the adequacy of both methods for Setswana PoS tagging. However, the SVM based tagger has an advantage over the MaxEnt tagger.

CombiTagger results

Here, we provide some experimental evaluation of the simple voting technique that is implemented by CombiTagger using both SVM and MaxEnt. If there is a disagreement among the taggers, the SVM tagger's output is chosen because of the highest overall accuracy it has. Results are shown in Table 2. A simple vote reduces the net error over the best of the two taggers; this difference is significant. The combinations of these two taggers have shown higher tagging accuracy than those achieved by individual taggers. The reason for this is that various taggers lean towards generating various errors. The acquired accuracies of the taggers are roughly comparable, as shown in Table 2, although the combination method performs better than the two taggers alone.

Table 2. MaxEnt, SVM, and Combi Tagger performances

Training data %	MaxEnt			SVM			CombiTagger		
	Accuracy	Precision	Recall	Accuracy	Precision	Recall	Accuracy	Precision	Recall
60	94.4	58	51	95.59	64	59	97.02	67	61

Several experiments with different resources are performed and, based on a deeper study of these experiments, combinatorial algorithms are proposed. The effectiveness of the combination system is shown by several evaluations and validations while considering the quantity and quality of the taggers engaged. The following points are stated to provide a summary of the most significant findings from this study:

- As can be shown in the results discussion section, the suggested combination system outperforms the other taggers when used on each of the two taggers independently.
- The PoS tagging is often carried out automatically and then manually corrected. The combination algorithm can be used to increase accuracy while reducing hand correction.

The existing combination algorithm can be made to perform better. For example, there is still room for improvement by increasing the number of taggers involved or using other combinatorial algorithms.

6. Conclusion

From the various simulations presented in the study, it was observed that the combination of two Setswana PoS taggers enhances the quality of the tagged texts, which, in turn, helps to produce good NLP applications. Even with basic voting methods, the total error rate for these machine learning techniques drops. This results in fewer mistakes and requires less effort from humans to develop new taggers. Additionally, combining taggers is helpful for resource scarce and morphologically rich languages such as Setswana. This study covers PoS tagging experiments carried out to identify the optimal method of PoS tagging. Even though not all tokens significantly benefit from these experiments, it is demonstrated in this study that accuracy can be improved through hybridization of taggers. This tagger can be helpful in several ways, such as making manual correction rules for a small number of fault types, rather than many is easier. It is encouraging to explore this option for a language with limited resources, because the experiments only require a basic understanding of the target language.

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Spectrum Optimization of Low Power Wide Area Network Utilization in Smart Cities

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Abstract
The discovery of this great technology known as Low Power Wide Area Networks (LPWANs) has significantly altered the way we live in a positive way. It is a technology with low power and long-range capabilities with impacts that cannot be overemphasized. The impacts range from making cities better with quality living, the environment with quality air and humidity, efficient waste disposal systems, smart metering systems, and traffic free road management to more efficient transportation. Our research focused on the optimization of the unlicensed spectrum occupied by LPWANs using cognitive radio and its utilization in smart cities. In this research, we proposed the spectrum sharing model and carried out our simulations using MATLAB. We discovered that the spectrum sharing model brought about an increase in channel capacity and a decrease in latency, which are basic parameters that determine the performance of the spectrum. After the research, there was a significant improvement in spectrum performance leading to higher quality of service (QoS).

Keywords: spectrum, smart city, cognitive radio, channel capacity, latency

1. Introduction

Radio spectrum is known to be the most important aspect of radio wireless communications. The evolution of different technologies making use of the spectrum is increasing on a daily basis. These emerging technologies bring about innovations that make communication far better than before. Nowadays, Low Power Wide Area Networks (LPWANs) have become an integral part of the Internet of Things (IoT) technologies and their presence permeates every aspect of life. However, the deployment of these technologies faces new obstacles because so many other technologies are found in the unlicensed spectrum, each causing interference and obstructing proper network communication, leading to poor quality of service, Markus and Fadeyi (2021). LoRa, Sigfox and NB-IoT are bridging the gap in that they are deployed in such a way that they produce high performance at a very low cost. This is the major reason why they gained acceptance, dislodging the traditional cellular networks. In the same vein, smart cities and all their features have become popular around the world due to LPWAN technology being adopted and, because it boasts of good features such as low power, long range, robustness and affordability. Therefore, the utilization of IoT/LPWANs in smart city focuses on how smart applications can improve the wellbeing of the citizens and improve their quality of lives as discussed by (Sandoval et al.,2019).

In an earlier paper by the authors (Sandoval et al., 2016) the technologies making use of LPWANs were presented as found in the unlicensed spectrum, where a lot of users can access it at any time. Due to their importance, they have attracted research interest in both the academia and industry leading to an improvement in the overall network viability. Their features can work with different and numerous devices which are interconnected to the IoT networks, enhancing the performance of smart cities. There are several applications of LPWANs such as those found in the Low Throughput Network (LPN), sensors as well as control systems, and they continue to have a notable impact on day-to-day communication among humans and the immediate environment. Some of the major uses of the LPWANs are found in the transportation management system, a subset of smart cities, where sensors that are placed in strategic locations can detect the working condition of lights on a 24-hour basis, thus

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reducing congestion which, in most cases, cause accidents. Also, in the smart watering systems, another initiative embedded in smart cities, where water leakages can be detected, and other problems associated with free flow can be rectified immediately because of smart sensors that monitor and notify authorities of any anomaly. Overall, this will enhance efficient city water management systems as stated by Athani et al. (2019).

Besides, it is important that spectrum is available so that LPWANs can function well in the context of smart city applications as discussed by (Wang et al.,2020). Many LPWANs are continually faced with the challenges of underutilization and overcrowding of the spectrum, and misdetection of available spectrum holes. The reason for this weakness is not far-fetched, because they are installed in the overcrowded, unlicensed frequency bands. In these bands, so many network users are transmitting and each user wants good use of the spectrum to have better communication and, because no user is licensed to use them, it becomes more challenging. To address or minimize these obstacles, there is a need to optimize the performance of the spectrum occupied by LPWANs for better mobile communication and quality of service. Many authors have talked about cognitive radio as an intelligent radio communication system specifically designed to address the problem of spectrum scarcity or spectrum underutilization. Without the efficiency of the spectrum, the noble goals of smart cities may not be achieved according to (Onunmanyi et al.,2020).

This research paper is arranged in the following ways: section 2 reviews the related work, section 3 looks at LPWANs and smart cities, section 4 considers the methodology, section 5 is about experiment and results, section 6 is the discussion and evaluation, and section 7 concludes the paper.

2. Related Works

(Ahmed M. Abass et al., 2020) in their research, talked about NB-IoT and failed to consider other LPWANs in the broader sense. They narrowed their work to smart meter networks in smart cities. In the real sense of it, smart metering is just a component of smart city management. However, their paper introduced a new integrated approach, which argued that in future, more demands for smart meters businesses for maximum use of the resources should be used to serve high numbers of NB-IoT users. Going further, they presented that the management of traffic as regards NB-IoT requires efficient use of spectrum and is a newly opened issue at the IoT 5G. In their work, they achieved spectra efficiency to improve performance of smart meters. They also reduced the signaling burden that occurred during each transmission request for the smart meter businesses. Although, their simulation results showed a great improvement in spectrum utilization and efficiency, it failed to account for the spectrum utilization involving other LPWANs. The performance of NB-IoT cannot be used to conclude other LPWANs since their research focused on technology in LPWANs as discussed by Abbas et al. (2020). Also, it was assumed for an ideal propagation without any impairment and in some situations, obstacles such as interference will show up, mitigating against efficient propagation of these LPWANs.

During the course of improving the spectrum to achieve better performance (Weiss et al.,2004) proposed a new approach that is known as spectrum pooling. This approach allows public users access to a primary user licensed spectrum. Also, it is applicable to unlicensed spectrum because, when one user utilizes the spectrum, the other user can wait till when there is a spectrum hole, which signifies the availability of spectrum. Moreso, it involves bringing together spectra ranges from various spectrum owners, be it the military or other licensed spectrum owners to a general pool. This shows that many mobile radio systems can coexist within a particular range of frequency (Fadeyi et. al.,2019). The overall aim of the spectrum pooling is to enable the spectrum to function efficiently by putting a new mobile communication system on top a previous one with the aim of making no changes to the spectrum of the licensed owner. The method adopted still could not account for the interference that can occur when such communication systems are put together (Weiss et al., 2004).

Besides (Wang et al.,2012) proposed a method that can quantify the queue dynamics of many secondary users of multiple channel cognitive

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radio networks. The method designed involves the critical below the layer functioning models, which include sensing anomalies in the spectrum, medium access control (MAC) protocols and adaptive technologies such as automatic repeat requests (ARQ), adaptive modulation and coding (AMC), and a limited buffer size. To show the impact on quality of service (QoS) performance for secondary users, they modelled it using the Markov Chain (FSMC). Consequently, the throughput and average queueing delay became better, which showed an increase in performance because of their proposed methodology going by (Wang et al.,2012). It failed significantly to show the impact on latency and channel capacity.

(Balapuwaduge et al.,2018) proposed two queueing schemes for secondary users, their proposition is based on a lag in the tolerance of abrupt elastic services. They agreed that in multiple frequency cognitive radio networks, the highest capacity can be achieved by the secondary users by using dynamic channel assembling (CA) methodologies. The drawback of the methodology is that the channel slots suffer from increased blocking and instant stoppage when the primary users become active. According to them, in the multiple frequency network with a lot of network traffic, more than one queue is independently assigned to frequent and non-frequent users. The frequency access chances are evenly distributed between these many queues in such a way that the frequent receivers have upper access before others. Markov chain access, similar to the (Wang et al.,2018) approach was used to get the performance of their proposed CA strategy. As can be seen, what these researchers have done was to analyze the performance of one or two LPWANs without considering the majority of the LPWANs as regards their performances in the smart city and, also how the spectrum will be improved. This research will fill this gap.

3. LPWANs and Smart cities

Smart city applications are gaining prominence among major cities of the world and LPWANs continue to play significant roles in the realization of the city of the future. Without this technology, the smart city dream would only be a mirage. Hence, smart city applications require the network coverage to cover the whole of the city and equally provide efficient services. These applications involve the collection of data of many important parameters, which will enhance the performance of the city; such parameters include pollution, waste level, humidity, temperature, mist, fug etc. Obviously, many nodes are needed for the proper deployment of the technology as regards smart cities, agreed by (Chaudhary et al.,2020), therefore, the network needs to have a large capability and must be scalable. There will always be several nodes of LPWANs deployed in the city so that the whole city can be covered and to ensure there is low consumption of power at a moderate level. As part of the smart city initiative, the ecological balance of the environment can be monitored by smartly placed sensors, which will, in turn, inform the state officials of the pollution monitoring in the environment.

In the area of waste bin management, LPWANs will help for proper disposal of the waste bins. The sensors can be placed on the smart waste cans tracking the level of the position of the waste in the cans. When they are full, they can be easily emptied. In the fire protection management systems, LPWANs can help detect fire alarms through sensors and quickly send an emergency notification to the department responsible for the task according to international telecommunication report, Marcus (2018). LPWAN technologies will continue to impact the smart city applications in various ways. They provide the ability to connect numerous devices at the same time and sharing information that is critical to the betterment of the city. As more cities around the world are becoming smarter, they will continue to make use of this great innovation. Moreover, a technology such as LoRa can reach several kilometers, and a lot of devices can be connected to each base station. Then it has the capacity to provide large connectivity and can penetrate deep into areas which traditional cellular networks cannot reach, going by what (Renato et al., 2021) and (Ghena et al., 2019) wrote in their papers.

In some instances, there may be network collisions which occur rapidly and cause the capacity of the network to be filled up quickly. At this stage, monitoring the services is not the only thing that needs to be done; the reliability of the wireless network also needs to be considered to

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ensure that it aligns with the required parameters of the available network (Bankov et al.,2019). A model can then be formulated due to the signal strength of the other available networks as well as that of other devices. The number of packets generated during this time can be used to compute the packet error rate (PER). The outcome will then influence the network reliability in large geographical areas (Fernandez et al., 2019).

4. Methodology

The method adopted was to use the MATLAB simulations to get the results of the experiment. MATLAB software was installed on our computers. We set simulation parameters at different values for bandwidth, maximum channel bandwidth, minimum channel bandwidth, and mean channel bandwidth. We also set transmission parameters because we knew it was a communication scenario. We set values for parameters such as power, channel gain, and interference. We ran the simulations on our computers, and it produced different results in graphs. We considered the latency and the channel capacity, with two major parameters showing the performance of the spectrum. Finally, spectrum sharing model and non-spectrum sharing model were utilized, and the results were also shown in the graphs.

5. Experiments and Results

In carrying out the research, the concept of cognitive radio was adopted and the spectrum sharing model was used to improve the performance of the spectrum. The idea is to find ways we can increase the number of users that will utilize the spectrum more efficiently. All the parameters that are involved in the spectrum performance such as channel gain, latency, bandwidth, and transmission power were put into consideration. Our simulation results showed an improvement in the performance of the spectrum. The simulation results are shown in the figures below. Considering the channel capacity against the number of channels on the spectrum, it increases using our spectrum sharing model. As can be seen, it moved from the lower part to the upper part, and then moved to the highest level. Also, the latency improved when the spectrum sharing model was used. The latency was lowered in the simulation results, showing that our model has improved the performance of the spectrum. Without the spectrum sharing model the latency was high.

(i) Spectrum sensing; the interference power of the primary user is low. We tried as much as possible to minimize the interference power, if the interference power is high, the secondary user may not be able to detect the free spectrum. High interference will lead to high misdetection on the part of the secondary user, and a reduction in the channel capacity.

(ii) Channel bonding means the secondary user can transmit over the spectrum at the same time that the primary use is making use of the channel. This can lead to a very high interference. When there is spectrum sharing, there is a significant improvement on the channel; because of the spectrum sharing model, there is also enhancement of the channel capacity.

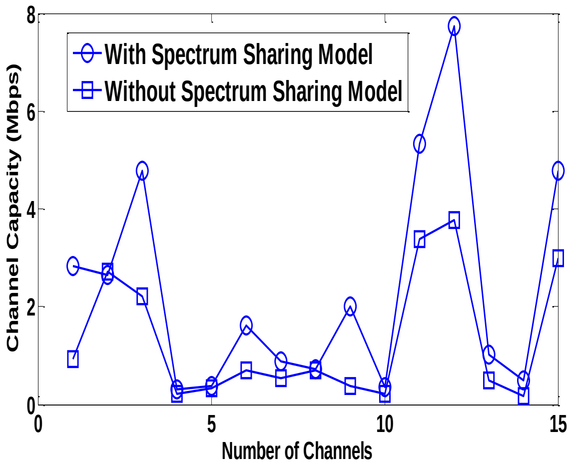

Figure 1: Effect of spectrum sharing model on channel capacity at bandwidth of 0.2518MHz

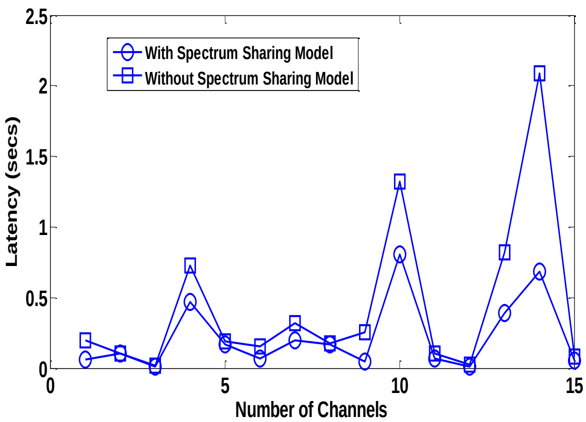

Figure 2: Effect of spectrum sharing model on latency at bandwidth of 0.2518MHz

Table 1. Parameters for Figures 1 & 2

Simulation Parameters	
Channel Bandwidth	MHz
Maximum	0.6099
Minimum	0.0314
Mean	0.2518
Channel Transmit Parameters	
Channel Gain	
Maximum	0.5391
Minimum	0.0124
Mean	0.2508
Power used for Transmission	
Power	Watts
Maximum	0.0020
Minimum	1.1469e-04
Mean	9.263e-04
Interference Channel Gain	
Interference Gain	
Maximum	0.1458
Minimum	0.0214
Mean	0.0851
Interference Power with Use of Spectrum Sharing Model	
Interference Channel Power	Watts
Maximum	2.0963e-4
Minimum	1.4838e-5
Mean	8.8321e-5
Interference Power without Use of Spectrum Sharing Model	
Interference Power	Watt
Maximum Interference Channel Power	0.0024
Minimum Interference Channel	8.3473e-5
Mean Interference Channel Power	0.0013

Result: Improved Channel Capacity = 41.9191; Improved Latency = 41.9191

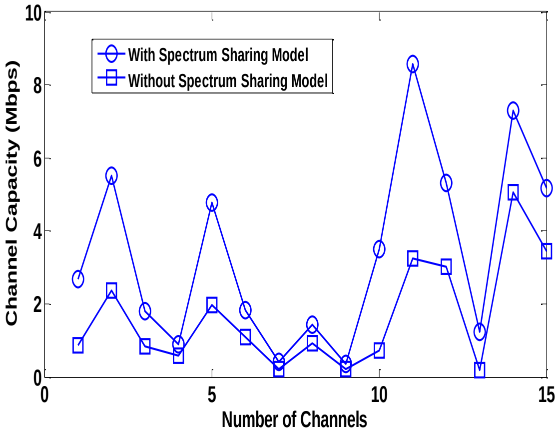

Figure 3: Effect of spectrum sharing model on channel capacity at bandwidth of 0.4042MHz

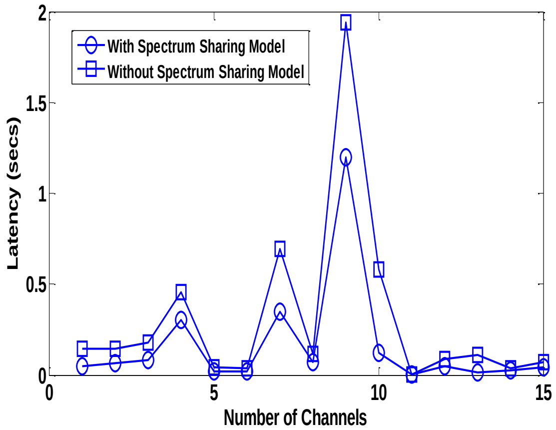

Figure 4: Effect of spectrum sharing model on latency at bandwidth of 0.4042MHz

Table 2. Parameters for Figures 3 & 4

Simulation Parameters	
Channel Bandwidth	MHz
Maximum	0.8170
Minimum	0.0426
Mean	0.4042
Channel Transmit Parameters	
Channel Gain	
Maximum	0.5264
Minimum	0.0078
Mean	0.2674
Power used for transmission	
Power	Watts
Maximum	0.0019
Minimum	2.3418e-04

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Mean	8.4566e-04
Interference Channel Gain	
Interference Gain	
Maximum	0.1365
Minimum	0.0330
Mean	0.0958j
Interference Power with Use of Spectrum Sharing Model	
Interference Channel Power	Watt
Maximum	2.1497e-04
Minimum	1.0312e-05
Mean	1.2021e-04
Interference Power without Use of Spectrum Sharing Model	
Interference Channel Power	Watt
Maximum	0.0025
Minimum	8.3473e-04
Mean	0.0018

Result: Improved Channel Capacity = 514208, Improved Latency = 51.4208

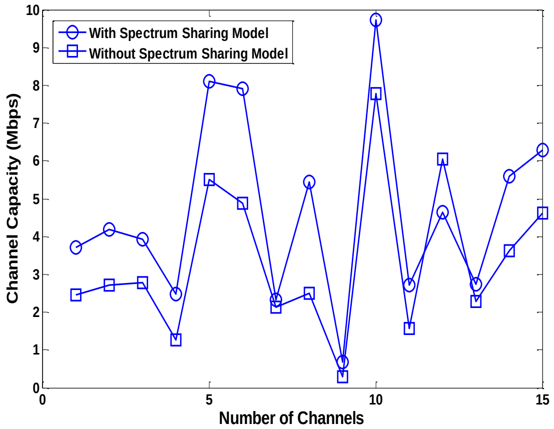

Figure 5: Effect of spectrum sharing model on channel capacity at bandwidth of 0.4142MHz

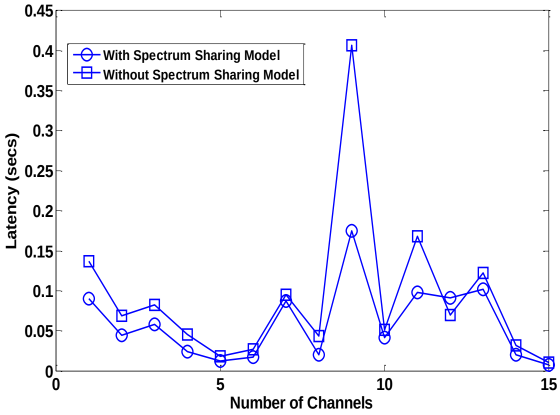

Figure 6: Effect of spectrum sharing model on the latency at bandwidth of 0.4142MHz

Table 3. Parameters For Figures 5 & 6

Simulation Parameters	
Channel Bandwidth	MHz
Maximum	0.7120
Minimum	0.0873
Mean	0.4142
Channel Transmit Parameters	
Channel Gain	
Maximum	0.5003
Minimum	0.1043
Mean	0.2976
Power used for transmission	
Power	Watts
Maximum	0.0019
Minimum	1.1110e-04
Mean	9.7089e-04
Interference Channel Gain	
Interference Gain	
Maximum	0.1479
Minimum	0.0066
Mean	0.0670
Interference Power with Use of Spectrum Sharing Model	
Interference Channel Power	Watt
Maximum	2.2572e-04
Minimum	1.4423e-05
Mean	1.0973e-04

Interference Power without Use of Spectrum Sharing Model	
Interference Power	Watt
Maximum Interference Channel Power	0.0023
Minimum Interference Channel	8.3467e-04
Mean Interference Channel Power	0.0013

Result: Improved Channel Capacity = 29.7925; Improved Latency = 29.7925

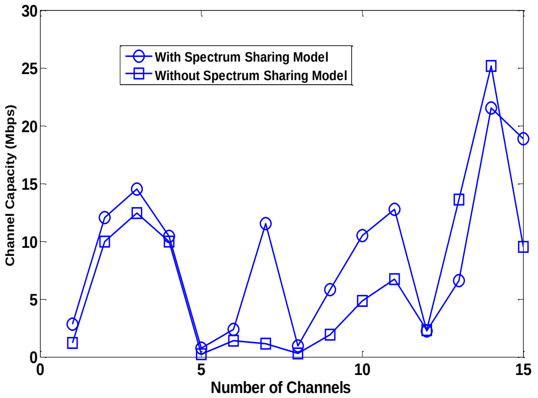

Figure 7: Effect of spectrum sharing model on channel capacity at bandwidth of 0.8509MHz

