



ASBIRES 2024

Proceedings of the
16th

Applied Science, Business & Industrial Research
Symposium
07th March 2025



25

1999 - 2024
Twenty-Five Years
of Commitment to
Higher Education

Faculty of Applied Sciences
Wayamba University of Sri Lanka
Kuliyapitiya



Faculty of Applied Sciences
Wayamba University of Sri Lanka



Proceedings of the 16th Symposium
On
Applied Science, Business & Industrial Research
7th March 2025

ASBIRES – 2024
Faculty of Applied Sciences
Wayamba University of Sri Lanka
Kuliyapitiya

© Faculty of Applied Sciences,
Wayamba University of Sri Lanka, 2025
Catalog in Publication Data approved by
National Library and Documentation Services Board

Symposium on applied science, business & industrial research (16th: 7th March 2025
Kuliyapitiya, Sri Lanka)

Proceedings. - Kuliyapitiya: Wayamba University of Sri Lanka, 2024 Vol. 16.
- 298p; 36cm.

ISBN 978-624-6674-05-2
ISSN 2989-0683

i. 607 DDC 23

ii. Title

1. Applied science - Research
2. Industrial management - Research
3. Mathematical sciences - Research
4. Computer and information system – Research

ISBN 978-624-6674-05-2
ISSN 2989-0683

Typesetting, Designing and Printing
at Faculty of Applied Sciences,
Wayamba University of Sri Lanka, 2025

This event is proudly organized by the
Faculty of Applied Sciences, Wayamba University of Sri Lanka

EDITORIAL BOARD

Prof. A. Pallegedara

Editor in Chief

Department of Industrial Management

Members

Dr. N.A.D.N. Napagoda	<i>Department of Mathematical Sciences</i>
Dr. G.V.R.K. Vithanage	<i>Department of Mathematical Sciences</i>
Dr. B. Munasinghe	<i>Department of Computing and Information Systems</i>
Ms. W.M.L.N. Wanninayake	<i>Department of Computing and Information Systems</i>
Ms. C.M. Liyanage	<i>Department of Industrial Management</i>
Ms. W.I.S. Wickramarathna	<i>Department of Industrial Management</i>
Ms. H.W.A. Hansamali	<i>Department of Industrial Management</i>

Editorial Assistance - Language

Department of English Language Teaching

Members

Mr. MKSM. Samaranayake	<i>Department of English Language Teaching</i>
Ms. PWRC Wijenayaka	<i>Department of English Language Teaching</i>
Ms. GN Madumali	<i>Department of English Language Teaching</i>
Ms. HMI Nawodya	<i>Department of English Language Teaching</i>
Ms. WPAP Senarathna	<i>Department of English Language Teaching</i>
Ms. EMSC Ekanayake	<i>Department of English Language Teaching</i>
Ms. JAGS Jayakody	<i>Department of English Language Teaching</i>
Ms. BMTC Basnayake	<i>Department of English Language Teaching</i>
Ms. AGNK Rathnayake	<i>Department of English Language Teaching</i>
Ms. HMHS Herath	<i>Department of English Language Teaching</i>

PANEL OF REVIEWERS

Prof. M.M.D.R. Deegahawature	Wayamba University of Sri Lanka
Prof. E.A.C.P. Karunarathne	Wayamba University of Sri Lanka
Prof. R.M.K.T. Rathanyaka	Sabaragamuwa University of Sri Lanka.
Prof. M. P. N. Janadari	University of Kelaniya
Prof. H.M.A. Herath	Wayamba University of Sri Lanka
Prof. VGTN Vidanagama	Wayamba University of Sri Lanka
Prof. D Nawinna	Sri Lanka Institute of Information Technology
Prof. SR Kodituwakku	University of Peradeniya
Prof. (Mrs.) N.V. Chandrasekara	University of Kelaniya.
Prof. (Mrs.) D.D.M. Jayasundara	University of Kelaniya.
Prof. A. Pallegedara	Wayamba University of Sri Lanka
Dr. Upeksha Perera	University of Kelaniya
Dr. Sujeewa Wijesiri	University of Kelaniya
Dr. Nadeeka Premadasa	University of Kelaniya
Dr. Mihiri De Silva	University of Kelaniya
Dr. K.K.K.R. Perera	University of Kelaniya
Dr. M.H.L. Weearasinghe	University of Kelaniya
Dr. Roshan Adhikari	South Western College, USA
Dr. Nilan Manoj Chaturange	University of Peradeniya.
Dr. Bimali Jayasinghe	University of Moratuwa.
Dr. Bhagya Upendra	Williams College, USA
Dr. Dilru Gammanpila	Eastern Kentucky University, USA
Dr. Saikanth Ratnavale	Marshall University, USA
Dr. Gayani Balasooriya	Ottawa University, USA
Dr. Shadhi Heenatigala	Texas State University, USA
Dr. (Mrs.) D. M. K. N. Seneviratna	University of Ruhuna
Dr. (Mrs.) D.M.P.V. Dissanayake	University of Kelaniya.
Dr. (Mrs.) I. Hewapathirana	University of Kelaniya.
Dr. (Mrs.) H.L. Jayetilleke	University of Ruhuna.