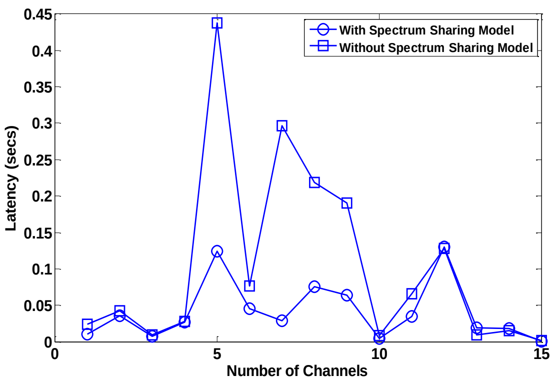

Figure 8: Effect of spectrum sharing model on latency at bandwidth of 0.8509MHz

Table 4. Parameters for Figure 7 & 8

Simulation Parameters	
Bandwidth	MHz
Maximum Channel	1.3748
Minimum Channel	0.0996
Mean Channel	0.8509
Channel Transmit Parameters	
Channel Gain	
Maximum	0.3192
Minimum	0.0260
Mean	0.1622
Power used for Transmission	
Power	Watts
Maximum	0.0013
Minimum	1.5455e-04
Mean	5.3665e-04
Interference Channel Gain	
Interference Gain	
Maximum	0.1391
Minimum	6.8904e-04
Mean	0.0837
Interference Power with Use of Spectrum Sharing Model	
Interference Channel Power	Watts
Maximum	2.1714e-04
Minimum	1.1854e-06
Mean	9.8221e-05
Interference Power without Use of Spectrum Sharing Model	
Interference Channel Power	Watt
Maximum	0.0021
Minimum	3.2612e-5
Mean	9.0310e-04

Result: Improved Channel Capacity = 30.2279; Improved Latency = 30.2279

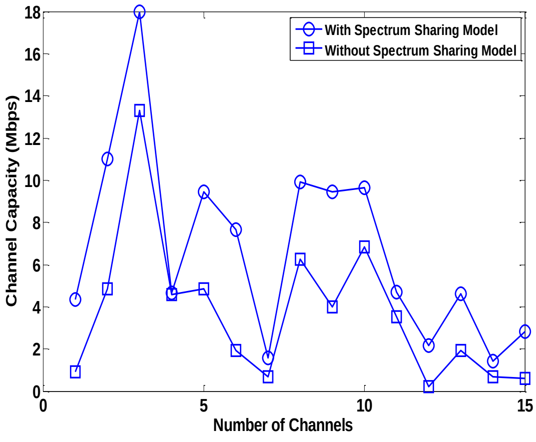

Figure 9: The effect of spectrum sharing model on channel capacity at bandwidth of 0.8086MHz

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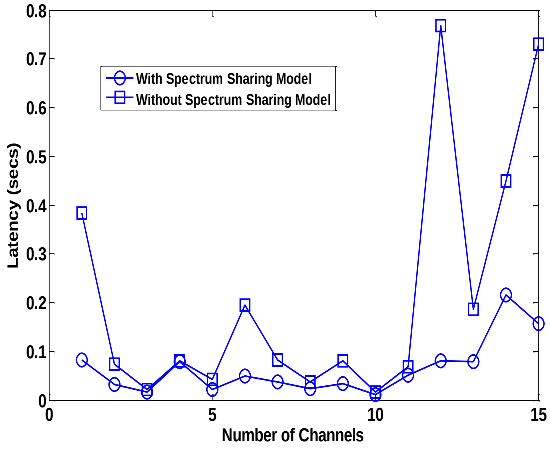

Figure 10: Effect of spectrum sharing model on latency at bandwidth of 0.8086MHz

Table 5. Parameters for Figure 9 & 10

Simulation Parameters	
Channel Bandwidth	MHz
Maximum	1.5420
Minimum	0.1054
Mean	0.8086
Channel Transmit Parameters	
Channel Gain	
Maximum	0.3384
Minimum	0.0322
Mean	0.1776
Power used for Transmission	
Power	Watts
Maximum	0.0013
Minimum	1.5455e-04
Mean	5.3665e-04
Interference Channel Gain	
Interference Gain	
Maximum	0.1494
Minimum	0.0110
Mean	0.0680
Interference Power with Use of Spectrum Sharing Model	
Interference Channel Power	Watts
Maximum	2.3946e-04
Minimum	1.8995e-05
Mean	1.1501e-04
Interference Power without Use of Spectrum Sharing Model	
Interference Channel Power	Watt
Maximum	0.0025
Minimum	2.26115e-04
Mean	0.0015

Result: Improved Channel Capacity = 51.2646; Improved Latency = 51.2646

6. Discussion and Evaluation

In Figure 1, the graph shows the relationship between the channel capacity and the number of channels with spectrum sharing model and without spectrum sharing model at channel bandwidth of 0.2518MHz. The graph of channel capacity increases with spectrum sharing model and higher than the one without spectrum sharing model, indicating an increase in channel capacity of the spectrum. Figure 2 shows how latency was affected by spectrum sharing model. With the spectrum sharing model, the graph of the latency is lower than without spectrum sharing model which means a lower latency at channel bandwidth of 0.2518 MHz. This is the case for the second scenario. In figure 3, at bandwidth of 0.4042MHz, the effect of spectrum sharing model on channel capacity was also tested, it can be seen that the channel capacity increased compared to when the spectrum channel model was not used. In figure 4, this is another scenario from the simulation, the relationship between the number of channels and the latency can be observed. It shows how the latency became low using the spectrum sharing model at the bandwidth of 0.4042MHz. The positive effect of the spectrum sharing model on the latency can be clearly seen. In figure 5, when the channel capacity was tested, it increased and reached the highest value with spectrum sharing model as shown. This shows the peak performance for the spectrum. We continued the testing using spectrum sharing model and noted the progress made by increased channel capacity and very low latency. Considering figure 6, using spectrum sharing model continued to show a lower latency for every number of channels. In figure 7, the channel capacity also increased and in figure 8, the results showed a very low latency again using the spectrum sharing model at channel bandwidth of 0.8509MHz.

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Figure 9 gave a higher value of channel capacity and Figure 10 gave a lower value for spectrum sharing model.

(i) Performance improvement due to optimization. The characteristic performance of the spectrum has been greatly improved since latency, transmitting power and the channel capacity of the nodes have been optimized using our spectrum sharing model. The concept of cognitive radio was adopted in the research because it is most applicable Haykins F. (2005). It is an intelligent system which can sense the environment and adjust itself for better communications (Javed et al., 2012) and Rampon N.G (2022). Due to our work, the bandwidth of the spectrum has also been increased, making it accessible without restrictions. With spectrum becoming efficiently optimized, smart cities will then run smoothly, and the goal of smart city initiative will be achieved (Wang et al.,2020) and (Wang et al., 2018).

7. Conclusions

In carrying out this research and using MATLAB for the simulation, our spectrum sharing model increased the channel capacity, which means many users can make use of the channel for their communication needs. Our model also reduced the latency. The simulation was repeated for different scenarios, and we found different results for each scenario. It was better for both channel capacity and the latency. We can then conclude that our spectrum sharing model has improved the performance of the spectrum and made it better for communication. To the best of our knowledge, no research work has been done in this specific area; most researchers focused on LPWANs individually, not collectively, as we have done as regards spectrum optimization. Our work is unique in that it focuses on the utilization of the optimized spectrum in smart cities.

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Evaluating the Effectiveness of Machine Learning Algorithms in Detecting Distributed Denial of Service Attacks in Mobile Edge Computing

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Abstract
Mobile Edge Computing (MEC) is the last mile technology in 5G designed to reduce latency and to execute delay-sensitive applications closer to the end-user. MEC is also known as Multi-Access Edge Computing, which extends the capabilities of cloud computing to the network's edge and brings more capabilities closer to the user. By deploying cloud capabilities to the edge servers, MEC reduces latency and delay. As a result, the end-user experience is enhanced. Unfortunately, the MEC is susceptible to security challenges. Therefore, security is a challenge that requires attention. This paper investigates and compares the effectiveness of machine learning algorithms designed to detect distributed denial of service (DDoS) attacks in MEC. DDoS is one of the security concerns that are negating the advantages of MEC. It degrades the performance of the network. In this work, network and application layer DDoS attacks were considered. The study observed that the Support Vector Machine outperformed other machine learning techniques, and the findings are fundamental to the development of our proposed security framework for MEC.

Keywords: Distributed Denial of Service, 5G, Machine learning algorithms, Mobile edge computing

1. Introduction

Fifth generation (5G) network is a new network technology proposed to offer a high data rate, improved quality of service, low latency and high reliability among other benefits compared to previous network technologies (Ramraj et al., 2022). Mobile edge computing (MEC) is one of the fundamental 5G enabling technologies that reduces latency by offering cloud computing capabilities closer to the end-users, leading to an improved user experience (GÜRKAN et al., 2022). However, security is a fundamental challenge to the realization of the requirements and objectives of this technology. Robust and reliable security measures are required to improve the quality of service (QoS) provisioning in the presence of attackers.

Man-in-the-Middle (MITM), Denial of Services (DoS) attacks, and Distributed denial of services (DDoS) (Rutvij et al., 2012), are the most common security threats in MEC. Hence in this work, the focus is on DDoS attacks since it is a direct threat to the central premise of MEC. DDoS attack seeks to overwhelm the target and starve legitimate users of the resources offered by the target (Osanaiye & Opeyemi, 2016).

This attack either targets the network, transport or application layers. In the literature, there is less work done on MEC, hence this paper focuses on MEC. Therefore, there is a need for the development of a robust and reliable DDoS attack mitigation scheme (TOMASZ et al., 2021). This paper designs a framework for future work by first comparing the following machine learning (ML) algorithms: Logistic Regression, Random Forest, Random Tree, Support Vector Machine (SVM) and Decision Tree which address the effects of DDoS attacks. Their performance was evaluated using the following metrics: accuracy, false alarm rate, recall/detection, precision, and F1-score. The comparative results show that the Support Vector Machine is the best-performing algorithm.

The rest of this paper is arranged as follows: Section 2 presents a literature review, and Section 3, briefly discussed the methodology. Section 4 presents the analytics of the results, and Sections 5 and 6 present the future work and the conclusion respectively.

2. Related Works

Work has been done on DDoS attacks in traditional networks. Unfortunately, much has not been done on MEC DDoS attacks. The ability of 5G technologies to deliver efficiency and flexibility is dependent on their ability to ensure the security of the technology, according to a study by the National Science Agency (Jude & Madhusanka, 2018).

Emerging technologies such as cloud computing and MEC are key targets of attacks because of the amalgamation of many technologies and use cases. Since 5G rely on virtualization and edge technologies, threats such as virtual machine exploitation, data leakage, DDoS, and MITM will all become increasingly common in the future (Thulitha et al., 2022). In (Jude & Madhusanka, 2018), the authors have also suggested some control mechanisms and strategies such as intrusion detection systems, and traditional host intrusion systems to mitigate these risks and provide guaranteed network security.

This is important because, for 5G to support the number of new applications and use cases that have been proposed, MEC and cloud technologies appear to be critical. As a result, security measures must be implemented to ensure that both users and service providers have confidence in the technologies. The paper (Jude & Madhusanka, 2018), focused more on comparing Mobile cloud computing (MCC) and MEC security threats, and our study focuses on DDoS attacks in MEC.

The use of a machine learning approach in detecting and preventing DDoS attacks on cloud servers was investigated by (Mishra et al., 2021 January). The authors evaluated the proposed approach by extracting statistical data from a data set. According to the findings, the proposed method was effective in detecting DDoS attacks with an accuracy of 99.68 per cent with low false positives. The scheme was based on supervised learning, therefore, the authors recommend that future research focus on unsupervised or reinforcement learning. The focus of the work was on traditional cloud servers. Hence, our study evaluates the performance of different machine learning (ML) algorithms in MEC instead of traditional cloud servers.

The algorithm which enhances centralized TSCH scheduling (ECTS) was used to schedule traffic when a time and wavelength division multiplexed passive optical network (TWDM-PON) is attacked by DDoS, and ECTS is proposed for edge computing optical networks. Based on the cooperation of EC nodes, ECTS decreases the number of delayed-sensitive services and achieved 7.92 per cent when the number of attacks reaches eight. The authors in this paper (Yingqi et al., 2020) have focused on the use of scheduling techniques in edge computing, whereas our study focuses on the use of machine learning algorithms in detecting DDoS in MEC. Authors showed that sensor edge clouds (SEC), incomplete resource information and the unknown state of virtual machines are utilized at the edge of the network to detect DDoS attacks. The defence model for mitigating the DDoS attacks was developed through the use of Bayesian game theory and, as a result, the resource allocation technique was able to maximize the reward for cooperative defenders while achieving marginal distribution. They also implemented a Q-learning-based search strategy for the establishment of a viable resource allocation plan using a machine-learning platform. The results showed that the Bayesian Q-learning game scheme is better than alternative defence mechanisms (Jingsen et al., 2020).

The authors investigated attack models in MEC systems with a focus on both mobile offloading and caching techniques. The findings of this study (Liang et al., 2018) indicated that MEC systems are vulnerable to numerous attacks, including DoS and rogue attacks. Secure mobile offloading is proposed to address jamming and smart attacks, and other solutions for security challenges are presented. The paper (Liang et al., 2018) also discussed edge security methods based on a fixed network and attack model. The RL-based method is effective in safeguarding the MEC system against various attacks with low overhead, according to simulation results. This study focused on thread models in MEC (such as jamming, DoS, spoofing attacks, clever attacks, MITM, and privacy leaks), and the key element not covered in this paper is the DDoS attack, which is addressed in our work.

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The development, testing, and empirical validation of a novel approach to the effective security of multi-tenant 5G networks from DDoS attacks are presented in this study (Ana et al., 2018). The benefit of the proposed solution is that it can secure segments of the 5G network, which is an encouraging security approach in Mobile Edge Security. The solution was evaluated against a realistic use case of over 256 simultaneous attackers flooding a 5G network with malicious traffic at 100 Mb/s using user datagram protocol (UDP). The proposed system is based on a Snort extension. It can be integrated with any Intrusion Detection System that reports events in a Unified format. The paper considered UDP, hence the proposed scheme may have a challenge in the presence of application layer-centric attacks.

Based on the scientific knowledge of network security, it is shown that DDoS threats have become more sophisticated despite the advancement of technology. A Feedback algorithm based on Autonomous Systems (AS) Edge Router which utilizes the convenience of control within AS is presented. According to the simulation results, the system maintains a high survival rate for legitimate traffic. To obtain a higher survival rate, the strategy may be improved. Based on this paper (Xiaoming et al., 2009) the analysis of security measures that make it simpler to detect DDoS attacks and manage the effects of DDoS will be incorporated into our study.

The authors demonstrated theoretically that the use of both 5G and fog computing makes it easier to implement security solutions for the Internet of Things (IoT) networks. With 5G networks, devices can communicate effectively and efficiently, while with fog networks, resources (storage and processing) can be provided for security solutions such as anomaly detection. To increase the detection and mitigation of DDoS attacks, a fog computing-based mitigation scheme is proposed in this study (Muhammad et al., 2021). The framework makes use of a database of attacks and a k-nearest neighbours' algorithm (KNN) classification to implement an anomaly-based mitigation strategy. The database maintains signatures of detected attacks, making future detection faster.

DDoS attack traffic passing through a fog defender was detected and filtered using implemented rules. DDoS attacks are detected and mitigated at the network edge rather than in the cloud. This technique protects TCP and HTTP traffic. As a result, it may be enhanced to provide security to protocols such as ICMP and UDP. By utilizing servers as fog devices, they demonstrated that more intelligence can be incorporated into the network's edge where load balancing and real-time decisions for mission-critical applications can be made (Deepali & Kriti, 2018).

In the domain of edge computing, DDoS attacks, and job offloading in edge computing, were studied in this paper (Ahmad & Islai, 2020). However, no implementations of the DDoS scheme and real-world scenarios were considered. Edge servers with limited capacity are used in the edge computing paradigm to support advanced latency-sensitive applications. Many elements of DDoS attacks, such as actual attackers, the handlers, zombie hosts, the target hosts and their effects on edge servers, such as agent-handler, IRC-based, web-based models, and several edge computing models were discussed.

A scheme designed to mitigate the effects of DDoS attacks at the network edge is proposed (Qiang et al., 2021). The basic concept was to distribute the malicious traffic to all edge servers so that servers are not overwhelmed by the attack. An EDMOpti and EDMGame were used to find the optimum small-scale EDM solutions using integer programming and the other for discovering sub-optimal large-scale EDM solutions using game theory. Our work seeks to minimize DDoS attacks at the network interface.

The authors proposed a MEC shield, DDoS mitigation architecture that makes use of MEC's capacity to install many smart filters at the attack source/edge destinations. MEC shield protects the network against malicious traffic from Heterogeneous Internet of Things (H-IoT) devices by deploying smart self-organizing map (SOM) filters in advance. Based on the experiments, the results show that SOM filters can detect local traffic (Nhu-Ngoc et al., 2021). Furthermore, the MEC shield's distributed design and control strategy addresses the bottleneck that occurs during DDoS attacks and saves about 10 per cent in CPU utilization when compared to other solutions.

The authors focused on service availability in edge computing by presenting the most serious security threat, such as DDoS Attack, which

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reduces the availability of cloud-provided services and resources. Three approaches for mitigating DDoS attacks were proposed in accordance with the specified objectives as major contributions (Opeyemi et al., 2016). Contribution 1: The study offered an IP spoofing detection technique that analyzes and matches the operating system of arriving packets in the front end of the cloud environment using host-based operating system fingerprinting in both passive and active stages. In both the active and passive stages, packet header characteristics are utilized to identify the source of the packets by determining the operating system (OS) to detect a fake source IP. In addition, throughout the active and passive stages of OS fingerprinting, the observed final time to live (TTL) value is employed to account for false negatives during detection. Contribution 2: Due to the large amount of traffic that must be processed during a DDoS attack defense in cloud computing, the study has developed an Ensemble-based Multi-Filter Feature Selection technique (EMFFS). Before categorization, the data is pre-processed. The results for EMFFS are combined. Information gain (IG), gain ratio, and chi-squared are four approaches for selecting filter features to pick essential characteristics, and reliefs. Contribution 3: Using the packet inter-arrival time to identify DDoS flooding attacks against cloud services, provides a change-point monitoring method (IAT). The technique takes advantage of the fact that a number of DDoS attacks are automated and follow a similar pattern. As a result, they may be differentiated from regular traffic and monitored using a cumulative sum technique. The study considered DDoS mitigation schemes in traditional cloud computing and our work considers MEC environments.

Most literature focuses on traditional cloud computing and DDoS attack that target one layer of the network. Hence, there is a need to develop robust mitigation schemes that focus on multi-layered DDoS attacks in MEC.

3. Methodology

We compared the effectiveness of the ML algorithms using the actual data collected in (Iman et al., 2019). The dataset was generated in a network which was under attack by the most up-to-date DDoS attacks. Additionally, it contains the outcomes of the network traffic analysis performed using CICFlowMeter-V3 with flows categorized according to the time stamp, source and destination IP addresses, source and destination ports, protocols, and types of attacks. We partitioned the data set into 80 per cent, and 20 per cent for training and testing respectively. Different performance metrics were used to evaluate the performance of the algorithms. The following tools were utilized, ANACODA3-2021 and Jupyter notebook to generate the results. We selected the Jupyter notebook since it is an open-source machine-learning algorithms simulator. The generated results were represented graphically for analysis. Table 1 present the parameters used in evaluating the algorithms, while Table presents the simulation environment.

Table 1 The parameters used

Algorithm	**Training parameters**
Decision Tree	Two leaf instances, three folds for the REPtree, and one for seed random data shuffling
Random tree	Ten random attributes, 25 minimum instances per leaf, 0.0002 minimum, 21 maximum depth for the tree, five folds for back fitting, and break ties randomly when many attributes appear equal.
Logistic regression	The maximum tree depth is 28.
Random forest	Infinite depth, maximum of forty trees, and six random fields per tree
SVM	Five layers, 30 epochs (one input, 3 hidden, 1 output)

Table 1 shows the optimization of the hyper-parameters approach depending on the Machine learning techniques used.

Table 2. Computational Environment

Parameters	**Values**
Operating System	Windows 10
Dataset	CICDDoS2019
Random memory	8gb
Machine Model	HP intel core i5 8^{th} generation
Tools	ANACODA3-2021 and Jupyter notebook

Table 2 shows the environment that was used in training and testing the machine learning algorithms. The operating system that was used to run the project was windows 10, running on HP intel core i5 8^{th} generation computer.

4. Experiments and Results

The experimental results were generated through the training and evaluation of different ML algorithms. To evaluate the performance of the algorithms, we used different performance metrics such as the Precision, Recall, Accuracy, False alarm rate (FAR), and F1-score. Comparative results are presented in Figure 1. The algorithms with high false alarm rates were compared to the ones that are less effective in detecting DDoS attacks. If the technique has low detection and high precision, it shows biasness in DDoS attacks detection and therefore the F1 measure is evaluated/computed to determine the best algorithm. For the algorithm to be regarded as the best, the F1-score rate must be high.

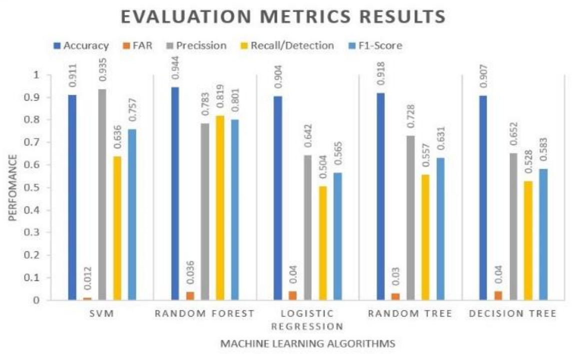

Figure 1 The performance of the machine learning algorithms

Figure 1 presents the ML algorithms' comparative results. The accuracy of all ML algorithms was more than 90 per cent with the random forest achieving the highest accuracy level. We can conclude that the ML algorithms performed well against DDoS attacks. F1-Score results indicate that Random Forest and SVM are the best-performing algorithms. The best two performing ML algorithms in terms of F-1 score achieved precision results that are greater than 75 per cent. All algorithms recorded an overall detection/recall probability of more than 52 per cent, and there is a minimal False alarm rate of less than 1.2 per cent for each algorithm. In analyzing the overall results, SVM is the best technique since it has the least error of 0.012 prediction and high accuracy of 91.1 per cent.

Table 3: Tabular representation of Figure 1

	SVM	Random forest	Logistic regression	Random tree	Decision tree
Accuracy	0.911	0.944	0.904	0.918	0.907
FAR	0.012	0.036	0.04	0.03	0.04
Precission	0.935	0.783	0.642	0.728	0.652
Recall or Detection	0.636	0.819	0.504	0.557	0.528
F1-Score	0.757	0.801	0.565	0.631	0.583

Table 3 below presents a clear representation of the results in Figure 1.

6. Conclusions and future works

The study investigated the performance of ML algorithms in mitigating the effects of DDoS attacks in MEC. The accuracy, FAR, recall/detection, precision, and F1-score metrics were used to evaluate the performance of the algorithm and comparative results were presented. The results were generated using the Jupyter notebook and ANACODA3-2021. ML techniques that were considered are Logistic Regression, Random Forest, Random Tree, SVM and Decision Tree. Based on comparative results, it is shown that algorithms with high False alarm rates are likely to increase the severity of DDoS in MEC. As a result, an algorithm with a high accuracy rate and a low False Alarm Rate will be more efficient in detecting DDoS attacks. This study was aimed at finding the best method of mitigating DDoS attacks in MEC. Hence, the support vector machine was shown to be the most effective solution in detecting and mitigating DDoS attacks such as the ICMP-flood, Smurf, TCP-flood, and UDP-flood. Our study used supervised learning. In future, we will consider a hybrid approach which integrates the best-performing ML algorithms observed in this study.

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Optimal Video Compression Parameter Tuning for Digital Video Broadcasting (DVB) using Deep Reinforcement Learning

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Abstract
DVB (digital video broadcasting) has undergone an enormous paradigm shift, especially through internet streaming that utilizes multiple channels (i.e., secured hypertext transfer protocols). However, due to the limitations of the current communication network infrastructure, video signals need to be compressed before transmission. Whereas most recent research has concentrated and focused on assessing video quality, little to no study has worked on improving the compression processes of digital video signals in lightweight DVB setups. This study provides a video compression strategy (DRL-VC) that employs deep reinforcement learning for learning the suitable parameters used in digital video signal compression. The problem is formulated as a multi-objective one, considering the structural similarity index metric (SSIM), the delay time, and the peak signal-to-noise ratio (PSNR). Based on the findings of the experiments, our proposed scheme increases bitrate savings while at a constant PSNR. Results also show that our scheme performs better than the benchmarked compression schemes. Finally, the root means square error values show a consistent rate across different video streams, indicating the validity of our proposed compression scheme.

Keywords: deep learning, digital video broadcasting, multimedia streaming, reinforcement learning, video quality assessment

1. Introduction

The interest in multimedia services continues to increase at a tremendous pace, evident in the increase in data rate in 2021, and hoping to increase by a large percentage by the end of 2022 (Pocovi et al., 2017). Many of these services are offered through subscribed-internet-based media, such as YouTube, Vimeo, Netflix, and Amazon's prime video. This "paradigm shift" has influenced terrestrial satellite-based broadcasting companies to adopt internet-based multimedia services through a lighter digital video broadcasting (DVB) box or a parallel subscription that enables online streaming. A common protocol to achieve this online streaming is the dynamic adaptive streaming over HTTP (DASH), known for its simplicity and flexibility (Ekmekcioglu et al., 2016). However, these complementary options come with concurrent tasks during broadcasting. Video signal compression is a vital part of these tasks, given its correlation with video signal quality. The major problem of adopting over-the-top (OTT) multimedia signal transmission is the significantly noticeable difference in quality from the traditional satellite-based transmission. However, the limitations of the current communication network infrastructure (mostly 4G and 5G) do not permit the transmission of the full features of video signals. Hence, a need to compress (or remove some features from video signals to a certain threshold before transmitting (Santhi et al., 2003; Tse & Viswanath, 2005). Therefore, it is crucial to work on improving the compression process of video signals while satisfying customers' quality of experience (QoE).

Generally, studies have developed and adopted different standards, algorithms, or techniques for video signal compression. The H.264 and H.265 are the most widely used compression standards, particularly for motion-based codecs. Studies (Wiegand et al., 2003; Schwarz et al., 2007) have developed a video transmission framework using H.264 encoders to transform video signals. The form of video codec is reported to have some spatial redundancies since the fundamental principle of compression is to move blocks of signals alternatively. Even with the use of scalable video coding in (Kalva, 2006) to extend the capabilities of the H.264, there is still an issue of complexity due to the increased bitrate for efficiency compensation. The study in (Xu et al., 2018) hasadopted H.265 for video compression to mitigate this effect. However, there are still potential spatial and temporal redundancies, which cause poor

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video signal quality. In fact, it was concluded in (Ohm et al., 2012) that H.265 encoders, using objective and subjective metrics, perform similarly to H.264 encoders while saving 50 per cent of the bitrate`.

Aside these compression standards, other standards have been developed, such as the texture warping and synthesis developed in (Zhang & Bull, 2011) to transform original images. The authors developed the algorithm such that the whole images are not encoded in the first phase before motion estimation. A complex wavelet transform was used to segment the image texture region focusing on the spatial and temporal properties. The artifact video metric was used to evaluate the quality of the reconstructed images, with results showing a 60 per cent bitrate saving. Kahu & Bhurchandi, (2017) developed a differential directional filter bank coding scheme to compress videos in a sequential manner. Their proposed algorithm was able to decrease redundancies in the motion compensation stage while their implementation of the adaptive rood pattern search scheme reduces the encoding time.

In the quest to improve video quality, recent studies have developed deep machine learning techniques. The deep network architecture developed in (Ballé et al., 2015) made this possible. A parametric nonlinear transformation is introduced to normalize features from natural images. It was shown that the transformed images could be differentiable and inverted, making it possible to use probability density to filter out image noise. Most importantly, it can be shown that the transformation model can be optimized using the normalization objective. This effort makes it possible to implement the optimization of the deep network architecture. Lu et al. (2020) developed the first end-to-end video compression framework using pixel-based motion compensation. The framework combines the H.264 encoder and the neural network while implementing motion compensation, motion estimation, motion compression, residual compression, and bit rate estimation. Another work on deep learning compression is done in (Wu et al., 2020), where a generative adversarial network (GAN) was used to reconstruct video frames in a surveillance video streaming framework. The GAN uses the spatial and temporal discriminator to increase the similarity between an original and the reconstructed video. The GAN was able to reduce distortion rate under a low bit-rate streaming.

The review has shown a substantial amount of work done on video compression, especially using deep learning techniques to generate quality video frames while maintaining low complexity. A major highlight is a relationship between bitrate and video quality. Finding the “right” bitrate remains a challenge for deciding video quality. Nonetheless, there has been little research on applying deep learning in a video streaming space, especially in a dynamic adaptive streaming over HTTP (DASH)-based DVB setup. As a result, this study presents a DRL system for identifying the optimum bitrate for developing video quality and analyzing efficiency and performance. The throughput is quite important since we are dealing with real-time streaming, which requires minimal delay. This work's significant benefits are presented below:

- We develop a DRL system to figure out the more suitable video bitrate for video compression in an end-to-end DASH-based online streaming DVB setup.
- We introduce a multi-objective optimization that utilizes a weighted sum aggregate approach to estimate video quality. The video quality is perceived using the PSNR, and SSIM, and the delay time is observed using network parameters in the real-time video streaming setup.
- Experiment findings indicate that the system surpasses commonly deployed encoders such as H.264 and H.265 in terms of efficiency and performance. The framework is also configured on different image transformation algorithms.

The paper is well categorized in this manner: Unit II discusses the system model; Unit III discusses the problem formulation; Unit IV describes the working of our recommended framework; Unit V displays the investigational outcomes from the framework, and Unit VI reviews the study.

2. System Model

We begin by explaining the DVB setup based on a DASH protocol, illustrated in Fig. 1. Based on a content delivery network, the incoming video stream from the server is packetized as a bitstream in a content server that is concurrently transmitted to end customers through the DVB setup. An OTT-based DASH protocol receives the stream and disseminates it to various end users. This process is ideal until issues such as intermittent buffering, outrageous lagging, and obvious low content quality start to emerge. These issues reduce the QoE, thereby causing dissatisfaction from customers. To tackle this issue, we concentrate on the compression characteristics and network parameters. Right before the video signals are transmitted to the cloud, we construct an end-to-end framework that processes the incoming real-time video.

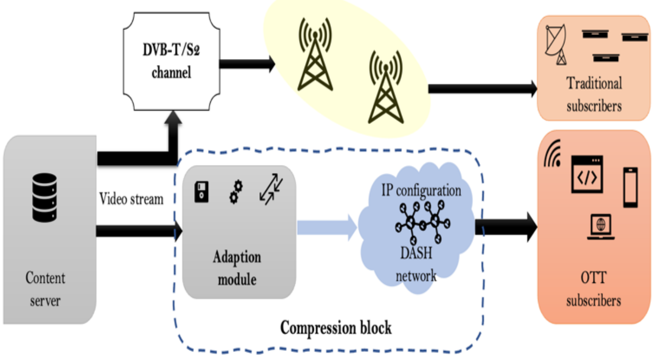

Fig 1. The DVB video streaming model.

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As demonstrated in Fig. 2, the end-to-end design incorporates encoding and decoding. The incoming stream going into the encoder is denoted as a video sequence, $V = \{f_1, f_2, \dots, f_{t-1}, f_t\} \in N$, where f_t represents a static frame of the incoming stream at time t and N denotes the overall amount of frames in the video stream. We extracted spatiotemporal features of the video stream using a recurrent neural network, yielding bitstreams $\breve{M}$ that represent the original images.

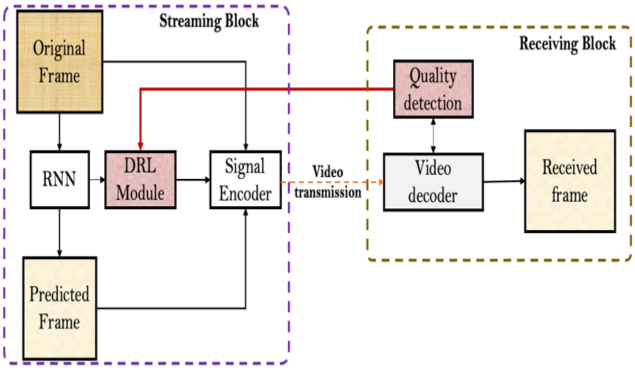

Fig 2. The DRL video compression framework.

The first step of the compression process is to quantize the video stream V. Knowing that the quantization process is not differential, thereby making end-to-end compression impossible, we draw inspiration from (Ballé et al., 2016), using the rounding operation to add uniformly distributed noise to the residual Spatio-temporal features of the incoming video stream. Therefore, having an output, $\hat{V}$. The next step is the entropy coding, where we used the arithmetic coding to encode $\hat{m}$ and $\hat{y}$ into bits. The bitrate value is then employed to compute the encoded probabilistic model stream $\hat{y}$ and compute the entropy of the bit price. Finally, in the decoder block, the video stream with a static frame f_t is reconstructed into $\widehat{f_t}$.

3. Problem Formulation

Service providers are tasked to provide high-standard video streaming on customers' devices. However, video quality is perceived differently according to customers' bias. We will be using an objective approach to measure the video quality and quantify customers' QoE. The following metrics are adopted for this study.

A. *Peak-Signal-to-Noise-Ratio*

The PSNR metric is applied for computing the most attainable signal concerning the introduced noise in a reconstructed or compressed video (or a snapshot image in a video). The PSNR value quantifies the difference between the original and reconstructed video, and, since these values can have a wide range, they are counted in decibels (dB), expressed as (Huynh-Thu & Ghanbari, 2008).

$$PSNR = 10\log_{10}\left(\frac{\mathcal{L}^2}{\frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[p_{mn}-q_{mn}]^2}\right) \quad (1)$$

where m and n represent the video frame dimension; p_{mn} and q_{mn} represent the original and reconstructed video respectively. Finally, $\mathcal{L}$ is the maximum dynamically possible pixel intensity of the image.

B. *Structural Similarity Index Measure*

An SSIM is considered a full reference technique for quantifying the current video frame based on the original, uncompressed video frame. This metric uses the structural properties of images for perceiving a similarity. The luminance, structure, and contrast similarity are taken for the original and compressed videos, using the circuitry from (Wang et al., 2004). The three measurements are combined using

$$SSIM_{p,q} = \frac{(2\mu_p\mu_q + g_1)(2\sigma_{pq} + g_2)}{(\mu_p^2 + \mu_q^2 + g_1)(\sigma_p^2 + \sigma_q^2 + g_2)}. \quad (2)$$

The μ_p and μ_q are the average values for the frame dimension; σ_p^2 and σ_q^2 are the variance of the dimension; σ_{pq} is the covariance of dimensions; while g_1 and g_2 are for stabilizing the denominator, computed as $0.01\mathcal{L}^2$ and $0.03\mathcal{L}^2$, respectively.

C. *Time Delay*

Our model deals with real-time video streaming, especially for live events. It is therefore important to measure the delay time between the sending and receiving time. Inspired by Huang et al., (2018), we used a delay gradient strategy to quantify the time transient across the two blocks, considering the mismatch in devices' clocks. The delay is expressed as

$$\mathcal{T} = \Delta F_t^R - F_t^S, \quad (3)$$

where ΔF_t^R is the change in sending time t for frame F, and F_t^S is the sending time t for frame F.

4. Reinforcement learning for video quality in DVB systems

Reinforcement learning (RL) techniques generally use value-based or policy-based approaches to learn random policies, either by directly choosing the best policy that relates to an action taken in a series of events or finding the temporal difference to quantify the future rewards, selecting the action that corresponds to the highest value function. Given the potential explosion of the state space when having continuous variables as in our case, bit rate, we use a deep neural network to represent state-actions pairs using weights. Firstly, we develop our problem using the Markov decision process (MDP).

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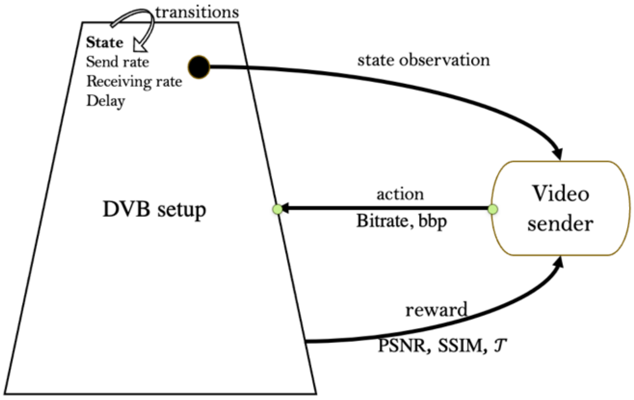

Fig 3. The reinforcement learning adoption for video quality.

D. Markov Decision Process

The problem is modeled as an MDP, using the notation, $M = \langle S, A, R, \gamma, P \rangle$ whereby S is the state of the environment, A represents the act by an agent in the environment, and R is the received reward after taking an action, used to determine if the quality of the action is taken according to the next stage of the environment. P is the probability distribution determining the transitions of states; and γ is the discount factor, used for leveraging the expected rewards to the present reward. Fig. 3 shows the application of MDP in our model.

State: Knowing that our environment is the DVB setup, we consider the state $S_t = \langle s, r, d, p, v \rangle$, whereby s and r are the sending and receiving video bitrate correspondingly, d is the delay between the sending and receiving time; p and v are the previous and predicted video stream quality respectively.

Action: The action taken by an agent is the sending bitrate selection at time t. Remembering the relationship between the bitrate and video quality, we aim to learn the optimal video bitrate to produce good video quality.

State Transition: This is the probability of taking an action A_t in state S_t; represented as $f(S_t, A_t)$.

Reward: When the agent takes the action A_t , it gets an immediate reward R_t. We aim to maximize QoE, we used a multi-objective-based reward framework, where three metrics from Section III, expressed as

$$R_t = w_1 PSNR + w_2 SSIM + w_3 \mathcal{T}, \tag{4}$$

Where w_1, w_2, and w_3 are the weights assigned to each metric. The weight assignment represents the preference scale of a decision-maker.

This study presents the use of Q-learning methodology for solving the bitrate decision issue. The effect of the sender (the agent) taking an action A on state S, following a policy ω is computed using the sum of the discounted expected rewards, shown in (4),

$$Q^{\omega}(S_t, A_t) = \mathcal{E}^{\omega}\left[\sum_{k=0}^{K} \gamma^k R_{t+k}\right], \tag{5}$$

where γ balances the short- and long-term reward over the expectation $\mathcal{E}$. The optimal policy, ω^* which maximizes the QoE is expressed as

$$Q^*(S_t, A_t) = \max_{\omega} Q^{\omega}(S_t, A_t). \tag{6}$$

We update the state-action pairs, $Q_t\ (S_t, A_t)$ by using the bellman's equation, described in (7). The next Q-value is determined by the old Q-value and the probability to move to the next state, learned by the α parameter. The new (or next) Q-value is learned as

$$Q_{t+1}(S_t, A_t) = Q_t(S_t, A_t) + \alpha_t[Q_t(S_{t+1}, A_{t+1}) - Q_t(S_t, A_t)]. \tag{7}$$

The Q-learning approach uses a look-up table to estimate the action-value pairs, but our state space consists of continuous variables. The continuous variables cause a large Q-table which could make the problem intractable. We address this problem by implementing a deep neural network (DNN) to appraise the action-value utility.

The traditional Q-learning algorithm will take the states of the DVB setup and feed them into a deep Q-network. We dub the algorithm as deep reinforcement learning video compression (DRL-VC). Algorithm 1 shows the DRL-VC's training process. The algorithm starts with the initialization of the DQN and target network parameters, θ and $\breve{\theta}$. Given several epochs, a **for** loop is created to update the DQN parameters based on the observed reward at each episode.

Algorithm 1 DQN Training process

Initialize the DQN and target network parameters; $\theta, \breve{\theta}$, episodes, $\mathcal{E}$
for all $\mathcal{E}$ **do**
  obtain state observation, using state, S_t
  for each time t
    select an action vector, A_t using a random parameter
    perform action A_t and receive the reward R_t
    transition to the next state, S_{t+1} using $f(S_t, A_t)$
    store the experience as a vector; (S_t, A_t, R_t, S_{t+1}) in a buffer, $\mathcal{D}$
    sample a batch of U samples from buffer $\mathcal{D} = (S_t, A_t, R_t, S_{t+1})\,_t^U$
    calculate $\breve{y}$ using the Q-value in (5) from the DQN target
      $\breve{y}_t = R_t + \gamma \max_{A_t} Q(S_{t+1}, A_{t+1}|\theta)$
    Update the DQN's weight from the main network
      $L_\theta = \frac{1}{U}\sum_t \left(\breve{y}_t - Q(S_t, A_t;\ \theta_t)\right)^2$
    Update the DQN parameters using a gradient approach $\theta \leftarrow \theta - \sigma \nabla L_\theta$
  end for
end for

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5. Results and Discussion

We discuss the evaluation of our proposed real-time video streaming compression scheme. The performance is evaluated using the KonVid test video database, streamed at 30, 40, and 60 frames per second at a varying time duration. The DVB setup was later analyzed with the proposed framework using live videos. The PSNR and SSIM values were compared to the bits per pixel (BPP) settings using each adopted video database. Fig. 4 shows the video quality using the PSNR for the average BPP, comparing our proposed DRL-VC to other compression schemes. It is observed that there the DRL-VC performs better than the benchmarked schemes, especially in the range of 0.15 to 0.2 bpp, our scheme performs significantly better than the H.264 and H.265 encoders, while slightly surpassing the DVC scheme by some margin.

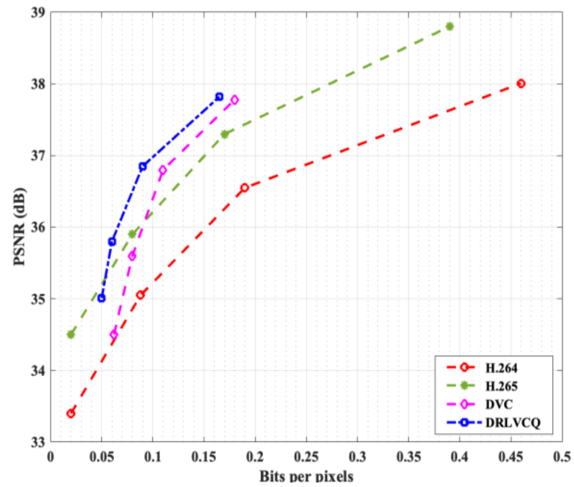

Fig 4. Video quality assessment for KonVid database using PSNR values

In Fig. 5, it is seen that the DRL-VC also, by some margin, outperforms the DVC, but is significantly better than other schemes. It is worth noting that the DRL-VC has a higher average performance than the DVC with the PSNR and SSIM metrics.

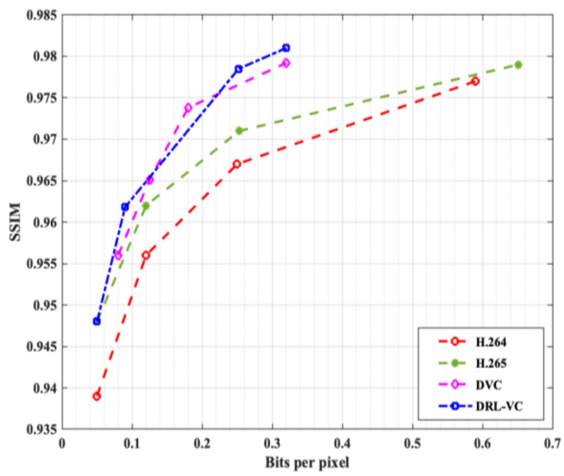

Fig 5. Video quality assessment for KonVid database using SSIM values

An ablation study is carried out on our scheme, starting with the impact of decision-making preference. The BDBR and BD-PSNR were adopted to assess video compression schemes' performance. BDBR is the bit rate savings percentage using a baseline compression scheme at the same PSNR, while the BD-PSNR depicts the performance gain using a baseline compression scheme at the same bit rate. The weight for each metric is varied to increase the preference rate and we pegged the favored metric to have 50 per cent weighting, meaning that the 0.5 is assigned to the metric of interest, while the remaining 0.5 is split between the remaining metrics. It is to note that the initial weighting system assigns equal weights to all metrics. Table I shows the results for each metric. It is seen that the best values are obtained when the SSIM is favored. The SSIM-focused scheme has a bit savings of 21.2 per cent while the PSNR-focused scheme can only produce a saving of 17.5 per cent. This outcome conforms to works in literature that report the significance of the SSIM metric in assessing video quality and its superiority over the PSNR. It is seen that focusing on the delay metric will not necessarily improve video quality; hence the poor values.

TABLE I. COMPARISON OF DIFFERENTLY WEIGHTED METRICS USING THE BDNR AND THE BD-PSNR

Weighted metric		Vid_Str1	Vid_Str2	Vid_Str3	Vid_Str4
PSNR (50%)	BDBR (%)	-25.51	-17.24	-18.16	-32.02
	BD-PSNR	0.75	0.51	0.64	1.12
SSIM (50%)	BDBR (%)	-28.59	-23.33	-19.27	-33.61
	BD-PSNR	1.22	0.66	0.92	1.42
DELAY (50%)	BDBR (%)	-21.02	-17.08	-13.85	--25.05
	BD-PSNR	0.71	0.37	-0.52	0.89

Using different network characteristics, we analyze the delay time using three configurations of our proposed compression scheme. We separately integrate three encoders in our scheme and assess the effect on the delay time. DRL-VC-1, DRL-VC-2, and DRL-VC-3 utilized the Arithmetic-based X.264, Hyperprior-based H.265, and the RNN encoder respectively. From Fig. 6, it is observed that the other encoders use a more complex process, delaying the video transmission. The RNN proves to be less complex.

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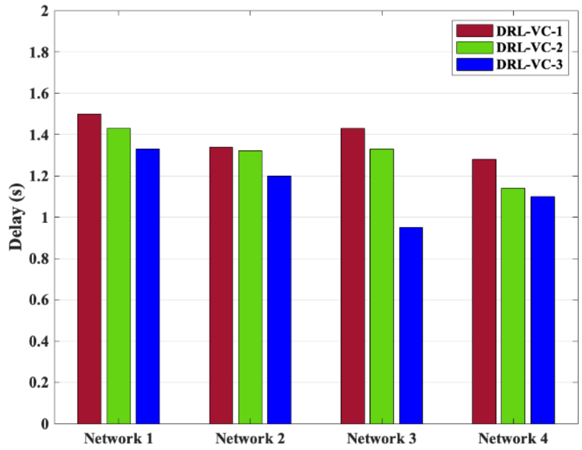

Fig 6. Delay time for different encoder-based configurations.