Dr. (Mrs.) K.D. Prasangika	University of Ruhuna.
Dr. (Mrs.) Anuradha Hewaarachchi	University of Kelaniya.
Dr. (Mrs.) Hemalika Abeysundara	University of Peradeniya.
Dr. (Mrs.) Lakshika S. Nawarathna	University of Peradeniya.
Dr. Sachith Abeysundara	University of Peradeniya.
Dr. (Mrs.) B Munasinghe	Wayamba University of Sri Lanka
Dr. C Wimalasooriya	University of Otago, New Zealand
Dr. (Ms.) DDM Ranasinghe	Open University of Sri Lanka
Dr. KASH Kulathilake	Rajarata University of Sri Lanka
Dr. S Kirushanth	University of Vavuniya
Dr. T Ketheesan	University of Jaffna
Dr. T Kokul	University of Jaffna
Dr. T Selvarajah	Charles Darwin University, Australia
Dr. T Sharmilan	University of Kelaniya
Dr. U Wijenayake	University of Sri Jayewardenepura
Mr. JRKC Jayakody	Wayamba University of Sri Lanka
Mrs. L Weerasinghe	Sri Lanka Institute of Information Technology
Ms. N Prasangini	Rajarata University of Sri Lanka
Mrs. RPTH Gunasekara	Wayamba University of Sri Lanka
Mr. S Thirukumaran	University of Vavuniya
Mr. T Arudchelvam	Wayamba University of Sri Lanka
Ms. T Bakmeedeniya	Uva Wellassa University
Mrs. WBMSC Wijyakoon	Uva Wellassa University
Mr. WCC Premarathna	Wayamba University of Sri Lanka
Mrs. WMLN Wanninayake	Wayamba University of Sri Lanka
Dr. W. Sanjeewa	Wayamba University of Sri Lanka
Dr. B.S. Habaragoda	Wayamba University of Sri Lanka
Dr. A.D. Dharmawansa	Wayamba University of Sri Lanka
Mr. D.M. Jayasena	Wayamba University of Sri Lanka
Ms. P.A.A.U. Jothirathna	Wayamba University of Sri Lanka
Ms. M.G.S. Dilanthi	Wayamba University of Sri Lanka