To further validate our proposed scheme, we ran an error test across different video streams using the root mean square error (RMSE). An RMSE can measure the correlation of errors across multiple outputs and explain the hidden variance across a dataset. From Fig. 7, the RMSE is plotted across different video streams. The video streams are characterized by their frame rates and dimensions. Knowing that the lower RMSE values indicate better and, with bright yellow being the lowest in the figure, it is seen that our framework performs significantly well across different video streams.

Fig 7. RMSE values for different video streams.

Finally, we analyze the multi-objective aspect of our proposed scheme. Pareto optimal solutions were generated using a variety of weights. Fig. 8 shows the Pareto front for PSNR and SSIM. The circled data point shows the compromise solution from other potential solutions. The solution shows an SSIM value of 0.9702 and a PSNR value of 37.92 dB.

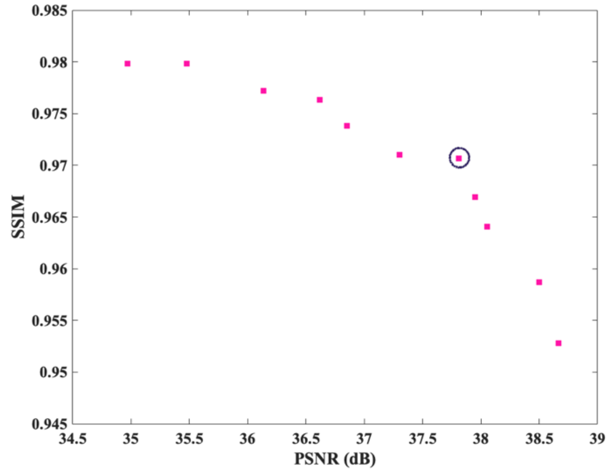

Fig 8. Pareto front for PSNR ans SSIM.

7. Conclusion

In this study, we presented a novel multi-objective deep reinforcement learning video compression framework for real-time applications in a digital video broadcasting setup. The study formulates a multi-objective problem, considering PSNR, SSIM, and delay time. We developed our scheme to start with an RNN-based encoder, followed by the DRL. The DRL was able to learn the optimal bitrate for producing video quality, considering network variability. The proposed scheme proves to perform better than benchmark schemes, using the PSNR and SSIM metrics. The bitrate savings is increased by a large margin, especially when the SSIM is given the most preference. The scheme was also validated using the RMSE to measure the error rate among different video streams, which prove effective with a minimal deviation across all streams. Using the weighting method, we were able to generate Pareto optimal solutions for the PSNR and SSIM. For further studies, we will introduce a technique for selecting actions in the DRL framework, hoping to generate better policies for video compression. Furthermore, the motion compensation part of the compression framework will be studied. We will also include the effect of heterogenous devices in the compression framework, making it more robust for implementation.

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A Framework for the Development of Human Centred ICT4D Initiatives: A Capability Approach Perspective

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Abstract
The term "development" is often used concomitantly with Information Technology for Development (ICT4D) and Information Systems for Development (ISD4D) initiatives in discussions related to these fields. Development as an outcome is often pursued through ICT mechanisms without questioning the assumptions about its contribution to human development.
Development, as a construct, has been the subject of increasing debate in the ICT4D research community, and is especially fuelled by the current global economic uncertainty. It is when the paradigm of development is shifted away from the predominant Western theory of development, as postulated by many economic development theorists, as well as other development theories, such as utilitarianism, for example, that new development outcomes can be explored. One such outcome is the result of a human centred development approach, where well-being and human development form the focal point of ICT initiative outcomes. The Capability Approach (CA), developed and promulgated by Nobel Prize laureate Amartya Sen, provides an operationalizable framework that views development as human development and having or obtaining certain freedoms. The CA affords the observer the opportunity to assert the social dimension of development and, in the case of this study, that of a rural community in South Africa, with the ICT4D artifact delineated to mobile health, or mHealth.

Keywords: Development, ICT4D, ISD4D, mHealth, Capability Approach

1. Introduction

It is broadly argued, on both local and international fronts, that information and communication technology (ICT), can be leveraged toward development in remote or rural communities of developing countries (Sinha, 2005; Lagsten, 2011). Mobile phones and technology, as part of the broader ICT field, have become one of the major, ever-growing, world-wide markets. The growth in the mobile technology market has been bolstered with the advent of smart mobile technologies such as, for example, the so-called smart phones and tablets and have initiated the convergence of the computer and the mobile device (Avgerou, 2015).

It was the mobile phone that became the prevalent communication tool in developing countries such as South Africa (ZA) in the late 1990s and early 2000s, and, to date, these devices are the primary gateways for accessing the Internet in the developing world, as opposed to the early wide adoption of the Internet through networked laptop and personal computers in first world countries. A major contributing factor to the foregoing was the lack of Internet service provider and connection infrastructure in developing countries, such as high-speed fibre optic cabling and asynchronous digital subscriber lines, or ADSL (Duncombe, 2011).

High speed Internet connections have only recently been introduced in developing countries and access is still relatively expensive and limited as these technologies are being rolled out. In contrast, mobile phone connectivity and infrastructure grew exponentially from its inception in developing countries.

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The fact that mobile data charges are often more affordable when compared to the charges levied for fibre optic connections in some instances, also mean that, in the South African context at least, more and more people opt for mobile access to the Internet.

A result of the development, introduction and subsequent dissemination of smart mobile devices was a new and crescent field of software development in the form of mobile applications, or *mobile app* development, with many mobile software applications that have been developed for diverse uses since. As the popular colloquialism goes "*There is an app for everything*".

The development of services that operate through mobile app technologies have seen a steady increase, ranging from having access to the local weather forecast to managing your finances, to name but two examples. One of the services that had emerged from the possibilities yielded by new mobile technologies (and of interest to this investigation), is mobile-health, or mHealth (Coleman, 2009; Martinez, 2012).

mHealth can be described as the practice of medicine and public health, supported by mobile devices through integrating mobile telecommunication and multimedia technologies to produce mobile and wireless healthcare delivery systems. mHealth is an evolutionary sub-category of *electronic-health*, or *eHealth* and there are a number of these initiatives currently active throughout ZA (Leon, Schneider, & Daviaud, 2012).

Evidence suggests that many of the introduced mHealth initiatives often fail in developing countries (Avgerou, 2000; Avgerou & Walsham, 2010; Avgerou, 2015). Understanding why these initiatives fail may lie in understanding what development impact such initiatives have or, set out to achieve.

How we define development will undoubtedly influence the development outcomes that are defined for a prospective initiative. A widely accepted and well-known definition of development is evidence of economic growth or, as a perceived increase in a region's gross domestic product, or GDP.

When the actual outcomes of ICT-driven development initiatives and ICT resources are refocused to address development and not development itself, the ICT initiatives become a means to an end, and not the end itself (Hatakka & De', 2011; Lagsten, 2011). Researchers in the fields of ICT4D and ISD4D are challenging mainstream neoliberal development discourse regarding development, what indicators of development are, and how development is assessed (Bada & Madon, 2006; Andersson, Grönlund, & Wicander, 2012).

Amartya Sen, a Nobel Prize laureate, is one of the foremost role players in the shift in perception regarding the terms that constitute development. Sen conceptualized the Capability Approach (CA) in 1980, and he improved and expanded upon this conceptual framework until 2009. The CA is an interdisciplinary, broad normative framework that can be operationalized as an alternative approach to welfare economics. Development is conceptualized as human development when viewed through the lens that is the CA, effectively moving away from the traditional theories that assesses development solely in economic terms. From this stance, development is essentially viewed as having, or obtaining, freedom (Sen, 1999).

Sen describes the doings and beings of an individual as an individual's *functionings*. Sen continues his philosophy by adding that an individual's ability to attain valuable functionings and choosing between these valuable functionings can be summarized with the term *capabilities* (Sen, Equality of What?, 1980; Sen, Development as Freedom, 1999).

This project aims to address two apertures which have been identified:

1. The absence of an mHealth application that aims to develop/expand community capabilities and realize potential health functionings in the context of a rural community in South Africa.
2. The lack of a conceptual framework that informs the development of ICT4D artefacts from a capability development perspective.

Using the theoretical and philosophical elements of the CA, this investigation is aimed at developing a mobile artefact with human development as the development paradigm, and mHealth as a delivery conduit to potentially realize capabilities on a community level. This study will therefore operationalize the basic concepts of the CA based on scholarly contributions and input from the community

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itself. Finally, the researcher aims to suggest theoretical adjuncts to the discourse related to ICT4D initiatives in the form of an artefact development framework as to accommodate the ability of a rural community to attain valuable functionings, or, what the investigator refers to as *community capabilities*. The term *community capabilities*, in essence, summarizes what a community is effectively able to do, and be, that an individual is not able to do or achieve on their own.

It is noteworthy to mention, at this juncture, that the assessment of the associated development outcomes falls beyond the scope of this discourse, but it did form part of a larger study and that the findings will be disseminated in due time.

The central question at hand is:

1. How can a ICT4D artefact be developed with human-development outcomes at the centre of the initiative?

Sub-questions to ask in support of the primary questions are:

i. What are the factors that inhibit ICT4D development goals to be achieved from a human-development perspective?
ii. What components of an ICT4D artefact are essential as far as functionality is concerned when considering a human-development approach, and,
iii. How can these components be identified?

Contextual Community Background

The *Sethakeng* community, near the town of Kuruman in the Northern Cape, agreed to be involved in the study after the aims, objectives, and expectations of the larger study, as well as the associated ethical considerations, were clearly outlined. The community can be described, from a cultural perspective, as a very traditional Sotho-Tswana people. The predominant languages spoken and understood by the community is seTswana (or simply Tswana), Afrikaans, English and South Sotho to a varying degree (Dioka, 2016).

It is worthwhile to mention that the Northern Cape province is the largest, but most scarcely populated province in South Africa, accommodating only 2 per cent of the total populous (Statistics South Africa, 2017) on a 372 889 km² area.

Figure 1 depicts the population density of each province in South Africa per square kilometre (Alexander, 2019).

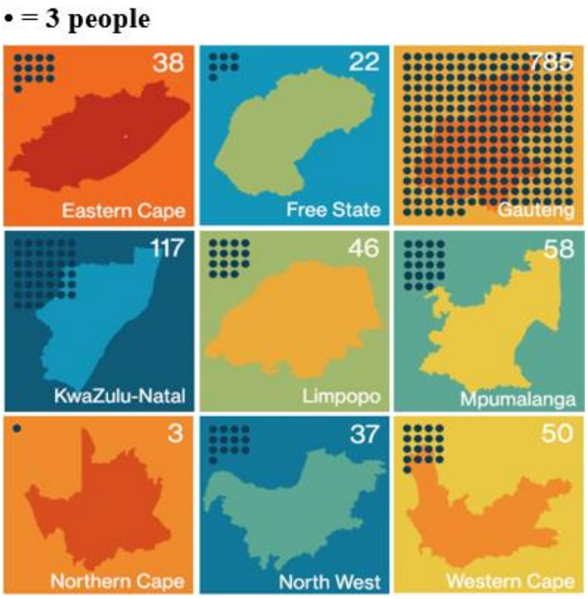

Figure 1: The population density of South African provinces per square kilometer

The age of the potential users of the ICT4D artefact was an important consideration, as one of the objectives of the study was to design, develop and disseminate an mHealth application within a community that exhibits clear health-deprivation issues. The aim was to proportionally collect data so that community members would be able to conceptualize the objectives of the study to some degree, have knowledge of operating mobile devices and applications, and would be able to communicate effectively.

The UNDP provides clear differentiations between age groups and is presented in table 1 (United Nations Development Programme, 2012):

Table 1: Age groups and classifications according the UDP

Classification	**Age Group**
Infants	0 – 2 years
Children	2 >= 12
Teenagers / Youth	12 >= 18
Young adults	18 >= 25
Adulthood	25 >= 40
Middle age	40 >= 60
Old age	60 > +

The classification schema presented in Table 1 was used to group community members into participatory groups, as explained in more detail in a latter section of this discourse.

The succeeding sections of this discourse are dedicated to an overview of related work, with a specific focus on Amartya Sen's Capability Approach and development, followed by an outline of the methodology employed to conduct this study within acceptable research parameters. An abbreviated description of how the data was collected and the results of the data analysis, including the mHealth artefact and the proposed conceptual framework follows, after which a summarized discussion, rooted in the findings, is presented. Finally, the conclusion, including limitations and possible future work is presented.

2. Related Works

It is meaningful to first consider a limited overview of the CA and its primary constituents to better understand the conceptual foundation of the approach employed for this investigation. The CA is distinguished from other approaches in that it does prescribe which variables to assess, is focused on actual outcomes as opposed to measurable variables, such as the average household income, incorporates a wide array of ideas and concepts, and places the human being at its core (Hatakka & De', 2011). The CA is then a more inclusive approach when compared to other development theories, and ventures beyond the space of achievement by considering the real opportunities that people have to be, who they want to be, or live a life that has contextual meaning (Krishnakumar & Ballon, 2008).

The CA is grounded in certain theoretical concepts, many of which are unique to the approach. The primary building blocks of the CA are *functionings*, *capabilities*, *wellbeing*, *freedoms* (or *choice* according to some sources), *agency*, and *conversion factors* (Sen, 1985). Sen posits that *capabilities* are, in essence, what a person is effectively able to do (Sen, 1993). Some literary sources also refer to capabilities as the combination of real opportunities that a person have access to realize functionings (Zheng, 2007). *Functionings*, according to the CA, can be defined as the "beings and doings" of individuals. Examples of functionings include "doings" such as swimming, driving, eating and so forth, whereas examples of "beings" include being literate, being frustrated, being respected etc. In its most rudimentary form, a functioning can mean not being thirsty by drinking water (Sen, 1989).

Functionings can be sub-divided into two classes. The first class is referred to as *potential functionings*, i.e., the future state or potential of a person's functionings, e.g., being educated. The second class is *realized* or *achieved functionings*, which refers to what a person is effectively able to do (Sen, 1989).

The dimension of *choice* plays an important role as far as functionings are concerned. Let's assume a person in question is a healthy individual, not suffering from any physical or psychological ailments. The person cannot swim, but the option to engage swimming lessons is available to them. If the person never chooses to enrol and actively engage the swimming lessons, they will never realize the potential functioning of being able to swim.

The ability of an individual, accompanied by choice, to bring about change in their own lives, or those of others, are referred to as *agency*. Sen describes agency as the manifestation of the conscious actions of a person that acts with the aim to realize functionings through a certain activity (Sen, 1999). To illustrate the fundamental conceptual differences between functionings and capabilities, consider the elementary example presented in Table 2:

Table 2: An example to illustrate the difference between functionings and capabilities

Functioning	**Capability (Opportunity)**
Being educated	Able to afford education Access to an institution of learning The ability of speech and to understand language …

The example presented in Table 2 allows for the following deduction: Functionings represent the "ends" of development, whilst capabilities embody the "means".

From the philosophical stance of the CA, *wellbeing* can be described as a balance between to the subjective, perceived notion or measure of utility on the one hand, and the objective wellbeing measure of commodities on the other (Van Staveren, 2015). In simpler terms, *wellbeing*

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is defined as the standard of living as perceived by an individual in relation to their own life as far as various activities, interactions and circumstances are concerned. In short: Is a person generally happy or unhappy with their life (Griffin, 1986; Robyens, 2005b).

Sen (and others) contend that *freedoms* are, in fact, capabilities that are perceived as real opportunities. In other words, the combination of different, available opportunities, and the ability or capability of the individual in question to realize different combinations of functionings, are the actual enjoyed freedoms of the person (Sen, 1990; Hatakka & De', 2011)

Conversion factors are those factors that determine the degree to which a person can transform a resource into a functioning. Conversion factors can be both inhibiting factors, or factors that encourage or assist the foregoing process of realizing functionings (Sen, 1997; Alampay, 2006).

The ICT domain has evolved at a staggering pace, fuelled by demand from almost every industry (Heeks, 2010). In their work, Islam and Grönlund (2010) bolsters the notion postulated by Heeks and adds that ICT4D initiatives are uniquely positioned to facilitate the process of personal freedoms to develop.

Sumner and Tribe (2008) outline three dimensions of development as far as ICT4D is concerned, namely *Development as short and medium-term goals*, *Development as long-term societal transformation*, and *Development as discourse.* These dimensions of development, according to the authors, are interconnected and coexist within the ICT4D domain and manifest contextually in varying value systems such as equality, happiness and fiscal positionings.

Figure 2 illustrates the dimensions of development as put forward by Sumner and Tribe (2008).

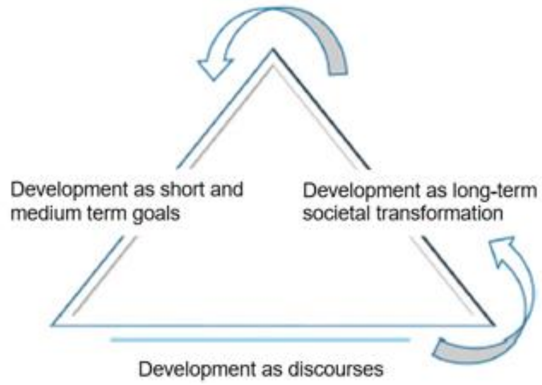

Figure 2: The dimensions of development associated with ICT4D

Zheng et el. (2017), highlights the importance of identifying and understanding the dimensions in which an ICT4D project will be positioned. They argue that knowledge about the domain can influence the development of ICT4D initiatives as well as the development impact thereof.

3. Methodology

For the sake of brevity, only a high-level, streamlined overview of the methodology in general, and the methods followed in relation to the identification of capabilities to assess and work performed in the community, is outlined in this section.

Research Design

An exploratory research design was adopted for this investigation, and the inquiry is positioned in alignment with interpretivism and critical realism. This decision is based upon the viewpoints outlined by Sen with the aim to understand why things are the way they are, produces what it produces and behave the way it behaves (Sen, 1990).

Design science research (DSR) was selected as the primary research strategy, followed by a case study design as secondary strategy. Henver (2014), Peffers (2017) and their colleagues are at the forefront of DSR research. Their contributions to the evaluation methods of ICT research have been adapted for this inquiry, as presented in table 3.

ISBN: 978-99949-0-888-2

Table 3: DSR evaluation methods for Information Systems and Information Technology research adapted from Henver et al. (2014) and Peffers et al. (2017)

Type of Evaluation	Method
Analytical	Architecture analysis, Dynamic analysis, Optimization, Static analysis
Descriptive	Informed arguments, Scenarios
Experimental	Controlled experiments
Observational	Case studies, Field studies
Analytical	Architecture analysis, Dynamic analysis, Optimization, Static analysis
Descriptive	Informed arguments, Scenarios
Testing	Black Box (functional) and White Box (structural) testing

Informed arguments and a case study, as outlined in Table 3, was selected to evaluate the mHealth artefact. A mixed method approach was employed as far as the research methods are concerned, and the data collection tools were comprised of group discussions, interviews, literature reviews and observations.

Finally, convenience sampling was used, as the community in question was known to the medical health practitioner involved with this investigation. The decision was made to limit the participants of the interviews, group discussions and observation to the teenage, young adult, adult, middle age, and old age groups for the reasons outlined in section 2.

As far as the design of the user interface (UI) of the application is concerned: A novel approach of presenting members of the community with interface designs based on anthropomorphism and affective design methodologies were used. The responses of the groups were recorded with the aim to isolate which design methodology they ascribed to. Designs for the interface were subsequently prepared based on the dominant design methodology, presented to the groups and refined according to their input until the final version of the UI was approved by the groups.

Which Capabilities to Assess?

The question of which capabilities to assess has been discussed in a myriad of scholarly contributions, as human capabilities are near infinite and can vary greatly from one individual to the next (Fukuda-Parr, 2003).

This investigation followed a participatory approach, involving the community directly to identify health capabilities and outcomes they deemed valuable. To guide the process, the researcher prescribed to the methodology posited by Robyens (2005a). She argues that a set of capabilities under intended scrutiny should be generated according to a set of criteria, suggesting the following criteria list, which was used to guide interviews, group discussions, and inform observation to identify and/or extrapolate relevant data:

i. *Explicit formulation:* The capability list should be made explicit. The list should also be thoroughly discussed and should hold up to scrutiny.
ii. *Methodological justification:* The way the list of capabilities was generated must be scrutinized upon and should be unambiguous based on the intended use of the CA.
iii. *Different levels of generality:* A two-tier approach is recommended based on the reasoning behind the selection of the capabilities. For example, a two-tier approach should be employed if the list of capabilities that are selected is aimed to allude to implementable policy proposals or, alternatively, at empirical application. Each tier will produce a different list, which may range from a pragmatic list to a level more associated with ideal theory. The outcome of the second and final tier should be the subject of considerations delineated to constraints and limitations that are related to the measurement design and data collection.
iv. *Exhaustion and non-reduction:* All relevant dimensions should be represented by the capabilities on the list. Non-market economy related capabilities, for example, should also be represented in the economic assessment of a particular region or country.

Data Analysis Approaches

The qualitative data gathered during the inquiry was analysed using primarily thematic analysis techniques, whereas text and trend analysis was

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identified as appropriate quantitative analysis approaches.

4. Experiments and Results

The interviews and group discussions were designed on the concepts of the CA, whilst also being employed to guide and focus the respective data collection efforts. Krueger's (2000) methods of conducting focus group discussions were also employed as an additional measure to solidify the data collection process.

Interviews were conducted in advance of the group discussions. Open-ended questions were asked in a manner to invite and solicit different types of responses, such as longer, deliberated answers, reflections and so forth. The use of interviews was primarily motivated by the objective to uncover how different age groups perceived different topics of discussion related to the study. The secondary motivation was to attempt to discover what different age groups perceive as being valuable on an individual- and community level without being aware of the views of their peers. To that end, the researcher attempted to limit the proliferation of the questions being asked and many questions were based upon answers provided; no two interviews, or group discussions for that matter, were therefore the same. The results from the interviews informed many questions and topics brought up during the group discussion sessions.

Separate, peer-based discussion groups for the teenager, young adults, adult, middle age, and old age groups were formed to allow for less inhibited discussions during group discussion sessions. The assumption was that participants in the discussions would be more forthcoming when the sessions were limited to include only peer groups; teenagers would assumably offer less than candid responses if grouped with more senior members of the community. Reflexibility was also encouraged to uncover data and insights that may not have come to light or overlooked during the interviews.

The intended outcome of the group discussions was that one statement would initiate a related statement by participants, leading to another statement and so forth and ultimately create a rich source of usable data. The researcher essentially adopted the role of moderator during these recorded group discussion sessions.

Three interview- and group discussion sessions with each age group were undertaken. Each session had its own objectives as far as uncovering capabilities, potential functionings and conversion factors were concerned.

The general, day-to-day doings and beings of the community were also observed over a period, whilst special attention was paid to the perceived contextual challenges and opportunities that existed within the community. Specific attention was paid to repeating phraseology when engaged in general dialog with community members in an attempt to uncover common themes, especially themes related to individual and community health needs.