TABLE OF CONTENTS

<i>Editorial Board</i>	<i>i</i>
<i>Panel of Reviewers</i>	<i>ii</i>
 Computing and Information Systems	
A Review on Smile Detection Techniques Sameeha MR, Gunasekara RPTH.....	01
A Tailored Approach to Overcoming Project Management Challenges in Modern Organizations Nadeeka RDC, Munasinghe B.....	07
An Ai Based Dress Design Pattern Selector For Entrepreneurial Fashion Designers De Silva WRJ, Munasinghe B.....	12
Analysis of Trading Partner Management: Use of IT Solutions for Supply Chain Sustainability and Transparency Perera BHD, Munasinghe B.....	17
Crime Prediction Using Object Detection and Deep Learning Katugampala KDYA, Vidanagama VGTN.....	23
Deep Learning-Based Automated Glacier Identification and Classification Gamage GDIC, Wanninayake WMLN.....	29
A Hybrid Approach for Effective Data Encryption for Cloud Computing Ranasingha RSN, Vidanagama VGTN.....	35
Effectiveness of Manual and Automated Testing in Software Quality Assurance: A Case Study Manawasinghe GAMU, Munasinghe B.....	41
Enhancing Fault Management in Telecommunications Networks Using Power BI: A Case Study Kodippily TND, Munasinghe B.....	47
Enhancing Python Interpreter Messages with a Natural Language Processing Approach Wijesundara WMDI, Munasinghe B.....	53
Evaluating the Effectiveness of Digitalized Software Documentation Solutions: An Industrial Case Study Wijesundara WMDI, Arudchelvam T.....	59
Machine Learning based Rainfall and Flood Forecasting in Rathnapura District Wijayasundara RJ, Wanninayake WMLN.....	65
Multimodal Knowledge Graph Construction for Event Analysis Sovis WRN, Gunasekara RPTH.....	71
Optimizing New Asset Request Management for Enhanced Operational Efficiency Piyarathne SHMCS, Vidanagama VGTN.....	76
Optimizing Project Management for Task Allocation, Monitoring, And Developer Assessment in The IT Industry Ravindika IWP, Vidanagama VGTN.....	81
Performance Evaluation of Cross-platform App Development Frameworks Hewenpola DRAK, Munasinghe B.....	87
Privacy and Security Challenges in IoT Devices: A Comprehensive Analysis and Solutions Rathnayaka RMSN, Vidanagama VGTN.....	93

Real-Time Eye Blink Password Detection Using Computer Vision Madhurangi BR, Premarathna WCC.....	98
Streamlining The Software Development Workflow Process Bulugahawaththa BMSR, Vidanagama VGTN.....	106
The Smart Home Gardening System with Machine Learning-based Crop Recommendation and IoT-enabled Environmental Monitoring Ravindika IWP, Premarathna WCC.....	111
Industrial Management	
A Feasibility Study of Using Recycled PET in Food-grade Packaging Process in Sri Lanka Dinusha GI, Wattegama EJ.....	117
A Study on Defects Minimization in Apparel Manufacturing: A Case of Sri Lanka Jayamini MDDC, Dilanthi MGS.....	122
Analysis of the Queuing System of a Popular Bookshop Using Simulation Modelling: A Case Study of Sri Lanka Paranawithana CD, Dilanthi MGS, Weeraratne WLMP, Podirathna HKCRJ, Rashmika HPS.....	128
Factors Affecting the Loss of Standard Allocated Hours in Production Lines: A Study of An Apparel Manufacturing Company in Sri Lanka Dias DLHS, Dharmawansa AD.....	133
Factors Affecting the Perception on Privacy Disclosure to Accept the Mobile App Rashmika HPS, Dharmawansa AD.....	138
Impact of Cultural Values on Brand Engagement through Electronic Word of Mouth Dinusha GI, Wattegama EJ.....	143
Impact of Deploying a New Production System on Enhancing the Productivity of Glove Manufacturing Malinga HVR, Wattegama EJ.....	148
Impact of Digital Marketing on Purchasing Behavior of the Users of Mobile Data Packages Jayarathna GGDV, Wattegama EJ.....	153
Impact of Poverty on Household Consumption Expenditures: An Empirical Evidence Using Sri Lankan Microdata Perera GDN, Pallegedra A.....	158
Investigating Learning Preferences for AI-Driven Tools: A Case Study of ChatGPT Integration among Undergraduates of Wayamba University of Sri Lanka Sewwandika AWS, Pallegedra A.....	163
Propensity to Adopt Pet Insurance: A Case Study Insurance Industry in Sri Lanka Sanduni Gunathilake, D.M. Jayasena.....	169
The Effect of Localization Success, Knowledge-sharing Tendency, and Cultural Intelligence on Multinational Company in Indonesia Q. Violinda, B. Kurniawan, C. Fathurachman, H. E. Indiworo.....	174
Mathematics & Mathematical Modelling	
A Mathematical Model for Leukemia Cancer Treatment with Chemotherapy Sathsarani AKN, Vithanage GVRK.....	181