The capabilities, conversions factors and potential functionings that was yielded from the data collection and -analysis processes are presented in table 4. A noteworthy finding that emerged from the data analysis was that conversion factors could be classified as either *personal*, *social* or *environmental.*

The data presented in Table 4 was instrumental in determining what realizations of potential functionings could be accomplished by exploiting the intrinsic features and possibilities inherent to smart mobile device technologies when disseminated in the form of an mHealth artefact. In short, the data was used to inform the design and development of the functionality of the artefact.

A good example of how smart mobile technology was exploited as a feature of the mHealth application, is the GPS location sharing with "medical alert" button. It uses the smart device's GPS location radio navigation transmitter and receiver in conjunction with mobile internet connections to help realize the potential functionings of "being able to contact emergency healthcare readily" and "saving time".

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Table 4: Identified community health and wellbeing capabilities, conversion factors and potential functionings

Identified Capabilities	**Potential Functionings**	**Identified Conversion factors**
Access to healthcare • To live longer • To be inoculated as the need arise • To have a healthy pregnancy • To have access to contraceptives **Relevant health information** • To lead a healthier life • To make better health decisions • To be knowledgeable /informed reliably and timely **Resources** • To access reliable emergency resources • To save money • To save time • To get the required medicine or treatment when required • To have access to reliable transport **Self-image** • To be treated with dignity and respect **Community mobilization** • To be cared for by the community when in need **Communication** • To communicate with a healthcare professional readily **Empowerment** • To have government support • To have health-needs met • To share health information with others	• Living longer • Living healthier • Having better immunity to disease • Accessing meaningful, relevant health information • Sharing health information within the community • Having a healthy pregnancy, a healthy delivery, and a healthy baby • Exercising informed health choices • Having access to quality healthcare • Being informed • Being able to contact emergency healthcare readily • Having access to reliable emergency services • Bridging healthcare disparities • Saving money • Saving time • Having access to medicine, specialists, medical equipment, and treatment • Having prompt access to reliable transport • Being treated with respect • Receiving home-based care • Reliably communicating with healthcare professionals • Receiving government support	**Personal** • Genetic disposition • Health choices • Level of literacy • Mobile ownership • Mobile data • Monetary challenges • Lack of technology skills **Social** • Influence of older community members • Traditional and cultural beliefs • Attitude of health workers • Community structure **Environmental** • Inadequate communication tools, policies, and procedures • Poor transportation system • Geographic location of healthcare services versus that of community • Service delivery issues at facilities • Availability of medicine and contraceptives • Availability, access and proliferation of relevant health information • Poor state of public health facilities • Access to reliable emergency services • Corruption of emergency vehicle operators • Government ignorance toward community • Access to medicine, specialists, medical equipment, and treatment • Access to reliable transport • Being treated with respect • Access to home-based care • Access to reliable channels of communication with healthcare professionals

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As far as the UI design of the artefact is concerned, the designs based on anthropomorphic design principles were found more favourable amongst the members of the community when compared with the designs based on affective design principles. Two software agents were ultimately developed based on these findings and most of the UI layout was based on anthropomorphism. Figures 3 and 4 depict the software agents and a limited view of the mHealth application interface respectively.

Figure 3: mHealth software agents developed for the ICT4D artefact

Figure 4: A limited view of the user interface of the mHealth intervention

The mHealth application was also designed with privacy in mind and features a dedicated, separate access portal for all who download and install it. For this study, the application was pre-installed on sponsored devices. Based on the experience that had been gained preceding this juncture of the investigation and informed by related literature, the framework presented in figure 5 is proposed using a bottom- up approach. The aim of the framework is to facilitate the development of ICT4D initiatives where human development forms the focal point of the development outcomes.

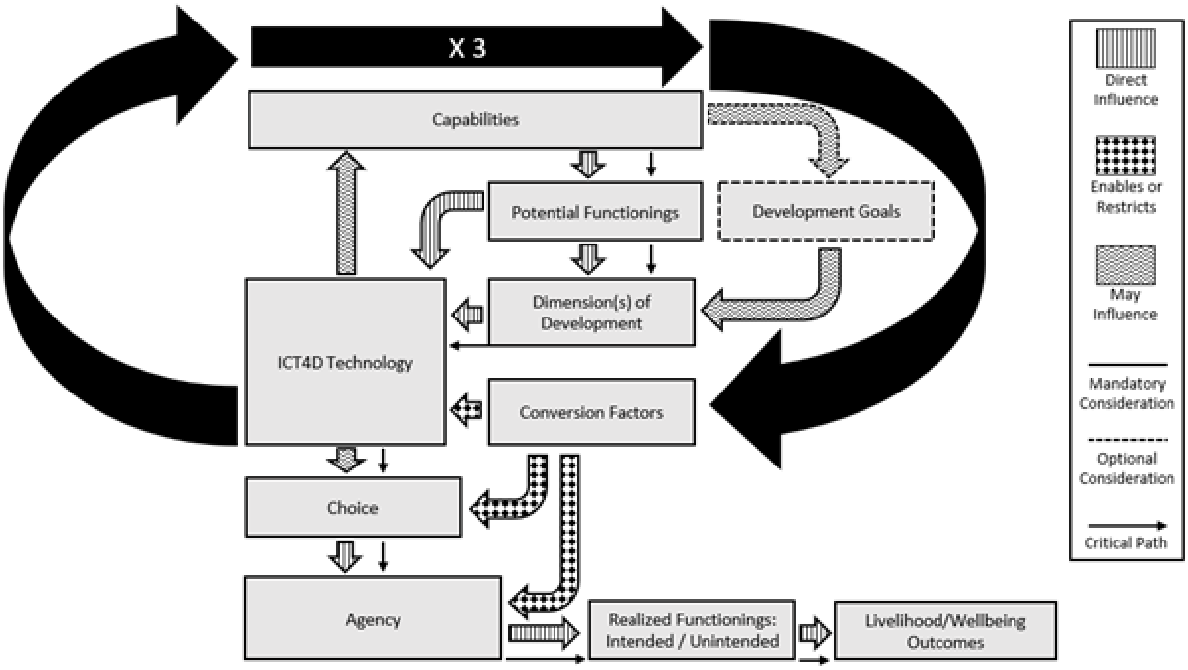

Figure 5: The first iteration of the conceptual framework for the development of human centered ICT4D artefacts

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The goal was not to evaluate the framework during this investigation. The objective was rather to draw on the lessons learned from the development of the mHealth artefact, informed by related literature to advance the framework in the form of its first conceptual iteration and receive theoretical/scholarly feedback directed at areas of possible improvement.

5. Evaluation and discussion

The mHealth artefact and its features was evaluated within the case community during third interview- and group discussion sessions.

The mHealth application also logged usage, recording data such as features most used, when a user posted, edited, or deleted a message on the feed, how long a feature was engaged and such. The idea was to try and learn about user patterns within the different age groups, uncover which functionality was confusing due to UI design or component issues. These possible issues were also discussed with the community members during the dedicated interviews and group discussion sessions to refine the application where evident issues were observed. The framework is initiated with the identification of the community capabilities using the approach put forward by Robyens (2005a; 2005c).

Capabilities have a direct relation to the potential functionings, but may also influence the development goals, as these may be a result of the opportunities at hand to the community. The development goals may also be affected by the investigator due to biases. The disquisition also uncovered some outliers as far as potential functionings were concerned. These were eventually uncovered as more of what is viewed as development outcomes that had no direct link to the capabilities that were identified. This exploration focused on the potential functionings, only as they directly relate to the identified capabilities, but the framework includes development outcomes for the sake of completeness and acknowledgement that they may emerge during the initial investigation or data collection phase.

The potential functionings have a direct association, as far as the data indicates, to the dimensions of development (Sumner & Tribe, 2008), which has a direct influence on the technology appropriated for diffusion, taking the conversion factors on either side of the spectrum (advancing and inhibiting) into account. The functionality and features will also be directly influenced by the potential functionings, as these are the objects and/or subjects to be realized.

The ICT4D technology may influence the capabilities under scrutiny, as capabilities are essentially the valuable opportunities available to the community. This train of thought is vindicated by taking under consideration that the ICT4D technology will become an addition to the existing capabilities as a valuable opportunity. This, in turn, may influence the potential functionings, development goals and the dimensions of development, in turn, affecting the ICT4D artefact. The framework proposes a cyclic approach to refine the technology and limit the cycles to three to compensate for scope creep.
The technology used, as well as the form it assumes may influence the choice component of the CA in this operationalization. Choice will have a direct influence on agency; choice and agency are therefore crucial cogs to realize potential functionings. Only when the potential functionings, or at least a subset of them is realized, will the livelihood and wellbeing outcomes be observable, essentially indicating the success or failure of the initiative.

The realized functionings can be either intended or unintended, just as Sen (1990) predicted. The message board, for example, was not only used to communicate or post health-related information, but also to post information about social gatherings, to name an example of one case.

The critical path of the framework is *capabilities, potential functioning, dimensions of development, ICT4 technology, choice, agency, realized functionings* and *livelihood/wellbeing outcomes.*

6. Conclusions

This investigation set out to discover how a ICT4D artefact can be developed with human-development outcomes at the centre of the initiative. To address this, a framework rooted in the CA is proposed to guide the development process of a human centred ICT4D artefact.

The factors that inhibit ICT4D development goals are referred to as conversion factors in the CA, and these factors will be unique to each case. Conversion factors are not confined to inhibiting factors only but can also be factors that advance the development goals of a project. As far

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impeding factors are concerned, these are the factors that directly hinder the potential functionings from being realized.

The essential components of an ICT4D artefact are those that will help bridge the limiting conversion factors and help realize potential functionings to intended and sometimes unintended functionings. These are therefore essential as far as functionality is concerned when considering a human-development approach, affecting livelihood and wellbeing outcomes.

These components can be identified by discovering the inherent capabilities and potential functionings of an individual or community, whilst accounting for advancing- and inhibiting conversion factors. Issues of choice and agency are also central to the development paradigm and should be promoted/encouraged through capability expansion and the realizing of functionings, and additionally, as was the case with this study, a co-developed, user-focused, and simplified UI.

The primary limitation of this investigation is regarding generatability: Since the mHealth artefact was developed for a specific case and the framework was subsequently rooted on this development, it is hard to gauge how generalizable both the application and the framework is. This calls for further investigation.

The assumption is that the practitioner utilizing the framework has a basic understanding of the CA. If this is not the case, it can be remedied by scrutinizing accompanying literature on the subject.

The primary objective going forward is to assess the actual impact the artefact has had on capability development/expansion, and how effective it was as a conduit to realize functionings. It may also prove useful to apply the proposed framework in a separate scenario where an artefact is developed using the framework from inception. There may also be value in overlaying the proposed framework with the United Nations Development Programme's (UDP) Human Development Index, or HDI, and the dimensions of development, and combining it with the knowledge gained from using the framework to develop a human centred ICT4D artefact in future iterations of the proposed framework to ultimately refine the framework itself.

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Improving Accuracy of Credit Card Fraud Detection Using Supervised Machine Learning Models and Dimension Reduction

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***Abstract*—Credit card fraud is a serious crime, and it is a common type of identity theft. Financial institutions and consumers are experiencing economical losses due to financial fraud caused by credit card transactions. Machine Learning Models can aid and alleviate credit card fraud by providing real time detection of credit card fraud before it takes place. The problem that arises with machine learning models is poor performance in terms of accuracy if the data objects in dataset have high dimensionality. In this paper we have tested and compared six machine learning models in detecting credit card fraud. Furthermore, dimension reduction techniques was used to improve the performance of these machine learning models. The results show improved accuracy on the machine learning models after applying dimension reduction and removing anomalies and imbalance.**

Keywords —*Machine Learning, Credit Card, Supervised Learning, And Fraud*

I. Introduction

Credit card has become a popular prominent preferred method of payment for both online and offline transactions in several countries due to high internet dependence Sailusha et al. (2020). It allows the consumers to purchase the goods and services on credit and pay later Adewumi & Akinyelu (2017). Credit cards provide users with good benefits, but there are risks associated with them. The great increase in the use of these credit cards has resulted in massive credit card fraud activities. Credit card fraud is a serious crime, and it is a common type of identity theft. Financial institutions and consumers are experiencing economical losses due to financial fraud caused by credit card transactions Popat & Chaudhary (2018). These credit card transactions take place in real-time processing. Real-time refers to the exact time a process or incident takes place Feng (2021). Popat and Chaudhary Popat & Chaudhary (2018) identified that the majority of online payments requires individuals' banking or credit card details, and this gets them exposed to financial fraud. The most popular credit card fraud is card-not-present (CNP).

Card-not-present occurs without the use of a physical card usually online or via a phone. Two main types of credit card fraud exist and these are called internal and external credit card fraud Awoyemi et al. (2017). According to Awoyemi et al. (2017), internal credit card fraud refers to a product of an agreement between the credit cardholder and the bank through using false identification to commit fraud, whereas external credit card fraud includes the use of counterfeit credit cards to obtain cash by illegal means. Internet and technological development have allowed fraudsters to create credit cards that look identical to the legitimate ones in a way that it is difficult for investigators to tell the difference Carneiro et al. (2017). According to Popat and Chaudhary in Popat & Chaudhary (2018), fraudsters use technology and the internet to steal individuals' credit card details online and thereafter create counterfeit identities to commit credit card fraud. Fraudsters regularly improve their tactics and methods to bypass credit card detection and preventive systems. They make sure that they find consumers weaknesses and vulnerable spots to attain their credit card details. They also exploit the financial institution's system flaws to obtain credit card information Varmedja et al. (2019). Dornadula and Geetha in Dornadula & Geetha (2019) stated that credit card fraud is a difficult issue that cannot be solved easily because fraudsters commit credit fraud crimes without the fear of being arrested as the internet and technology make it easy for them to erase their tracks making it hard for investigators to trace them. Dimension reduction is a process which is used to improve the performance of machine learning models Cunningham (2008). In most machine learning applications the data objects are subject of analysis and usually these data objects have high dimensions which can hinder the performance of machine learning models Cunningham (2008).

Reducing the dimension in these data objects can improve the computational efficiency of machine learning models and the accuracy of the analysis of these models Cunningham (2008). As an example, most biology or life science experiments record data objects with many variables of data which can create performance challenges for machine learning models. To tackle this researchers can use dimension reduction techniques which involve mathematical functions to reduce high dimensions on data objects. There is clearly a need for more research to be pursued based on the above-mentioned credit card fraud challenges. One manner in which to prevent these challenges is to improve existing real-time credit card fraud detection models for better efficiency. Credit card fraud detection is the method of detecting transactions that are illegitimate and focuses on analyzing the card purchase patterns

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Awoyemi et al. (2017). This study aims to improve existing supervised machine learning models to effectively detect credit card fraud on multiple big data datasets in real-time. The rest of the research paper is organized as follows. Section 2 discusses related work. Section 3 Supervised Machine Learning Models. Section 4 provides results and discussion. Section 5 provides conclusion and future work.

II. Related Work

Fraudulent activities are continuously causing a critical loss in financial institutions and individuals. As fraudsters constantly evolving and introducing new strategic forms of committing fraud making fraud a focus area of interest for researchers and motivating researchers to discover solutions that would detect and prevent fraud. Therefore, several methodologies and measurements have been developed and evaluated in previous studies to provide solutions to identify fraud, ranging from supervised, unsupervised, and hybrid approaches. In this research paper we focus primarily on the ones which implemented different techniques to improve accuracy. In this study, a highly imbalanced dataset was used, and Synthetic Minority Oversampling Technique (SMOTE) was applied to balance the dataset. Various classification models based on logistic regression, support vector machines, random forest, stacked classifiers and gradient boosted trees are developed and applied to both the under-sampled data and actual data Mishra & Ghorpade (2018). The result of the analysis shows that all the classification algorithms on the under-sampled data performed better with both precision and recall over 90% . However, with an actual imbalanced dataset, the models also performed well. The gradient boosting was used to boost the model's performance. Random forest classifiers have proven to perform better compared to other classifiers with a recall of 96%. Under-sampling of data in this study improved the recall accuracy of the models. The performance of logistic regression, decision tree and random forest for credit card fraud detection is investigated Lakshmi & Kavilla (2018). The results show accuracy for the random forest as 95.5% followed by a decision tree with 94.3% and logistic regression with 90.0%. The comparative results report that random forest performs better than logistic regression and decision tree techniques in detecting credit card fraud applied to an oversampled dataset.

This study investigated the performance of logistic regression, naïve Bayes and k-nearest neighbour on highly skewed credit card fraud data. Data pre-processing was performed and a hybrid technique of under-sampling and oversampling is applied to the skewed data. The classifier performance is evaluated on the raw and pre-processed data using accuracy, sensitivity, specificity, precision, Matthews correlation coefficient and balanced classification on the rate. The results show that logistic regression did not indicate much improvement from 10:90 to 34:66 data distribution for false negative rates. However, it indicated overall best performance in the un-sampled distribution. Moreover, the k-nearest neighbour showed the best performance for all evaluation metrics, because it recorded no false positive in the classification. However, Naïve Bayes performed better than K-nearest in accuracy for the 10:90 data distribution. This study shows that hybrid sampling on an imbalanced dataset improves the binary classification performance.

A comparison of the decision tree, KNN, logistic regression, random forest and naïve Bayes are analysed on an imbalanced dataset Khatri et al. (2020). In this study, the threshold values are applied the 0.4 and 0.5. The default threshold is set to 0.5. The result shows the models obtained the best results when the threshold value was taken as 0.4. However, an increase changed was observed in the precision and sensitivity of naïve Bayes, random forest and logistic regression. The KNN sensitivity is higher than that of the decision tree, however, the testing time taken by KNN is long and for that, the study researchers chose the decision tree over KNN. The reason for this is for a good prediction a minimum time is required to detect fraud. In this study, the four machine learning classifiers' comparative performance was drawn based on accuracy metrics. The principal component analysis was applied to the data to transform the values. K-nearest neighbours (KNN), Naïve Bayes (NB), Logistic Regression (LR) and Decision Trees (DT) performance are analyzed. The dataset that is used for the study is highly skewed. Therefore, the dataset is balanced using a hybrid sampling approach after the algorithms were applied. KNN performed better than the other machine learning algorithms with an accuracy of 0.9913% followed by Naïve Bayes showing good accuracy of 0.9698% as compared, to the Decision tree with 0.9640% percent and logistic regression with 0.9627% Dighe et al. (2018).

Sadgali in Sadgali et al. (2019) presented a comparative study of four supervised machine learning techniques, Decision tree, support vector machine and random forest and k-nearest neighbour for credit card fraud detection. The data is imbalanced with 99,72% of transactions accounting for the non-fraudulent and 0.28% fraudulent transaction class. SVM was proven to be the best in detecting credit card fraud better than other models with an accuracy of 99,7 percent followed by KNN 97,1 percent, Random Forest 82,5% and Decision tree 78,9%. All the findings of the aforementioned studies we shall take into account and learn from them to develop better dimension reduction techniques to improve the accuracy of the machine learning models. In the next section we discuss this process in detail.

III. Dimension Reduction on Supervised Models

According to Khatri et al. (2020), machine learning is an artificial intelligence (AI) application technique to allow machines to learn on their own through experience. There exist two types of machine learning which is Supervised machine learning and Unsupervised Machine Learning. In this paper we focus primarily on the former.

A. Supervised Machine Learning Algorithms

There are many Supervised Machine Learning models that exists which can be used on different applications. For the

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scope of this research paper we have chosen to focus only on six models which are as follows:

1) Linear Regression: Linear Regression is the supervised machine learning model that is used to determine the relationship between the dependent and independent variables. It is a straight line fit. It is similar to logistic regression Chowdari (2021). Linear regression deals with the relationship between the X and Y attribute. The goal of linear regression is to understand how the value of Y gets influenced by a change in X value. The model focuses on the variable's dependence Weisberg (2005). Linear regression also has multiple linear regression where more than one regressor is involved.

2) Gaussian Naïve Bayes: Gaussian Naïve Bayes is defined as a probabilistic classifier that can predict several classes. This means that the model has the capability to make predictions for several classes at once Rahman et al. (2021). Naïve Bayes employs the Bayes theorem for the independence hypothesis Faraji (2022). This indicates that the existence of one feature in the probability of a given event has no influence on the presence of another, and every predictor has an equal impact on the outcome Dhankhad et al. (2018). This model employs a set of algorithms rather than a single algorithm, but they all share a similar idea. Each feature contributes an equal and distinct amount to the output Rahman et al. (2021). The algorithm performs classification by using the Bayes theorem to calculate the probability of a true class Rajora et al. (2018). It applies conditional probability to make decisions Rahman et al. (2021).

3) Support Vector Machine (SVM): SVM is a classifier for both classification and regression. It maps features from a higher-dimensional non-linear input space Faraji (2022). The purpose of this transformation is to convert a complex classification problem into a linear problem in a higher-dimensional space. This mapping is accomplished through the use of the kernel function Nadim et al. (2019).

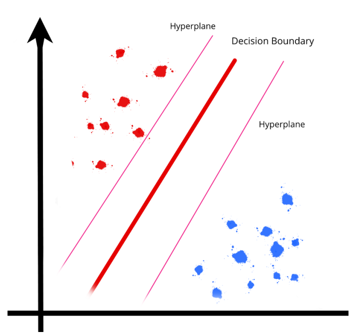

Fig. 1. Illustration of SVM.

The SVM algorithm aims to identify which class a new data point belongs in, it does so by using a hyperplane. A hyperplane visible in Figure 1 is created with the maximum distance between two classes of data points. It separates the classes of data points on each side of the plane Kumar & Veer (2020).

4) K-Nearest Neighbor (KNN): KNN is utilized for classification and regression Chowdari (2021). Its performance is determined by three variables namely the distance rule, the distance metrics and K value. Distance metrics provide the measurement for locating the nearest neighbours of each incoming data point as visible in Figure 2. The distance rule assists in classifying a new data point by comparing its attributes to those of data points in its neighbourhood and the value of K determines the number of neighbours to compare.

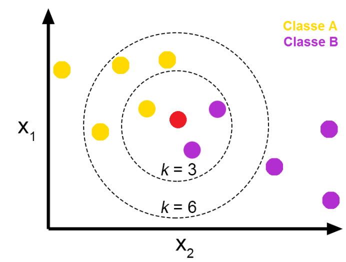

Fig. 2. Illustration of K-Nearest Neighbor.

The training and validation datasets are segregated from the initial dataset to achieve the optimal value of K Mandava (n.d.). KNN classifies the data based on neighbor and it stores every single computation that is an accessible occurrence. It calculates the distance between data points applying Euclidean distance and then allocates a category based on the most common category.

5) Decision Tree: Decision Tree is a non-parametric data classification supervised learning algorithm algorithm Chowdari (2021). It consists of decision tree classifiers and is used primarily for both classification and regression tasks Rahman et al. (2021). As the name states it has a tree structure composed of the root node, branches, internal nodes and leaf nodes and creates decision trees for each sample Mandava (n.d.). The tree structure which is inverted which is non-parametric and can handle large and complicated datasets efficiently Safavian & Landgrebe (1991). One of the biggest drawbacks of decision trees is that of dependencies. A small change on the data usually leads to a big change in the structure which can affect the performance Safavian & Landgrebe (1991).

6) AdaBoost: An AdaBoost also known as Adaptive Boosting is classifier algorithm in Machine Learning used as an ensemble method. Adaptive Boost builds models and provides them with equal weights on all the data points Ying et al. (2013). Adaptive Boost is closely associated and resembles much of decision trees in that in its basic form it is a decision tree with one level. This classifier is known to be a meta-estimator which works firstly by fitting a classifier on the initial dataset then proceed to recursively fit additional copies of the classifier on the same dataset where the weights of incorrectly classified instances are adjusted Schapire (2013).

B. Dimension Reduction Algorithms

In this research paper we have adopted three, well known dimension reduction algorithms to improve the accuracy. These algorithms are t-Distributed Stochastic Neighbor Embedding, Principal Component Analysis, and Truscated SVD respectively. Most scholars and researchers mostly use one of the three aforementioned algorithms to perform dimension reduction however, applying all three even though it is laborous provides increased accuracy.

1) t-Distributed Stochastic Neighbor Embedding (TSNE): t-Distributed Stochastic Neighbor Embedding (TSNE) technique is primarily used for visualizing high-dimensional data. t-SNE proposed in 2008 by Van der Maaten & Hinton (2008) provides a visual intuition of how data objects are organized in a high-dimensional space. There have been many applications of TSNE in machine learning applications by researchers over the years and there many implementations depending on the nature of the data Chan et al. (2018), Althuwaynee et al. (2021), Platzer (2013), Van Der Maaten (2014). In this research the TSNE algorithm is employed to improve the computational accuracy of the aforementioned six machine learning algorithms by applying it on the Credit Card Fraud sub-sampled dataset which will be discussed briefly on the experiment section. TSNE converts similarities between data points to collective probabilities while minimizing the Kullback-Leibler divergence between these collective probabilities of low-demensional embedding and high dimensional data Platzer (2013).

2) PCA Algorithm: Principal Component Analysis, or PCA, is a dimensionality-reduction method that is often used to reduce the dimensionality of large data sets, by transforming a large set of variables into a smaller ones that still contains most of the information in the large set Abdi & Williams (2010). PCA can be formulated in two ways with either the Maximum Variance Formulation (MVF) or the Minimum Error Formulation (MEF) Vidal et al. (2016).

$$\sum_{i=1}^{D}(x_i - y_i)^2 \tag{1}$$

The primary goal of MVF PCA is to find orthogonal projection of the data into a lower dimensional space while keeping the variance of the projected data at maximum levels Vidal et al. (2016). While in the latter PCA exists in a linear projection format which minimizes the average projection cost also known as the Mean Squared Error (MSE) portrayed in equation 1. MSE is implemented between the data points and their projection.

The implementation of PCA used in this research paper used in this research paper is MEF version of the PCA and is defined as follows:

Let X be the $d \times n$ matrix of high-dimensional points ($d > n$). We neglect to explicitly estimate the covariance matrix, instead the following method is employed:

$$\Big(\frac{1}{n}XX'\Big)W = W\Lambda, \tag{2}$$

$$\Big(\frac{1}{n}X'X\Big)X'W = X'W\Lambda, \tag{3}$$

$$\Big(\frac{1}{n}X'X\Big)V = V\Lambda. \tag{4}$$

We've reduced the problem to finding the eigen-decomposition of $\frac{1}{n}X'X$, which is $n \times n$, instead of $d \times d$. By re-projecting,

$$\frac{1}{n}X(X'X)F = XFV, \tag{5}$$

$$\Big(\frac{1}{n}XX'\Big)(XF) = (XF)V, \tag{6}$$

so XF are the eigenvectors of $\frac{1}{n}XX'$. Since

$$\frac{1}{n}X'XF = FV, \tag{7}$$

$$(F'X')(XF) = nF'FV \tag{8}$$

$$(XF)'(XF) = nV, \tag{9}$$

we have $E = \frac{1}{\sqrt{n}}XFV^{-1/2}$.

A generalized form of PCA with noise distribution reduced and link function added can be represented as follows:

$$X \;\; p(f(g(A)h(B))). \tag{10}$$

An alternative form of PCA exists which is known as the Hubber Loss was proposed by authors in Safavian & Landgrebe (1991). This method performs better than the traditional PCA to avoid complexity. Hubber Loss is less sensitive to outliers than the traditional PCA which relies on MSE. It treats errors as a square only when its inside an interval.

$$L_\delta = \begin{cases} \frac{1}{2}(y-\hat{y})^2 & if\ |(y-\hat{y})| < \delta \\ \delta((y-\hat{y}) - \frac{1}{2}\delta) & otherwise \end{cases} \tag{11}$$

In dimension reduction reducing the number of variables from data objects come at an expense of accuracy in terms of prediction or detection of machine learning models. The idea is to make sure that one trades a little amount of accuracy for simplicity because its easier to work with smaller datasets and visualize them and it becomes much faster to analyze them and backtrack to improve than if the datasets are of larger size. Lastly we explore the Truncated SVD algorithm which the last of the dimension reduction algorithms we choice to use on our research work.

3) TSVD Algorithm: Singular-Value Decomposition (SVD) is a method widely used in machine learning to implement dimension reduction for matrices. The truncated version of SVD also is a matrix factorization technique which has similarities to the PCA discussed above. The primary difference between the former and the latter is that we perform TSVD on data matrix and PCA on a covariance matrix. TSVD factorizes matrices where the number of columns is known to equal the truncation Doğu et al. (2020). Another advantage of

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TSVD is that unlike PCA it does not need to center the data before computing SVD and it can work with sparse matrices effectively and efficiently. In the next section we implement all three dimension reduction techniques on the sub-sampled credit card fraud dataset we have prepared.

C. Experimental Setup and Model Training

In this section we discuss the experimental setup and how we prepared the credit card dataset and applied the dimension reduction algorithms to further improve the performance of the machine learning algorithms.

1) Dataset processing: For this research paper the Kaggle Credit Card Fraud raw dataset which is obtainable from Kaggle was used to train the aforementioned machine learning models. This data on its own is raw and has a lot of imbalance with high dimensionality. The hinders and obstructs the performance and accuracy of the machine learning models. In its unaltered form the nature of the Kaggle dataset has a high imbalance and is composed of 492 fraud transactions out of 284,807 transactions.

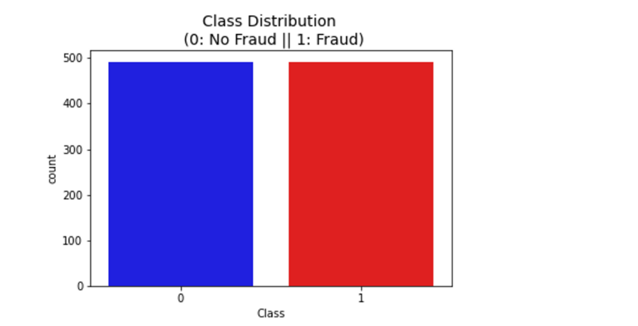

Fig. 3. Subsampled Dataset Class Distribution.

In its natural form this dataset contains only 0.172% of transactions that are fraud. Clearly this will not be beneficial for the machine learning models in terms of training. To mitigate this problem a subsample was created where the imbalance will be removed. The Sub-sampled dataset contains all the columns from the original dataset with nothing changed except that the focus is on an equal sample for both fraud and non-fraud transactions within the dataset. From the Kaggle dataset a new subsample dataset was created which is composed of 50% Fraud and 50% Non-Fraud transactions as evident in Figure 3. The original dataset is not gonna serve the machine learning models very well. Since both the transactions of Fraud and Non-Fraud are of equal size this will aid in training the models and help them to make accurate predictions. In figure 4 a correlation matrix is shown of the balanced sub-sample dataset.

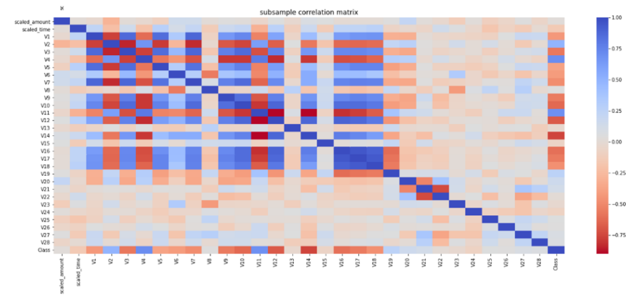

Fig. 4. Correlation Matrix of the Sub-Sample Dataset.

As can be seen from the correlation matrix the data is well mixed. The subsample correlation matrix shows results of shuffled 50% non-fraud and 50% fraud data, hence the correlation matrix shows a mixture of scattered fraud and non-fraud transactions. The shuffling will serve well in testing the prediction accuracy of all the machine learning models. If we perform the same correlation matrix on the default Kaggle dataset and not the sub-sampled one a different result can be seen in Figure 5 from what is visualized in Figure 4. Clearly this will not serve the machine learning models well because the data is highly skewed and imbalanced.

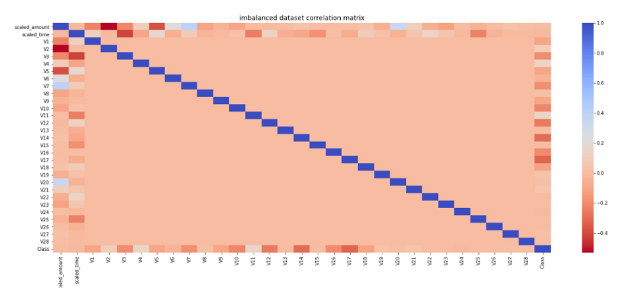

Fig. 5. Correlation Matrix of the Raw Dataset.

A correlation matrix helps us visualize the data so we can see the correlation coefficients for the different variables of data. Even though the new sub-sampled dataset is showing balance it is imperative to check for anomalies and outliers on this newly created dataset as the data was shuffled and randomly sampled and therefore there may be outliers which can create false positives.

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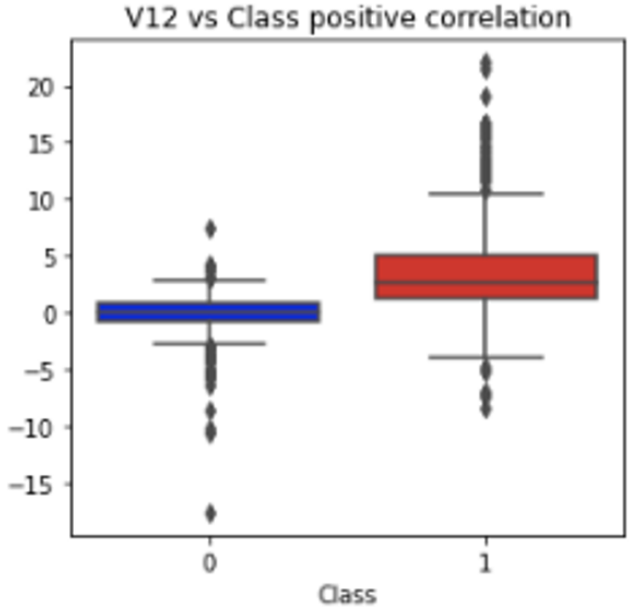

Fig. 6. Box Plot for Value 12 Positive Correlation.

The box plots on both negative and positive correlated values in the new sub-sampled dataset are shown in Figure 5 and Figure 6. These box plots are utilized to visualize and identify where these anomalies lie on the new sub-sampled dataset. On the new sub-sample dataset v10 was among the identified values which are classified to be columns with negative correlated values. V10 is a column within the dataset which contains both fraud and non-fraud transactions. While V12 on the new sub-sample dataset was among the values identified with a positive correlation.Therefore, these columns will be worked on to remove the negative correlated values, because if they are left unchanged, they will have an impact on the machine learning models and trigger overfitting. The models were trained on the new subsampled dataset with no outliers removed and no dimension reduction applied. The Fraud Detection Accuracy Scores are shown in Table 1.

Table 1. Model accuracy scores with no Dimension Reduction.

Machine Learning Models	Fraud Detection Accuracy Score (FDAS)
K-Nearest Neighbor	FDAS = 94%
Decision Tree	FDAS = 90%
Adaboost	FDAS = 94%
Gaussian Naive Bayes	FDAS = 93%
Logistic Regression	FDAS = 95%
Support Vector Machine	FDAS = 94%

Table 1 shows the supervised machine learning models accuracy performance trained on a new subsample dataset with no dimension reduction applied and no outliers removed. As visible from the table Logistic Regression has a high accuracy score of 95% than the KNeighbours classifier, SVC, Decision Tree classifier, GaussianNB and AdaBoost classifier. The lowest performing of all is Decision Tree. Clearly this indicates that the accuracy is there but the performance is low.

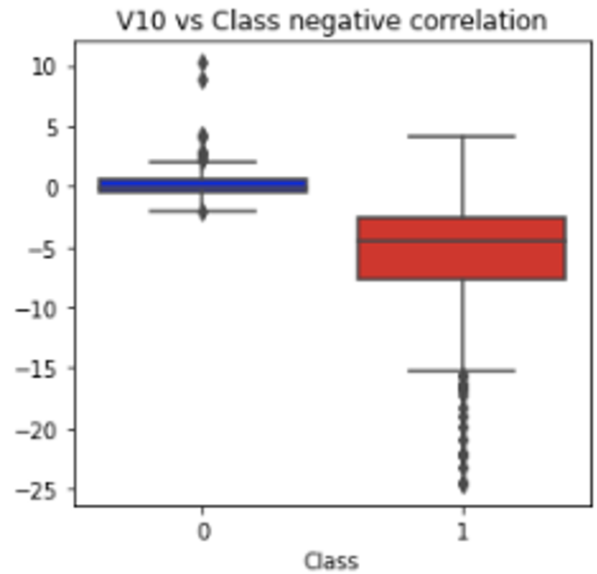

Fig. 7. Box Plot for Value 10 Negative Correlation.

To mitigate this bottleneck on the performance and increase the accuracy we used Box Plots (Figure 6-9) to remove outliers on both positive and negatively correlated values on the sub-sampled dataset. Furthermore dimension reduction was employed where TSNE, PCA and TSVD were computed and applied on the subsampled dataset. The elapsed computation time for each is illustrated on the table 2.

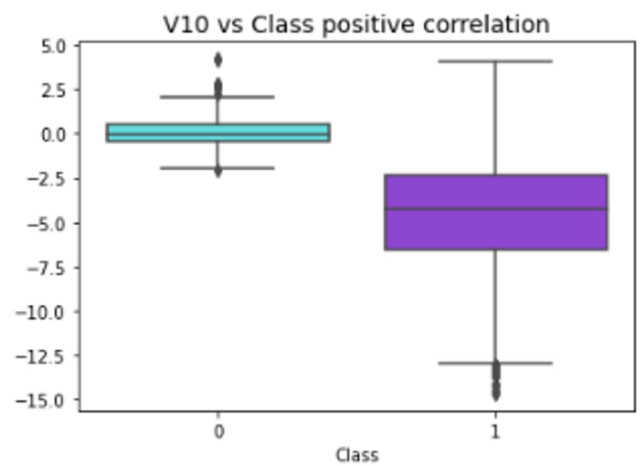

Fig. 8. Box Plot for Value 10 Outliers Reduced.

Outliers were removing and Figure 8 shows box plot for V10 negative correlated values with majority of outliers removed. This will aid in reducing false positives for the supervised machine learning model classifiers. This was applied to all the values that were identified to have a highly negative and highly positive correlated values.

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Table 2. Dimension Reduction Implementation.

Dimension Reduction Technique	Elapsed Time (ET)
TSNE	ET = 5.0s
PCA	ET = 0.042s
TSVD	ET = 0.04s

Outliers were also removed for Value 12 and this is evident in Figure 9 which shows box plot for V12 positive correlated values with majority of outliers removed. Removing these outliers helps reduce false positives for the supervised machine learning models. As can be seen from the figure when compared with Figure 7 a lot of outliers we're removed to improve accuracy and reduce false positives.

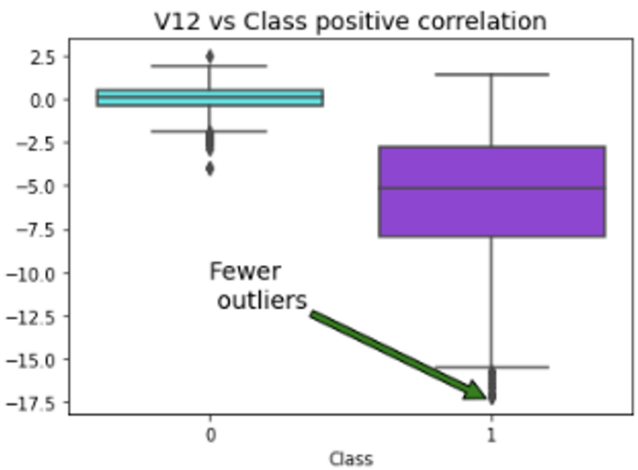

Fig. 9. Box Plot for Value 12 Outliers Reduced.

Lastly we computed all the three dimension reduction algorithms discussed on the subsampled dataset. The elapsed times are shown on Table 2. As expected TSNE elapsed more time than the other two since it is compute intensive. The conversion of similarities of data points is what consumes a lot of time for TSNE. Both PCA and TSVD took optimal times as expected. On the next section a discussion of the obtained results from implementing dimension reduction and removing outliers is provided.

IV. Results and Discussion

A. Dimension Reduction Results

We computed all the three dimension reduction algorithms on the subsampled dataset. Before the computation of the three dimension reduction techniques outliers were removed by means of box plots and the original dataset was sub-sampled to create a balanced data set so that this does not affect or create overfitting for our respective machine learning models. In Figure 10 we see the results of TSVD visualized and from the graph we see that even though the data points were shuffled on the dataset the TSVD did its best to cluster the data points and separate them in the respective clusters of Fraud and None Fraud. This performance of TSVD is very satisfactory and should aid the machine learning models and simplify detection and classification for them. Lastly from Table 2 we see that even though TSVD elapsed minimum time of 0.04 seconds it did perform well in terms of clustering the data points.

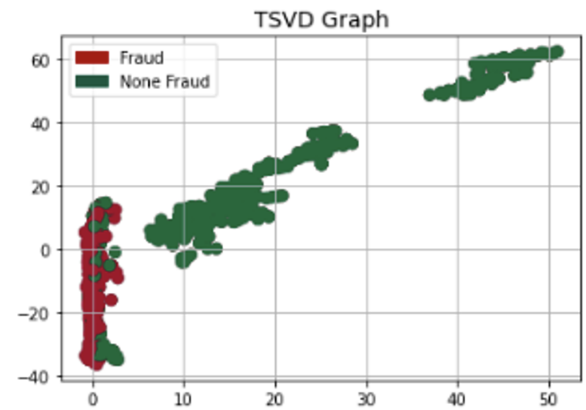

Fig. 10. Results of TSVD on the Sub-Sampled Dataset.

We further computed PCA on the sub-sampled dataset. PCA did not consume too much time before delivering results as seen in Table 2. In Figure 11 we see the results of PCA visualized and from the graph we see satisfactory performance in terms of clustering. Similar to TSVD the data points were clustered accordingly with minor Non-Fraud data points still present in the Fraud cluster. PCA is not computed to be 100% accurate in terms of clustering and reducing dimensionality hence why it is called a dimension reduction technique. We can see from Figure 11 that from the shuffled sub-sampled dataset it managed to reduce dimensionality and cluster data points accordingly to a satisfactory level where machine learning models can improve the performance.

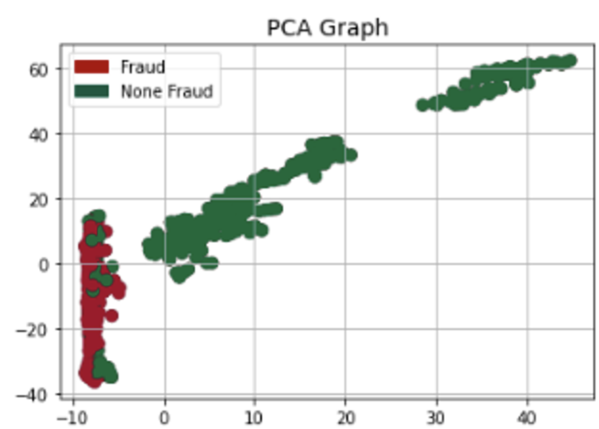

Fig. 11. Results of PCA on the Sub-Sampled Dataset.

Lastly we computed TSNE on the sub-sampled dataset and of all the three dimension reduction techniques TSNE consumed more time and resources than the other two dimension reduction techniques. Even though this was the case it still delivered optimal results as evident in Figure 12. TSNE has more computing complexity from the other two dimension reduction techniques. From the graph we can see that the data points were clustered accordingly and this should simplify work for the machine learning models.

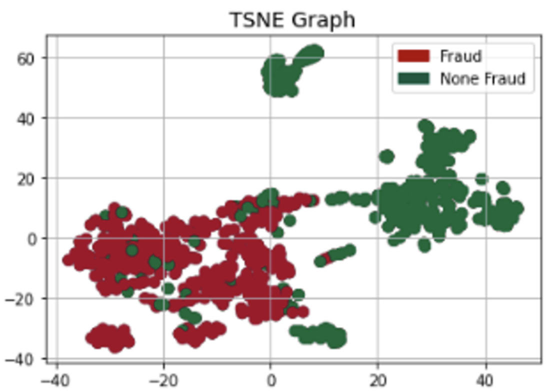

Fig. 12. Results of TSNE on the Sub-Sampled Dataset.

From the above results of dimension reduction we can see that the three dimension reduction techniques performed very well in reducing dimensionality on our sub-sampled credit card fraud dataset. Next we discuss the training learning curves of the machine learning models and summarize the false positive rate of each classifier we profiled.

B. Training Learning Curve Results

In Table 1 we showed the performance of the supervised machine learning models on unprepared data with no outliers removed and dimension reduction applied. Clearly from Table 1 we can see that the performance of these supervised machine learning models was poor. In this section we shall observe closely the Training Learning Curves of each classifier independently and see how it performs over time as the training size grows in correlation with the validation scores. In Table 3 we provide the validation scores for each supervised machine learning model we tested. Validation scores are used as a tool to find out how much can we gain from adding more training data and wether this will affect the performance of our models which as a result can make the suffer from variance error or bias. In Table 3 we see the validation scores for each supervised machine learning model and as evident in Table 3 Logistic Regression has the highest Validation Score of 94.05% While Decision tree has the lowest validation score from all the supervised machine learning models with a score of 90.87%.

Table 3. Training Validation Scores.

Machine Learning Models	Training Validation Score (TVS)
K-Nearest Neighbor	TVS = 93.12%
Decision Tree	TVS = 90.87%
Adaboost	TVS = 93.25%
Gaussian Naive Bayes	TVS = 91.67%
Logistic Regression	TVS = 94.05%
Support Vector Machine	TVS = 93.52%

In Table 3 we see that no classifier has a validation score above 95.0%. In Table 4 we can see a different result in contrast to Table 1. Table shows significant performance in terms of accuracy. As an example in Table 1 SVC and Logistic Regression each had accuracy score of 94.0% and 95.0%. After applying dimension reduction we see improved performance in Table 4 with SVC and Logistic Regression each scoring of 97.05% and 97.02%.

Table 4. Improved Model Accuracy Scores with Dimension Reduction Applied.