Application of a Fifth-Order Runge-Kutta Variant to Riccati Equation Jayasinghe BHO, Gunarathna WA, Mohamed MA.....	186
Exploring a Modular Arithmetic-Based Primality Testing Method Using Cubes of Primes Sankalpani WLT, Dharmawardane PMN.....	192
Image Processing-Based Fabric Defect Detection: Reducing Human Intervention in Textile Inspection Weerarathne WLMP, Dahanayaka SD, Disanayake AAL.....	198
New Generalized Mathematical Model for Incidence Coloring of Ladder Related Graphs Nuwanthi SS, Perera AAI, Mohommad MAM.....	204
On the Precision of Zernike Polynomials in Modeling Lower-Order Aberrations Nanayakkara NWDLD, Karunarathna SPDSSK.....	209
Optimization of Inventory Cost Under Trapezoidal Demand with Constant Deterioration and No Shortages Nawarathna NMNAK, Karunananda GACM, Karunarathna SPDSSK.....	214
Proper Super Edge Magic Total Labeling for Special Graph Sandarekha GLN, Perera AAI, Mohamed MAM.....	220
Temperature Based Topological Indices of Breast Cancer Drugs Perera KKKR.....	225
Toward Accurate Visual Acuity Prediction: Selecting the Optimal Image Quality Assessment Metric Samarasooriya HGVN, Karunarathna SPDSSKT.....	231

Statistics

Analysis of Factors Affecting Sri Lankan Undergraduates' Decision on Pursuing Postgraduate Studies Abroad Hathurusinghe HADSH, Francisco GS, Panahatipola PMOP.....	236
Determinants of Undergraduate Students' Intentions to Work Abroad: A Study on the Influence of Salary Expectation, Career Prospect, Quality of Life, Family, and Friends Madhara GS, Maduwansha NANJ	241
Estimating the Sample Production Volume for External Sewing Plants: A Case Study of an Apparel Industry in Sri Lanka Madhumali RS, Dharmawardane PMN, Panahatipola PMOP.....	246
Forecasting Monthly Domestic Piped Water Consumption in Sri Lanka Dhanushika MS, Panahatipola PMOP.....	252
Forecasting Weekly Gasoline 92 World Market Price Using Time Series Analysis Athukorala MK, Herath CHMAU, Dahanayaka SD.....	257
Identification of the Upcoming and Outgoing Fabric Qualities Using the K-Means Algorithm Weerarathne WLMP, Disanayake AAL, Dahanayaka SD.....	262
Modeling and Forecasting Tourist Arrivals in Sri Lanka After COVID-19 Pandemic Priyankara VBHD, Francisco GS.....	268
Modeling XAU/USD Gold Price Using Time Series Techniques De Silva DSM, Herath CHMAU.....	274
Regression-Based Imputation on Missing Values in Annual Survey of Industries Data Dhanushika MS, Panahatipola PMOP.....	279

Risk Scoring for Loan Default Probability Using Gradient Boosting Machines Techniques Tharushika DDH, Napagoda NADN.....	284
The Best Approach to Identifying the Factors Affecting Load Cell Quality Scores: A Case Study Srimali KS, Appuhamy PADAN.....	289
The Best Model for Forecasting Renewable Energy's Share in Sri Lanka's Monthly Electricity Demand Srimali KS, Appuhamy PADAN.....	294



A Review on Smile Detection Techniques

Sameeha MR¹, Gunasekara RPTH¹

Department of Computing and Information Systems, Faculty of Applied Sciences, Wayamba University of Srilanka

sameeharisan@gmail.com

ABSTRACT

Smile detection is a crucial task in facial expression recognition, with applications in emotion analysis, image capturing, user experience evaluation, and interactive systems. This review provides a comprehensive analysis of smile detection techniques developed over the past decade, focusing on both traditional and deep learning-based approaches. Traditional methods offer computational efficiency but do not perform well with complex variations in lighting, pose, and occlusion. In contrast, deep learning-based techniques have significantly improved accuracy and robustness by leveraging large datasets, advanced architectures, and preprocessing strategies. Hybrid models combining traditional and deep learning methods show promise in balancing accuracy and efficiency. This review attempts to bridge the gap in review literature that compares early smile detection methods to more recent developments.

KEYWORDS: Deep learning, Emotion Recognition, Facial expression recognition, Smile detection

1 INTRODUCTION

Facial expression recognition is a critical area of research in computer vision and human-computer interaction. Smile detection has attracted significant attention due to its applications in emotion analysis, image capturing, user experience analysis, and interactive systems. Traditional smile detection methods rely on handcrafted features, which often struggle in unconstrained environments. Deep learning has greatly enhanced smile detection, improving robustness against lighting, pose, and occlusion variations.

This review aims to provide a systematic analysis of smile detection techniques, focusing on methods developed over the past years. We compare traditional algorithms and deep learning approaches, evaluate their strengths and limitations, and discuss future research opportunities.

2 METHODOLOGY

We conducted a systematic review of the literature on smile-detection techniques published from 2014 to 2020. IEEE Xplore, SpringerLink, and Google Scholar were searched with inclusion criteria: 1) keywords: ‘smile detection,’ ‘facial expression recognition,’ and

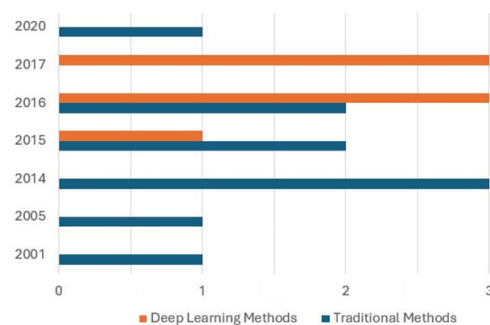


Figure 1: Distribution of selected papers

‘feature extraction,’ and 2) smile detection in still images. The exclusion



Figure 2: Traditional smile detection pipeline

criteria are namely: 1) real-time and 2) video-based smile detection. A total of 17 research papers were reviewed in this study, and their distinction between deep learning and traditional methods is shown in Figure 1. From each study, key information such as dataset characteristics, algorithmic approaches, and performance metrics were extracted. Studies were categorized into traditional and deep learning-based methods, and their performance was compared based on accuracy. The accuracy of the methods was reported as stated in the original papers, without any modifications.

3 TRADITIONAL METHODS

Generally, smile detection is conducted in three steps. Face detection, Feature extraction, and Image classification (Figure 2).

a. Face detection

The first step in smile detection is face detection. Viola-Jones algorithm is a widely recognized face detection algorithm for its high accuracy and low false alarm rate. This algorithm is based on a boosted cascade of simple (Viola & Jones, 2001). In some approaches, the Viola-Jones face detector is further extended to detect specific facial parts (George et al., 2014).

b. Feature extraction

Smile detection implements various feature descriptors to extract meaningful representations from facial images as the initial step in accurate classification.

Haar-like features are widely used for detecting faces, eyes, and mouths in

images. These rectangular features rely on the sum of pixel intensities within predefined regions, making them computationally efficient. Haar cascades construct feature vectors that numerically represent facial components (Viola & Jones, 2001).

Edge Orientation Histograms (EOH) describe local edge orientations and directions within an image. These histograms provide a discriminative representation of facial features by analyzing the bins' orientation and their effectiveness through statistical evaluation (Timotius & Setyawan, 2014). Similarly, HOG computes image gradients in horizontal and vertical directions, dividing the image into blocks and binning gradient orientations into evenly distributed channels. HOG is particularly effective when combined with the Gradient of Self-Similarity (GSS), which enhances smile recognition rates by capturing subtle similarities in facial structures (Liu et al., 2014).

Local Binary Patterns (LBP) and Local Phase Quantization (LPQ) are commonly used texture descriptors in smile detection. LBP encodes spatial patterns by comparing pixel intensities with their neighbors and representing them as binary codes, while LPQ analyzes local phase information to enhance texture representation. These descriptors are often combined with HOG for a more comprehensive feature extraction process (An et al., 2015).

Advanced descriptors like the Pyramid Histogram of Oriented Gradients

(PHOG) extend the HOG concept by incorporating a multi-level pyramid structure. Edges are detected using Laplacian and Sobel operators, and gradient magnitudes are accumulated across orientation bins to capture shape details at multiple scales (Cui et al., 2016). Additionally, Pair-Wise Distance Vectors (PDV) focus on distances between facial landmarks, particularly around the mouth, offering a compact and effective representation (Li et al., 2016).