Machine Learning Models	Fraud Detection Accuracy Score (FDAS)
K-Nearest Neighbor	FDAS = 92.93%
Decision Tree	FDAS = 90.60%
Adaboost	FDAS = 93.05%
Gaussian Naive Bayes	FDAS = 91.37%
Logistic Regression	FDAS = 97.02%
Support Vector Machine	FDAS = 97.05%

This is a significant improvement which also above the validation scores as well. This performance improvement clearly attests that dimension reduction techniques can be used to improve the accuracy of credit card fraud detection of supervised machine learning models.

Table 5. Accuracy Scores on Original Dataset with No Dimension Reduction.

Machine Learning Models	Fraud Detection Accuracy Score (FDAS)
K-Nearest Neighbor	FDAS = 93.0%
Decision Tree	FDAS = 89.0%
Adaboost	FDAS = 92.0%
Gaussian Naive Bayes	FDAS = 91.0%
Logistic Regression	FDAS = 93.0%
Support Vector Machine	FDAS = 93.0%

In Table 5 we see the scores on the raw original dataset and we can see that the performance was very poor. Lastly we profile each model and see how it performance as the training size increases. We do this by means of implementing learning curves on each machine learning model.

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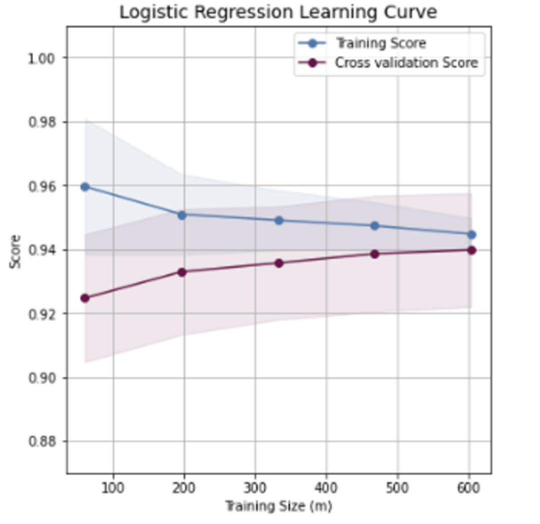

Fig. 13. Logistic Regression Classifier Learning Curve.

We start by examining the learning curve of Logistic Regression and see how it performs as the training size grows. From Figure 13 it is evident that for Logistic Regression both the validation score and the training score converge to a value that is quite low with increasing size of the training set. Thus Logistic Regression will not benefit if we feed it more training data.

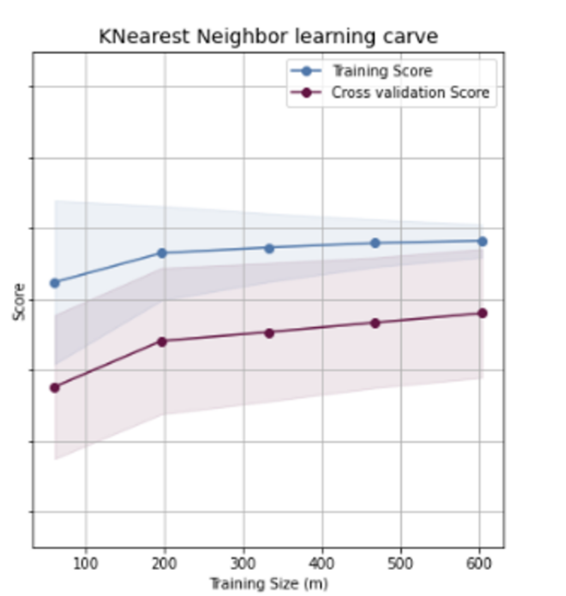

Fig. 14. KNN Classifier Learning Curve.

However, in Figure 14 we see a different result with KNN Classifier. The results of the learning curve visible in Figure 14 show that the KNN Model will improve as the training size increases and this growth is in correlation with the validation score. Unlike the what we have seen in Figure 13 for Logistic Regression. This is expected since each Machine Learning models performs differently from each other and therefore for this dataset this is an optimal performance for KNN.

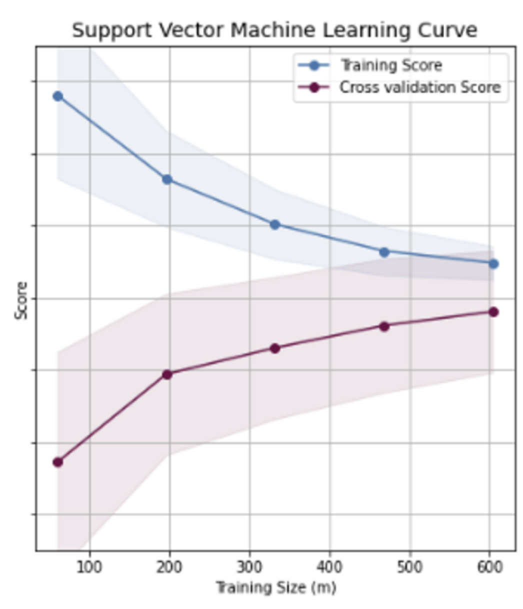

Fig. 15. SVC Classifier Learning Curve.

Next we observe the learning curve for the Support Vector Machine. SVC is one of the highest performers after Logistic Regression in Table 4 which shows the improved accuracy after implementing dimension reduction. From Figure 15 it is evident that SVC validation score and the training score converge to a value the performance is affected significantly if we increase the training size. This is similar to what we saw in Figure 13 for Logistic regression. Since both of them had high performance both of them exhibit the same behavior when we observe the learning curves.

Fig. 16. Decision Tree Classifier Learning Curve.

In Figure 16 we observe the learning curve for Decision Tree. From the Table 4 decision tree was the worst performer in terms of accuracy. The Learning curve shows that increasing the training size will not aid in improving the performance for decision tree. This is also similar to SVC and Logistic

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regression.

Fig. 17. Gaussian Naive Bayes Classifier Learning Curve.

Next we see the results of the learning curve for the Gaussian Naive Bayes Classifier which is displayed in Figure 17. The results show that they two points converge at a lower point and the performance stays stagnant and flat throughout as the training size is increased. This is different from other classifiers in terms of how they performed as the training size increased. The other classifiers did not exhibit a flat curve as the training size increased. However, the general observation is that Gaussian Naive Bayes Classifier does not improve in terms of performance when the training size is increased overtime

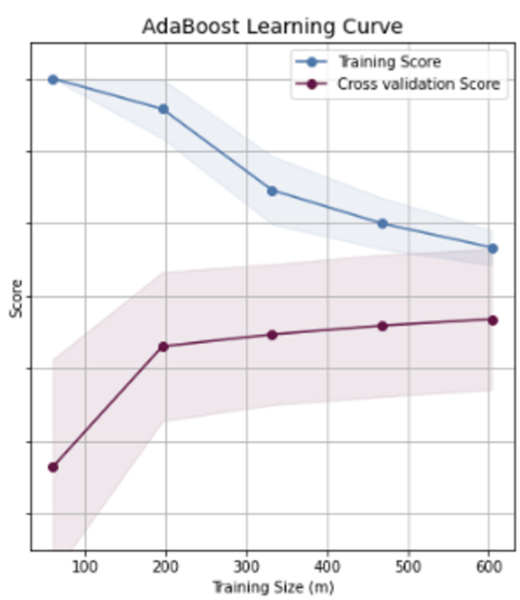

Fig. 18. Adaboost Classifier Learning Curve.

In Figure 18 we observe the Learning Curve of Adaboost classifier. In Table 4 Adaboost had a score of 93% which was not the highest in the pack when compared to other classifiers. The graph also shows that the performance drops significantly the moment we increase the training size. So clearly Adaboost does not need training size to increase in order for it to perform well.

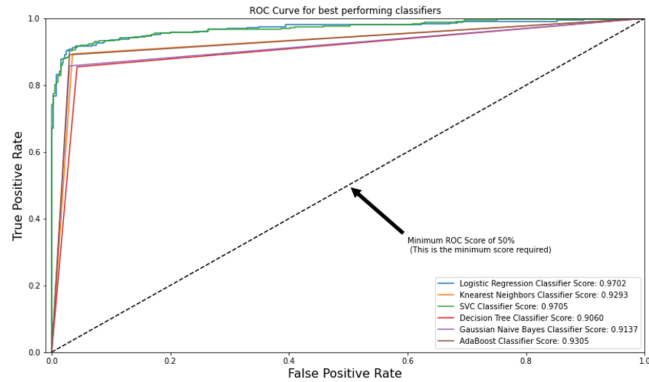

Fig. 19. ROC Curve Graph for Machine Learning Models.

Lastly we observe the Receiver Operating Characteristic Curve for all the supervised machine learning models we tested in this research paper. The ROC Curve graph is used to evaluate the performance of classification algorithms. It is produced by calculating and plotting the true positive rate against the false positive rate. From figure 19 we observe that the True Positive Rate is higher than the False Positive Rate and all our classifiers are above the minimum threshold score of 50%. This is a desired result and attests that our classifiers are useful and do not suffer from undercutting.

V. Conclusion and Future Work

Credit card fraud continues to be a serious crime and it is a common type of identity theft across the world. Financial institutions and consumers are experiencing economical losses due to financial fraud caused by undetected credit card transactions. Machine Learning Models can alleviate credit card fraud by providing real time detection of credit card fraud on transactions that happen online. The problem that arises with machine learning models is poor performance in terms of accuracy if the data objects in datasets have high dimensionality and have many outliers. In this paper dimension reduction techniques were employed to improve the accuracy of six supervised machine learning models classifiers. The results show significant improvements in terms of accuracy for the tested machine learning models. This provides evidence that Dimension reduction is a valuable tool for data scientists who want to improve the performance and accuracy of credit card detection machine learning models. In Future we aim to test this on unsupervised machine learning models.

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Towards Fault Tolerance Management Systems in SDN

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Abstract
The issue of network operation, monitoring, and availability in traditional network environments has been one of the major challenges to addressing network administrators' struggles to deal with. The capacity for the network to comprehend the status and the performance of every node has been one of the priorities amongst others for network administrators to protect during troubleshooting in their network. However, the growing use of software-defined networks (SDN) technologies, as well as virtualization, pave the way to the solution of network operation, monitoring, and availability of hardware and services in a network environment. SDN has emerged with a novel paradigm of network abstractions that is dynamic, able to monitor network performance and fault management automatically, using its programmable capability. This paper presents a design of a fault tolerance management system for SDN controller framework for small to medium-sized networks capable of detecting controller faults and nodes/links faults in case entire network access is unavailable. The fault management system applies various approaches for fault detection and recovery to ensure the reliability and availability of the network resources.

Keywords: SDN, fault-tolerant, network virtualization, network management

1. Introduction

The growing use of software-defined networks (SDN) technologies, as well as virtualization, has paved the way for the solution of network operation, monitoring, and availability of hardware and services in a network environment. SDN has emerged as a novel paradigm of network abstractions that is dynamic and able to monitor network performance and fault management automatically using its programmable capability. The evolution of SDN with its various features has simplified network management and enabled an innovative way of monitoring networks and ensuring reliability. Besides this advantage, SDN suffers from the disadvantage of various network faults and errors that undermine its reliability and make it difficult to solve (Yu et al., 2019). SDN, as a new paradigm, is still undergoing constant development and has attracted research attention from academia and various computing industries (Hu et al.; Jarraya et al., 2014; Diego Kreutz et al., 2015). It has been demonstrated that SDN-based deployment is advancing the development of many other emerging telecommunication networks such as NFV, Cloud, IoT, and 5G technologies (Bizanis & Kuipers, 2016; Jain & Paul, 2013; Jarraya et al., 2014; Li & Chen, 2015). Hence, for current and future modern network technologies, SDN is promising a high capability for network management and monitoring solutions.

The idea of SDN deployment is to simplify network management and provide flexibility by separating the control plane from the data plane (Yu et al., 2019). In the SDN, the control functionality has been shifted to a logically centralized controller, while simply maintaining the forwarding abilities in the network devices. The network controller offers a northbound interface, which permits the creation of high-level network management applications, and a southbound interface, which manages network devices through a vendor-independent protocol. Although SDN technologies adoption is increasing, the challenge of ensuring network reliability, and fault management, mostly concerning fault detection, localization, prevention, and recovery, it continues to cause key concerns for network administrators and users (Diego Kreutz et al., 2015; McKeown et al., 2008). The logical centralization control and programmable ability of SDN interfaces are being

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used as a novel approach to provide solutions to various fault management problems existing today. Based on its design, the SDN architecture is composed of three layers, namely: the infrastructure layer, which is completely in charge of data forwarding and statistics storage, the control layer, which maintains the network view and offers core network functions, and the application layer, which uses abstractions provided by the control layer to implement network business applications such as firewall, load balancer, implementing networking policies and network requirements (Kozat et al., 2014; Lee et al., 2014; Lee et al., 2015).

The SDN layered architecture presents new challenges such as new points of failure such as faults, errors, and single points of network failure that may affect the network services in the data plane. Various control techniques have been used to control the effects of these faults in SDN such as fault detection, controller state monitoring, localization, and fault recovery, as well as fault tolerance mechanisms and distributed SDN architecture (Paradis & Han, 2007b; Yu et al., 2007b). In the literature, many studies have been conducted on fault management solutions that cover software fault (Kazemian et al., 2013; Kazemian et al., 2012; Khurshid et al., 2013), forwarding path verification (Mahajan et al., 2016; Perešíni et al., 2015; Scott et al., 2014), network behavior inspection (Botelho et al., 2014; Chandrasekaran et al., 2016), as well as fault recovery and tolerance (Zeng et al., 2012b).

Therefore, this paper presents the design of a fault tolerance management system for a single SDN controller in a small-scale network capable of detecting controller fault and nodes/links fault in case entire network access is unavailable. The fault management framework employs various approaches for fault detection and recovery to ensure the reliability and availability of network resources.

The next section of this paper is structured as follows. We give a fundamental overview of SDN Fault Management, provide a summary of elated works in controller Fault Management in SDN networks, Controller Placement formulation, the network design of the control plane, fault monitoring and detection in the proposed FMS, FT-Based SDN Architecture, Experiments, and Results Evaluations and conclusion.

2. SDN Fault Management

Fundamentally, a failure is an inability of a network to perform correctly due to hardware or software fault or error- based on some internal and external factors. The fault management process in a network comprises fault detection, localization, prevention, and recovery to ensure that the fault or error is being resolved. In a multi-controller network, unlike a single controller network, the control plane consists of several controllers, and all of them are attached to the East-West bound interfaces. Likewise, the control plane/application relates to the Northbound interface, and the control plane/application plane relates to southbound interfaces. Fault management, as indicated above, is the process of detecting, locating, resolving, and preventing network failure in the network in the event of an error or a fault (D. Kreutz et al., 2015; Paradis & Han, 2007a). Hence, it is important to design suitable fault tolerance management system solutions for achieving the best SDN network reliability deployment. There are various classifications of fault management techniques according to the literature. Most of them are divided into four tasks namely, system monitoring, which addresses system behavior, fault diagnosis, fault recovery and fault tolerance which deals with preventing that fault (Paradis & Han, 2007a).

The focus of this paper is on a fault management system that applies various approaches for fault detection and recovery to ensure the reliability and availability of network resources. Compared to other SDN fault tolerant in the literature, our proposed FTF can be used in a medium-sized networks environment and makes use of mobile agents' techniques for fault detection and recovery. In addition, it uses placement to determine the number of controllers that they need to use and their position on the network. The following section discusses related research work on the fault management system.

3. Related Works

Fault management in SDN networks has been discussed previously which reference for (Chen, J.Chen, et al., 2015; Kreutz et al., 2013; D. Kreutz et al., 2015; Sharma, Staessens, D.Colle, et al., 2013; A. S. da Silva, P. Smith, A. Mauthe, & A. chaefer-Filho, 2015). Different protocols are utilized to solve difficulties caused by various sorts of defects, such as OSPF (Yu et al., 2007a), AMQP (Zeng et al., 2012a), and so on. Fault tolerance concerns` such as hardware failure,

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software failure, and link failure, which are common in traditional networks, are also common failures at the data plane layer in SDN. These difficulties are due to the centralization of network administration and programmable capability in the SDN. Several studies have presented solutions to these problems at various levels, including hardware, software, and link failure. The most common causes of network failures are switch/router software bugs, hardware failures, protocol misconfiguration, and external factors, according to a survey of network administrators, while the most common symptoms of failures are reachability issues, degraded throughput/latency, and congestion (Zeng et al., 2012a).

As a method to address bidirectional forwarding detection, (Sharma, Staessens, et al., 2013b) offered a loss of signal recognition of interface failure, which consists of evaluating whether a particular switch port is up or down (BFD). Shame's study (Sharma, Staessens, et al., 2013b) described several failure detections and recovery approaches in SDN. The research in (Kreutz et al., 2013) argued about fault tolerance and reliability issues in SDN while (A. S. da Silva, P. Smith, A. Mauthe, & A. Schaefer-Filho, 2015) discussed resilience in SDN focusing on six aspects: security, traffic tolerance, survivability, resiliency, interruption tolerance, performability, and dependability are all factors to consider (Anderson Santos da Silva et al., 2015). The study also defined strategies for determining which SDN plane each endeavor can apply to (Anderson Santos da Silva et al., 2015) . Moreover, fault tolerance in the traditional networks was explored by (Chen, Chen, et al., 2015) while determining the OpenFlow protocol features suitable for fault tolerance in the network. The study investigated the relationship between fault tolerance and SDN. In the event of a fault in SDN, protection (proactive) and restoration (reactive) methods of fault recovery are used to keep the network running. Backup pathways are pre-configured in the switches, and they utilized flow rules that are fixed (Lakhani & Kothari, 2020). The restoration approach is followed by the notification strategy. When a component in the network fails, a notification is sent to the controller, which analyses the signal and determines the type of fault or error. In the event of a link failure, it determines an alternate path and installs a switch flow. Both restoration and protection have advantages and disadvantages. These methods are typically used to reduce recovery time, bandwidth optimization, and network utilization (Lakhani & Kothari, 2020).

In the literature, several strategies have been used as solutions to various sorts of defects that affect network performances to address fault-tolerant issues in SDN. Some of these solutions focus on the hardware (controller) and some on the link and nodes. Even though each approach addresses a different aspect of fault tolerance, they all have advantages and disadvantages (Zang et al., 2018). A solution was provided in (kempt et al., 2012) to evaluate the switch port status to determine the failure. In this study, a detection and recovery strategy was used by continuously evaluating the switch port status to assess whether it's up or down, determine the possibility of an error or fault, and initiate a recovery procedure (Sharma, Staessens, et al., 2013b). In contrast to (Sharma, Staessens, et al., 2013b), a controller replication mechanism was suggested as a way to fix controller flaws (Fonseca et al., 2013). This solution employed a passive or active replication mechanism to ensure that communication between the controllers and switches is never interrupted. To address the issue of fault that affects nodes and link failure on SDN, a protection mechanism was developed in (kempt et al., 2012) as a solution in the OpenFlow network using a monitoring function protection tool to manage faults and errors. Other solutions have used time frames for node and link detection and recovery processes (Raeisi & Giorgetti, 2016; Sharma, Staessens, et al., 2013a). An FTF with three components and a fault manager technique was suggested by (Bassey et al., 2018) to guarantee reliability and resiliency for small and medium networks. The system's goals were to monitor, detect errors using heartbeat messages, and recover from faults and network failures using the checkpoint. Additionally, the suggested system in (Bassey et al., 2018) uses a passive replication strategy, managing the network with a single controller at a time. In the event of a failure, a new controller was chosen by election and voting.

The proposed FMS presented in this paper is an extension of (Bassey et al., 2018). The SDN-SDWSN, for fault tolerance, employs multiple controller approaches and in the event of failure, it uses the election and voting techniques to select a new controller to handle the issue of network state consistency. Based on its evaluation and acceptance performance operation in ensuring

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strict consistency and fault tolerance systems. This paper adopted some of its approaches and improved them to address fault tolerant issues in medium-sized networks environment. The proposed FMS uses mobile agents' techniques for fault detection and recovery, to ensure network reliability and consistency as well as placement to determine the number of controllers to be deployed and their position on the network. The following section will discuss controller placement formulation problem.

4. Controller Placement

This section presents the formulation of the controller placement problem, which involves using a mathematical model to determine the number of controllers and switches needed to be deployed and where to place them. This is to find the best placement that can reduce the average latency of the controllers, increase reliability, and ensure high availability of the network. A multiple controller approach architecture segment in medium manageable clusters is designed to evaluate controller placement in a medium-sized network with topology and metrics. The network partition of the SDN problem can be formulated using the SDN-enabled network, with given nodes and links of the physical topology of undirected graphs as G = (V, E) where V is the SDN set of nodes that represent both switches and controllers in the network, E is the set of physical links among the nodes. For instance, if the number of partitioned graphs is given as k when SDN is considered the network partition can be defined as:

$$SDN_i(V_i, E_i) \tag{1}$$

Equation (1) is subject to conditions in equations (2) – (5).

$$\cup_{i=1}^{k} V_i = V;\ \ \cup_{i=1}^{k} E_i = E \tag{2}$$

Equation (2) represents the total subnetworks required to cover all the network elements nodes and links.

$$SDN_i \cap SDN_j = \emptyset;\ \ \forall_{i \neq j,\ \ i,j \in k} \tag{3}$$

Whereby $\emptyset$ is an empty set, which means that a node or link can only be allocated to one subne

$$similarity(SDN_i) = TRUE,\ \ \forall_{i \neq k} \tag{4}$$

Equation (4) implies that the element in one sub-network is similar

$$similarity\left(SDN_i \cap SDN_j\right) = FALSE,\ \ \forall_{i \neq j, i, j \in k} \tag{5}$$

Equation (5) indicates that the elements allocated to different subnetworks are different. The similarity is defined as the latency, specifically when the network is expected to be divided in a way that the nodes in one cluster have a smaller latency Equation (4), while the nodes in different clusters have a larger latency Equation (5). This is characterized by the propagation delay set by network topologies that determines the optimal placement. Hence, control reactions with a remote controller that can be carried out with adequate speed and stability are constrained by propagation latency. This is the way the network topologies require more controllers to minimize latency.

$$SDN_I \text{ are connected regions} \tag{6}$$

Equation (6) indicates that all the vertices in one sub-network are connected by links.