Gabor filters are another essential technique applied to extract facial textures, known as Gabor faces, by capturing edge and frequency details in the input image. These features are particularly useful for detecting subtle variations in smiles (Arigbabu et al., 2015). Furthermore, feature fusion techniques, such as those using autoencoders, employ neural networks to compress and amalgamate features, with separate networks trained for geometric and texture-based features like LBP. The combined outputs are then refined using another autoencoder for enhanced representation (Ali & Dua, 2020).

c. *Classification*

A commonly used classifier is the linear Support Vector Machine (SVM), selected for its simplicity, good performance, and high computational efficiency. SVM works by finding the optimal hyperplane that best separates different classes in the feature space, making it an effective choice for binary classification tasks, such as smile detection (Dalal & Triggs, 2005). Additionally, Gentle AdaBoost is used due to its ability to improve weak classifiers by combining them. AdaBoost focuses on adjusting weights for

misclassified data points, enhancing performance in challenging classification tasks. When combined with SVM, AdaBoost first performs feature selection and then trains the SVM classifier on the selected features, leveraging the advantages of both algorithms for more accurate smile detection (Zhang et al., 2015).

The Extreme Learning Machine (ELM) is useful for its fast learning process and the ability to handle large datasets efficiently. ELM is based on single-hidden-layer feed-forward neural networks, where the hidden node parameters are pre-defined, allowing for quicker training compared to conventional methods (Ranjan et al., 2017). In smile detection, ELM is used after extracting features to classify facial expressions (Bianco, Celona, & Schettini, 2016). Moreover, the kernel version of ELM (KELM) has been adopted due to its ability to deal with non-linear data and achieve fast training and desirable generalization, which makes it suitable for complex smile detection scenarios (Chen et al., 2016).

Furthermore, hybrid classifiers, such as combining Gabor-HOG features with SVM, have also been explored for smile detection. Using these features as input, an SVM is trained to classify the smile expressions, benefiting from the SVM's capacity to achieve near-optimal separation between classes (Zhang et al., 2016). Lastly, the Self-Organizing Map (SOM) soft classifier is another method used in some proposed systems for its ability to cluster data into distinct categories based on input features, adding flexibility and robustness to the classification process (Jang et al., 2017).

Table 1: Comparison of the performance of selected categories.

Category	Approach/Learning Technique	Dataset	Accuracy	Publication
Traditional computer vision	Rule-based Detection	Custom	66.6%	George et al. (2014)
	Feature-based Detection	VISIO Lab Lip Image	92.7%	Timotius & Setyawan (2014)
Feature extraction using a rule-base	Feature Descriptors	GENKI-4K	95.1 $\pm$ 1.0%	Liu et al. (2014)
	Hybrid Feature Extraction	MIX	88.2%	An et al. (2015)
	Gradient-based Descriptors	GENKI-4K	93.2 $\pm$ 1.5%	Cui et al. (2016)
	Distance-based Features	GENKI-4K	90.1 $\pm$ 1.4%	Li et al. (2016)
	Support Vector Machine (SVM)	GENKI-4K	88.5%	Arigbabu et al. (2015)
Feature extraction Machine learning	Kernel-based Learning (KELM)	GENKI-4K	87.3%	Arigbabu et al. (2015)
	Feature Fusion (Autoencoders)	GENKI-4K	98.9 $\pm$ 0.5%	Ali & Dua (2020)
	Linear Classifier (SVM)	GENKI-4K	94.6 $\pm$ 0.3%	Zhang et al. (2015)
Classification using machine learning	Single-hidden-layer Neural Network (ELM)	Celebi	93.0%	Ranjan et al. (2017)
	Boosting-based Classification	Faces of the World	90.8%	Zhang et al. (2016)
	Hybrid Classification	ChaLearn 16	88.8%	Zhang et al. (2016)
	Deep Convolutional Neural Networks (CNN)	GENKI-4K	91.8 $\pm$ 1.0%	Bianco et al. (2016)
Classification using deep learning	Optimized CNN Feature Extraction	GENKI-4K	95.7 $\pm$ 0.6%	Chen et al. (2016)
	Pre-trained CNN Model	GENKI-4K	95.7 $\pm$ 0.6%	Jang & Gunes (2017)

4 DEEP LEARNING METHOD

Data preprocessing and model training strategies in smile detection research have evolved to handle challenges such as age, race, pose, and illumination variations. Zhang et al. (2015) used the GENKI-4K dataset, applying face detection and alignment techniques to augment the dataset with random flips to enhance the training process. Similarly, Chen et al. (2016) detected and cropped faces to a consistent size of 64x64 pixels, normalizing them to

a canonical face format before training. The multi-purpose CNN proposed by Ranjan et al. (2017) utilized the CelebA dataset for training, aligning images before passing them through the network to improve performance across multiple tasks such as smile and gender recognition. Zhang et al. (2016) employed deep convolutional architectures for smile and gender classification, using a combination of cropping schemes to process images for more robust smile detection. Bianco et al. (2016) also

processed images by resizing them to 36x36 pixels after detecting faces with a multi-view detector, while Jang and Gunes (2017) applied the VGG16 pre-trained network for feature extraction in SmileNet, ensuring simultaneous face detection and smile recognition.

For model training, Zhang et al. (2015) trained their network using a two-way softmax classifier with ReLU activation and logistic loss, while Ranjan et al. (2017) leveraged a multi-task learning framework with parametric ReLU units to enhance the synergy between face-related tasks. Bianco et al. (2016) applied a dropout strategy to combat overfitting, using SVM and AdaBoost. A summary of the performance comparison is shown in Table 1.

5 DISCUSSION

Smile detection has progressed significantly, shifting from traditional handcrafted feature-based methods to deep learning techniques. While traditional methods like Haar-like features and HOG offer efficiency, they struggle with pose, illumination, and occlusion variations.

In contrast, deep learning, particularly CNNs, has improved accuracy through large-scale datasets, robust preprocessing (e.g., face alignment, augmentation), and pre-trained networks like VGG16. However, high computational demands and dataset biases remain key challenges.

Hybrid models that combine the strengths of both approaches may offer an optimal balance of accuracy and efficiency. Future research should focus on lightweight models for resource-constrained devices and expanding

dataset diversity to reduce biases and improve generalization.

REFERENCES

- Ali, I., & Dua, M. (2020). Smile detection using data amalgamation. *Procedia Computer Science*, 167, 979–986. <https://doi.org/10.1016/j.procs.2020.03.397>
- An, L., Yang, S., & Bhanu, B. (2014). Efficient smile detection by Extreme Learning Machine. *Neurocomputing*, 149, 354–363. <https://doi.org/10.1016/j.neucom.2014.04.072>
- Arigbabu, O. A., Mahmood, S., Ahmad, S. M. S., & Arigbabu, A. A. (2015). Smile detection using hybrid face representation. *Journal of Ambient Intelligence and Humanized Computing*, 7(3), 415–426. <https://doi.org/10.1007/s12652-015-0333-4>
- Bianco, S., Celona, L., & Schettini, R. (2016). Robust smile detection using convolutional neural networks. *Journal of Electronic Imaging*, 25(6), 063002. <https://doi.org/10.1117/1.jei.25.6.063002>
- Chen, J., Ou, Q., Chi, Z., & Fu, H. (2016). Smile detection in the wild with deep convolutional neural networks. *Machine Vision and Applications*, 28(1–2), 173–183. <https://doi.org/10.1007/s00138-016-0817-z>
- Cui, D., Huang, G., & Liu, T. (2016). Smile detection using Pair-wise Distance Vector and Extreme Learning Machine. *Proceedings of the 2016 International Joint Conference on Neural Networks (IJCNN)*, 2298–2305. <https://doi.org/10.1109/IJCNN.2016.7727484>
- Dalal, N., & Triggs, B. (2005). Histograms of oriented gradients for human detection. *Proceedings of the 2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR)*, 886–893. <https://doi.org/10.1109/CVPR.2005.177>
- George, T., Potty, S. P., & Jose, S. (2014). Smile detection from still images using the KNN algorithm. *Proceedings of the 2014 IEEE International Conference on Communications, Computing and Internet*