The k-means clustering-based partition algorithm is used to elaborate on how the partition of the network is done in sub-networks to shorten the maximum end-to-end. For clarification, the initial nodes, which are selected to perform clustering algorithms, are the 'center' with the actual center of each cluster termed a 'centroid'. The *k-means* clustering algorithm includes four main steps:

Algorithm: k-means clustering

Input: node values
Output: cluster formulation

Steps:

1 initialize centres
2 Distribute the vertex v (v$v(v \in V)$ to one of the K clusters using the relation, whereby $v \in cluster_i$, if $d(v, ci) < d(cj), \forall j \in \{1,2, \dots, k\}$ whereby $d(u, v)$ represents the shortest path between the node u and v.
3 update centroids $C' = \{c'^1, c'^2, \dots c'_k\}$such that the sum of the shortest path between distance from all points in the $cluster_i$ to the new centroid c'_I is minimized.
$C'_I = v_m$, *if* $d(v_m, v) = minimum$
And $\forall m \in$ *size* $cluster_i$, v $\in$ cluster, I = $\{1, 2, \cdots, k\}$
4 Repeat steps 2 and 3 until there is no change in each cluster
5 Initialize k-clusters and allocate one centre for each cluster using random sampling
6 Allocate nodes into one of the clusters based on Euclidean distance.
7 Recalculate the centroid for each cluster
8 Repeat steps 2 and 3 until there is no change in each cluster

Figure 1. k-means Clustering Algorithm

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The k-means defines the total within-cluster variation as the sum of squared distances. Euclidean distances between the item and the corresponding centroid as shown in equation (7).

$$d(C_k) = \sum_{x_i \in c_k} (x_i - \mu_k)^2 \quad (7)$$

Where x_i is a data point belonging to the cluster, c_k, μ_k is the mean value of the points assigned to the cluster c_k which represents the shortest path from node $v \in V$ to $s \in V, n = |V|$, S is the number of controllers to choose from, S' is the number of controllers to place such that $|S'| = k$. The average latency for placement of controllers $L_{avg}(S')$ is modelled as in equation (8).

$$L_{avg}(S') = \frac{1}{n} \sum_{v \in V} \min_{s \in S'} d(v, s) \quad (8)$$

The average latency uses a *k-median* optimization approach. The k-median is a clustering method used to find the k-cluster center such that the sum of the distances between the center and all other points in the cluster is minimized. To address the issue of controllers' placement in the proposed SDN-FTF architecture, we employ the *Cityblock* distance metric in MATLAB using the algorithm to calculate the sum of absolute difference x, plus the distance in y. We deployed K-means and K-medoids clustering to solve this problem. The *Cityblock* distance between two points, *a* and *b* with *k* dimension is denoted and calculated as in equation (9).

$$\sum_{j=i}^{k} | aj - bj | \quad (9)$$

To compute the distance using different distance metrics, and to find out the centroid clusters between the controllers and switches, whereby *x* represents the distance, and *c* the centroid, it is presented in equation (10).

$$d(x,c) = \sum_{j=i}^{k} | aj - bj | \quad (10)$$

The main objective of using the above equation is to compute the k-means clustering algorithm to define the location of the controllers, as well as to specify the distance between them. The anticipated result of the evaluation is to find out the optimal controller placement distance between several given switches in the clusters and, defining the best location for those controllers, will increase the capacity of the controller and decrease the average propagation latency. In the following section we discuss proposed FMS.

5. Proposed FMS

The proposed FMS in this paper is designed to implement and execute fault tolerance in the control plane of the SDN. Its responsibility is to ensure successful monitoring of the controllers against any potential faults, errors, or failures (Bassey et al., 2018). A fault is considered as the root cause of an anomaly where the problem generates in a system, an error results in a fault in the system and a failure is reflected as the outcome whereby the system is down (Bassey et al., 2018; Raeisi & Giorgetti, 2016; Sharma, Staessens, et al., 2013a). The type of faults that the system detects include controller faults and nodes and links faults whereby the entire accessibility is unavailable (Bassey et al., 2018; Raeisi & Giorgetti, 2016). Controller fault happen when the controller does not receive incoming demands from the switches, or fails to send messages to respond to the switches' demands (Bassey et al., 2018; Raeisi & Giorgetti, 2016). A node and link fault occurs when a controller receives an incorrect message in response to the switch's message (Bassey et al., 2018; Raeisi & Giorgetti, 2016). The assumption is that no faults or errors caused by any attacks can result in total failure of the system (Bassey et al., 2018; Raeisi & Giorgetti, 2016). All activities executed in the FMS will ensure the reliability and availability of the network. Figure 2 illustrates all the phases that are involved during the monitoring or detection and recovery process.

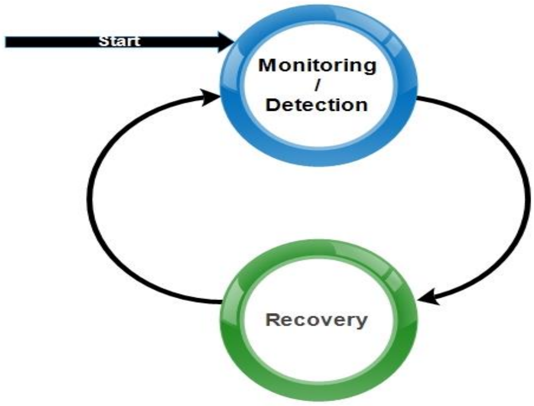

Figure 2. FMS Phases

A. Network Design

The network design of the control plane uses a single controllers or multiple controllers depending on the choice of the control plane's architecture to avoid a single point of failure. Following that, we deploy multi-controller architecture with a ring configuration so that each of them provides a continuous global view of the

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network status. The main reason for the deployment of multiple controllers is to segment the network topology into small-medium manageable clusters to overcome the challenges posed by single controller SDN network design.

B. Fault monitoring and detection

In the proposed FMS, the monitoring and detection module oversees and ensure that all types of faults in the network caused by the controllers are being detected. We employed two Stationary agents (SA): $SA_{\mathbf{fms}}$ and SA_c, and a modified central controller. While SA_c is integrated into the modified controller, the $SA_{\mathbf{fms}}$ are in the FMS module to facilitate the communication between them in terms of fault monitoring and detection or failure that results in the controller. SA is a mobile agent designed to continually monitor all network events as well as controllers' status as shown in Figure 3, and the monitoring and detection framework. The FMS module is designed to be incorporated in the control plane, but external to the controller, to avoid placing too much burden on the controller. Moreover, the proposed functionalities are discussed as follows. The module has three main components: $\mathbf{SA}_i$, **Mlog** and the **sDB**.

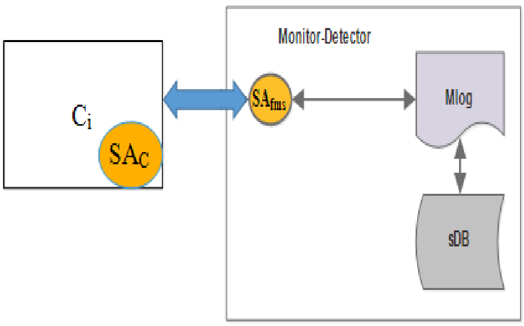

Figure 3. Monitor-Detector module

1) $\mathbf{SA_i}$**:** These are mobile agents, software designed to be installed in both the controller and the FMS to monitor and detect possible fault or failure in the system. For effective monitoring and reliability, SA_C and the SA_{fms} continuously communicate to check the state of the controller by sending periodic information to all nodes on the networks and checking the response to detect whether the controller is UP or DOWN.

   The main responsibility of SA is to establish communication between the controllers; SA_C takes information about the state of the controller, in which house it is and sends it to SA_{fms} which oversees monitoring each controller's state and notifies the FMS. Below are various functions and methods used by the SA.

   a) **Request()**: send continuous messages to check the state of the controller periodically in 40 secs to all nodes in the networks. It uses the controller ID and addresses to determine its status. Its main responsibility is to establish constant communication between the controllers and share that with all nodes connected in that network. If the message is sent and, after 40 seconds, there is no reply, it's considered that the controller is dead.

   b) **Reply()**: checking periodically the message from the sender and returning a response to detect whether the controller is UP or DOWN. It takes information about the state of the controller and notifies the FMS.

2) **Message Logged (MLog):** This is used for the checkpoint, and the recovery of the checkpointed information such as messages sent and received to the controllers, then identifies the type of faults and specifies the kind of recovery technique needed. MLog log FMS events such as hardware and network fault, helps it to provide a set of functions that enable the FMS to detect a failure and to avoid a single point of failure in the system. MLog also checks continually the network and controllers state to ensure quick recovery in the event of a fault. Figure 4 shows an illustration of the message's information Logged.

Message_ID	LogTime	Type_of_Message	Status	Action	Is_Event_Logged
A001	0:55	DEAD	DOWN	Recover	Yes
A002	0:20	ALIVE	UP	Update	No
A003					

Figure 4. Logged messages

3) **Stable Database (sDB):** The sDB is used to store only vital information about the global controller on the network and FMS events. This information consists of the type of faults that occurred in the FMS as well as the techniques used to recover them. Information stored in the sDB assists the system in the fast

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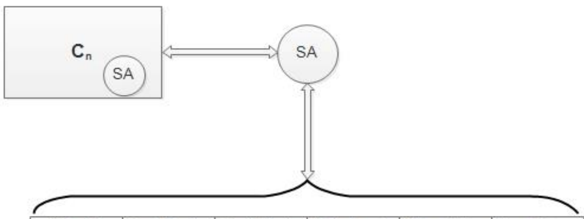
fault detection process by comparing information stored with the information of the current events to identify if the fault is vital or not. The type of faults that are stored in the sDB are controller failure and network link fault. sDB stores information, such as controller ID (Cnt_ID), which displays all the details of the controllers connected on the FTF, and controller position (Cont_Positn) specifies the position of a specific controller on the network so that each controller can be identified in the case of a fault. The controller state (Cont_State) define that the controller is either UP or DOWN, controller location (Cnt_loctn) that defines the position of a controller on the network to facilitate placement, time delay (Time_Dlay) that shows time delay of the controller to respond when connecting with SA, as a well as response time that is responsible for recording all the successful response time (Rsp_Time) for the controller to communicate with SA. Figure 5 shows the illustration of this process.



Cnt_ID	Cnt_Positn	Cnt_State	Cnt_Loctn	Time_Dlay	Rsp_Time
C_1	1	UP	k=2	0:00	0:35
C_2	2	UP	k=4	0:50	1:00
C_3	3	DOWN	k=3	1:30	2:20
C_4					
C_n					

Figure 5. Stable Database Communication with SA

4) Fault monitoring and detection process

As shown in Figure 6, the fault monitoring and detection process are handled by the SA_{fms} that communicates with SA_C using Request() and Reply() messages to check if a controller is dead or alive for possible fault detection. It uses the MLog to record all events and the controller's status. Once a fault is detected, it notifies the FMS to identify the type of fault, error, or failure and initiate the best diagnosis procedure and plan for the recovery process for a new controller to be chosen and return the system to its normal state. Figure 6 shows the fault detection algorithm.

Algorithm: Monitoring and Detection

Input: ***Message from SA_c***
Output: ***Updated controller status***
Steps:
Initialize SA_{fms}
  For every 40 sec. do
    SA_{fms} send Request() to SA_c;
      If Reply() is sent within 40 Sec Then
        Controller = "ALIVE"/ **UP**;
    Else
        Controller = "DEAD"/ **DOWN**;
    If "DEAD"/DOWN
      resend Request() and check ***MLog****;*
    Else if logging is in the ***MLog*** then
      update controller status.
    End
Else
    Activate the recovery process.
End

Figure 6. Fault detection algorithm

With the operation fault, it is detected as follows:

i. SA_{fms} sends Request() to SA_c every 40 sec. If Reply() is not received from a specific controller within a given time interval defined by the system, such controller is considered DEAD, Otherwise, UP.

ii. If "DEAD", SA_{fms} uses a message logged to take a record of all network events and controllers' status, which the FMS use in identifying the type of fault/failure and initiating the best diagnosis process as well as recovery mechanism process. Vital information for the recovery process is stored in the sDB. This communication between SA_{fms} and *MLog* is periodical.

B. Recovery

The recovery process is handled by two components of the FMS, namely, elector and executor as shown in Figure vv. These components oversee and initiate the recovery process and strategies for the FTF to recover in the event of faults as shown in Figure 7.

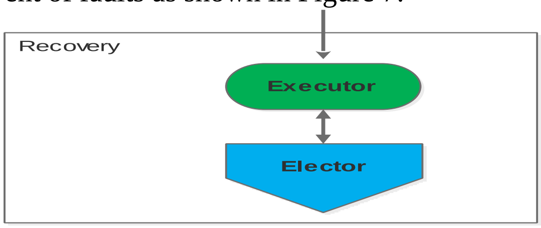


Figure 7. Recovery components

Executor: As a fault is detected, the SA_{fms} activates the executor to implement the recovery

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process. The executor is in constant communication with MLog and SA_{fms} to check the type of faults to initiate the appropriate action to solve them. Is also responsible for signaling the election process to the elector by checking in the sDB to identify the type of vital fault that needed to be recovered or not. The main role of the executor is to serve as an interface between the detector and the elector as in Figure 8.

Algorithm: Fault Recovery Algorithm

```
Input: SAfms information, Old_Leader Controller ID number
Output: New_Leader Controller

Steps:

SAfms activate Executor;
Executor activate Elector;
Cn[] = {C1, C2, C3, …, CN-1}
While New_LEADER = NULL do
Old_LEADER = k;
LinerProbe ();   HashTable [k%N]
   If (Cn [i] = LinearProbe() {
      int new Cn_id =rand.nextInt(n);
New_Leader  = Cn[i];
 Delete all events in sDB list except the new LEADER
Update the election information in the list
      Return ()}
end
```

Figure 8. Fault recovery algorithm

Elector: The elector oversees executing the election process once signaled by the executor. This is important to choose and assign responsibility to a new controller designated as a lead controller in the event of a fault. For the election process, the proposed FMS apply a novel algorithm based on the hashing concept of the *hashTable[k % N]*, where k is the failed controller ID number, and N is any given prime number equivalent to the total number of controllers in the network. In this case, each controller is assigned a unique ID number from *1* to N, to make it easy for the system to choose a leader controller in the event of a fault. To avoid a collision, we employed linear probing to find the next available controller to be elected the LEADER. Employing the *LinearProbe()* algorithm is to ensure that only one controller is elected as the leader in the event of failure by comparing the controllers' IDs in the SDN ecosystem. Even if all controllers participate in the election process, it will make sure that all controllers agree on the new controller without causing chaos in the network. The process for electing a leader is shown in Figure bb and is described as follows:

i. Once the elector is notified of a possible fault by the executor, the elector will invoke the *LinearProbe()* algorithm to use k as the failed controller's ID to generate a key between 0 and N-1.
ii. This generated number will be compared to the controllers' ID and that controller is automatically chosen as the leader, except if the health status or response time is bad. However, if the number generated is "0", or any other number colliding with the ID of the failed controller, the *LinearProbe()* will generate a new number using generate a new number using "hashTable[(k+i) % N]", where i= 1,2, 3, ….. in this case, the process will continue until a new key is produced that has no collision with the ID of the failed controller.
iii. As soon as a new leader has been chosen, the control is then passed to the executor who notifies the detector.

The following section discusses the proposed SDN-based architecture.

6. FT-Based SDN Architecture

SDN removes the control plane from network hardware and implements it in software instead, which enables programmatic and, as the outcome, makes the network automated and more flexible to manage. In the SDN architecture, the controller plays a vital role as it is the central point where decisions such as network configuration, new policies and most of the changes implemented on the network are made. The proposed FTF is applicable for small to medium-scale types of SDN networks. However, it can also be modified to be used on a large scale. Its design introduced a Stationary Agent (SA) by modifying the original SDN controller. In the control plane, SA ensures effective monitoring communication between the controller and FMS to accomplish a robust fault tolerance. The purpose of integrating the SA in both controller and the FMS is to check continually the status of the controller to determine if it is up or down using continuous exchange messages with the FMS. The FMS as a core component of the proposed FTF, implements and executes fault tolerance in the control plane, and it ensures continuous monitoring of the controllers in the event of fault or failure. To ensure that all controllers maintain active connection, the proposed FTF makes use of an active replication strategy in the control plane to make sure that information among the controllers is synchronized in real-time. In the event of failure of one controller, the entire network should not be disrupted, nor stop, but the rest of the controllers should keep running. The proposed design for the FTF assumed that the FMS is fault free and resistant to any security attack or malicious attack that may cause the system to malfunction or shut down. To ensure optimized placement, the K-centre algorithm was used to define the number of controllers required and the controller workload in the data plane as indicated in the experiment in the previous section.

The function of the proposed FTF is to guarantee full monitoring of the network, as well as the SDN controllers in real-time, and to detect any faulty components in the system in the event of a fault or failure. Once a fault is detected, the system implements a fault-tolerant mechanism and recovers from the failure within seconds by applying multiple controllers' strategy using active replication to ensure that failure does not affect the operations of the entire network. In the event of a fault or a failure of the master controller, the system selects a new controller to take charge of the master controller's responsibilities. The election process of a new controller is done using a novel approach involving a random generator algorithm that generates a unique number equivalent to the controllers' unique identification (ID). The election decision for the FMS is based on the hashing algorithm using Controller ID to elect the new leader to take over control and the executor of the system. Figure 9 shows the proposed FTF Architecture.

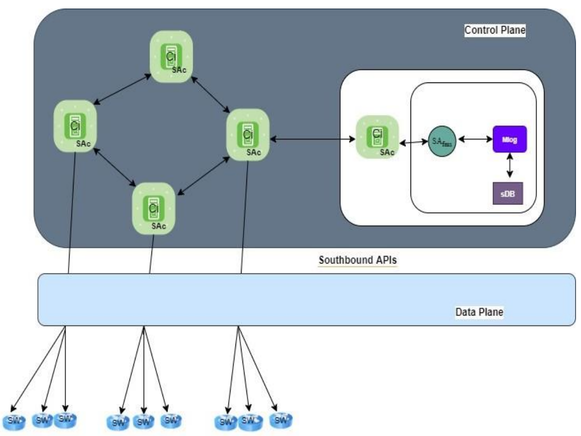

Figure 9. Proposed FMS for SDN Architecture

The following section presents experiments and results of the evaluations of the proposed SDN-based architecture.

7. Experiments and Results

Table 1. Simulation Parameters

Parameter	**Value**
Algorithm	k-means clustering
Protocol	S-MAC
Simulator	NS2 version 2.31
Patch	16-Sep-22
Simulation Area	31-Oct-22
Simulation Time	1-Nov-22
Node movement model	30-Nov-22
Transmission range	300m
Data transmission interval	0.1 seconds
File size	128bytes
Routing protocol	AODV
Trajectory	Random
Transport protocol used	UDP
Application traffic instance	CBR
Initial energy per node	100J
Number of secondary users	26
Number of base station(s)	1

Based on the above procedure and using equation (10) we performed a simulation in MATLAB to achieve our goals of defining the optimal locations to place the controllers and optimizing the number of controllers to be deployed in the proposed SDN-FTF network infrastructure. To assess this, we create a set of random numbers using x, and y coordinates and make use of a matrix that holds randomly generated usage numbers for each switch and to define the number of clusters to be used (essentially = to the number of controllers) on the network. The key factor in this mathematical model is to define the distance between switches and controllers to plot the designed network topology partition as shown in Figure 10.

The plot shown in Figure 10 displays the network partition randomly generated to define the best arrangement of switches. This partition is important in determining the optimal number of controllers to be deployed and their location. In this scenario, the locations are generated randomly.

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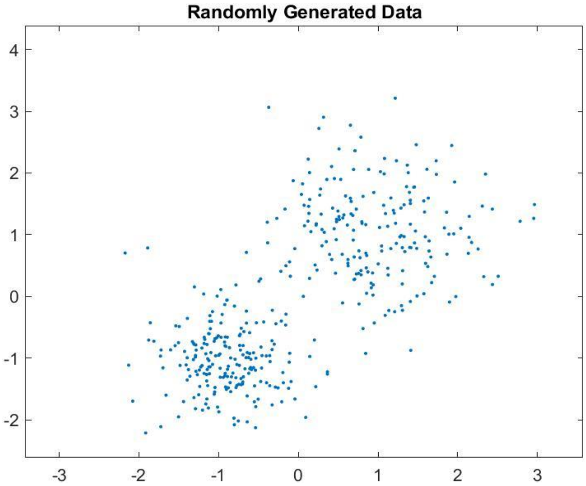

Figure 10. Topology Formation

For the deployment of multiple controllers, we segment the network topology into small-medium manageable clusters to overcome the challenge of the single controller by initializing the city-block distance metric randomly using the K-Means algorithm to find out the optimal controller placement distance between several given switches in the cluster as shown in Table 2.

Table 2. Distance Metric

Replicate	Iterations	Total Sum of Distances
1	11	88.2602
2	8	92.3789
3	9	89.3037
4	6	92.6302
5	8	91.1183
6	7	96.1411
7	10	92.0779
8	9	93.9656
9	6	91.2769
10	7	99.2522
Best total sum of distances		88.2602

Out of the 10 randomly initialized instances of the K-mean, with various iterations, the minimum sum of the distance between all points clusters switches and their centroid is *88.2602.* Considering this distance matric, we plot the clusters allocations that define the best network sections using the above matric to partition them into 10 small segments (clusters) as shown in Figure 11. Each segment is represented with a specific color to allow the plotting of the centroids for the controllers' deployment. The number of clusters generated is essentially equal to the number of controllers needed to be deployed.

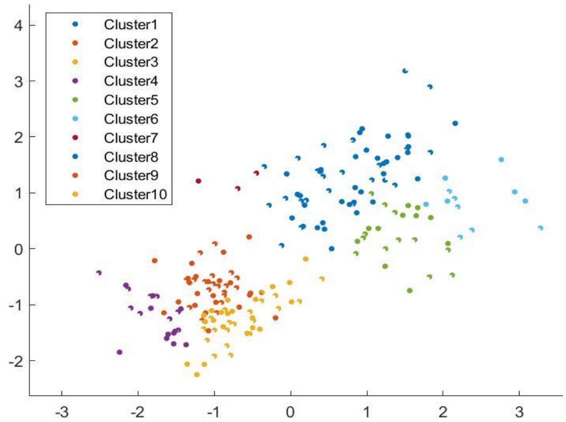

Figure 11. Cluster Allocations

A. Theoretical evaluation of proposed FMS

To analyze and validate the proposed FMS architecture, there is a need to consider numerous scenarios based on the design principles of an accurate use case, corresponding to a fault-tolerant system. Table 3 shows an illustration of various scenarios for evaluation of the proposed FMS.

8. Conclusion

This paper presents a design of a fault tolerance management system for a SDN controller framework that can be deployed for small to medium-sized networks. The system can detect and recover controller faults and nodes/links faults in case the network is unavailable. The fault management system applies various approaches for fault detection and recovery to ensure the reliability and availability of the network resources in the event of a failure or a fault. The components of the FTF were presented and explained in detail, their functionality, design, as well as the algorithms used in the design were presented. Furthermore, the design principles of the system was discussed in detail and the choice of the constructed FTF was validated.

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Table 3. Evaluation of the Proposed FMS

Principles	**Description**
Placement	• Placement is achieved by defining the number of controllers on the network and their deployment. • The FTF ensure load balancing, minimize latency between controllers and switches • To improve network performance and save cost. • Placement is achieved by the minimum K-center and minimum K-media algorithms
Reliability	• The FT deployed a multiple-controller approach to avoid a single point of failure in the event of a fault. • The FMS detects faults and recovers them to allow the network to be continuous. • The FMS allows the controllers to control the network permanently. • The number of controllers is increased and in the event of the failure of the leader, another controller is elected immediately to take charge.
Availability	• The FT introduced multi-controller deployment for fast fault detection and recovery. • The use of an active replication scheme is used for synchronization to keep the system working continuously in good condition.
Network Consistency	• Controllers in the FTF are placed in a distributed fashion to guarantee constant control and update of network states • All controllers are synchronized and share information about each other state in real-time to allow system functionality in the event of a failure. • The controllers have the global view of the network to allow rapid election without the need for rollback operation.
Consensus	• Controllers in the FTF use synchronized replication and make sure that all controllers have the same view of the network at all time • The election of the leader in the proposed FTF is done by applying a random number generator algorithm to identify the new leader • Fault-tolerant logging with globally consistent sequencing event of the network • Controllers in the FTF communicate together and agree in selecting one controller in the event of a failure to take place of the lead controller