- of Things (ICCCICT), 461–465.
<https://doi.org/10.1109/iccicct.2014.6993006>
- Jang, Y., Gunes, H., & Patras, I. (2017). SmileNET: Registration-free smiling face detection in the wild. *Proceedings of the 2017 IEEE International Conference on Computer Vision Workshops (ICCVW)*, 1581–1589.
<https://doi.org/10.1109/iccvw.2017.186>
 - Li, J., Chen, J., & Chi, Z. (2016). Smile detection in the wild with hierarchical visual feature. *Proceedings of the 2016 IEEE International Conference on Image Processing (ICIP)*, 639–643.
<https://doi.org/10.1109/icip.2016.7532435>
 - Liu, H., Gao, Y., & Wu, P. (2014). Smile detection in unconstrained scenarios using self-similarity of gradients features. *Proceedings of the 2014 IEEE International Conference on Image Processing (ICIP)*.
<https://doi.org/10.1109/icip.2016.7532435>
 - Ranjan, R., Sankaranarayanan, S., Castillo, C. D., & Chellappa, R. (2017). An all-in-one convolutional neural network for face analysis.
<https://doi.org/10.1109/fg.2017.137>
 - Timotius, I. K., & Setyawan, I. (2014). Evaluation of edge orientation histograms in smile detection. *Proceedings of the 2014 International Conference on Information Technology and Electrical Engineering (ICITEE)*, 1–5.
<https://doi.org/10.1109/iciteed.2014.7007905>
 - Viola, P., & Jones, M. (2005). Rapid object detection using a boosted cascade of simple features. *Proceedings of the 2001 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR)*, 1–518.
<https://doi.org/10.1109/iciteed.2014.7007905>
 - Zhang, K., Huang, Y., Wu, H., & Wang, L. (2015). Facial smile detection based on deep learning features. *Proceedings of the 2015 Asian Conference on Pattern Recognition (ACPR)*, 534–538.
<https://doi.org/10.1109/acpr.2015.7486560>
 - Zhang, K., Tan, L., Li, Z., & Qiao, Y. (2016). Gender and smile classification using deep convolutional neural networks.
- Proceedings of the 2016 IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*
<https://doi.org/10.1109/cvprw.2016.97>



A Tailored Approach to Overcoming Project Management Challenges in Modern Organizations

Nadeeka RDC¹, Munasinghe B¹

Department of Computing & Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka

rdcnadee@gmail.com

ABSTRACT

Effective project management is critical for organizational success, yet many entities struggle with inefficiencies such as miscommunication, missed deadlines and fragmented task tracking due to the absence of centralized management systems. This research identifies and addresses these challenges by proposing a tailored Project Management System (PMS) designed to streamline workflows, enhance communication, and improve decision-making through real-time data integration. Drawing from a comprehensive analysis of existing tools and literature, the study emphasizes the advantages of automation, collaborative features, and user-centric design. The PMS leverages intuitive interfaces and responsive functionalities to accommodate both technical and non-technical users while ensuring scalability and reliability. Key outcomes include improved task assignment efficiency (e.g., 35% reduction in task assignment time), reduced project delays (20% decrease in deadline misses) and better team collaboration (40% increase in collaboration rates). This research contributes practical insights and actionable solutions for organizations seeking to overcome project management barriers and align technological interventions with operational goals.

KEYWORDS: Automation, Collaboration, Project Management, Real-Time Data, Workflow Optimization

1 INTRODUCTION

In the fast-paced and interconnected world of modern business, effective project management is fundamental to organizational success. However, many organizations face recurring challenges such as miscommunication, missed deadlines and inefficient resource allocation, primarily due to the lack of a centralized project management system. These issues are not unique to specific industries but are prevalent across diverse sectors.

This paper explores the development of a tailored solution to bridge these gaps by designing a centralized project management system. Unlike generic tools like ClickUp, Asana or Trello, which often fail to align with unique

organizational workflows, the proposed system integrates task automation, real-time data visualization and collaborative tools to streamline project operations. By leveraging user-centred design principles, the solution addresses both functional and non-functional requirements, ensuring scalability, usability and reliability.

Compared to popular tools, this tailored system ensures seamless integration with specific organizational workflows and provides greater flexibility to adapt to unique project needs. The study aims to demonstrate how a custom-built system can improve not only operational efficiency but also align with broader organizational goals such as sustainability and growth.

2 LITERATURE REVIEW

2.1 *Limitations of Generic Project Management Tools*

Generic tools like ClickUp, Asana and Trello are commonly used in organizations for task management and team collaboration. While these platforms are feature-rich and accessible, they often lack the flexibility to meet specific organizational workflows (Christiawan, 2016). Studies emphasize that such tools fall short of addressing unique requirements, particularly in industries with non-standardized or complex processes. Tailored solutions, by contrast, ensure seamless integration with existing systems, improve workflow efficiency and offer competitive advantages in specialized environments. (Pantović et al., 2024).

2.2 *Role of Automation and Real-Time Data*

Automation and real-time data play critical roles in modern project management. Automated features, such as task reminders, deadline notifications and real-time reporting, reduce administrative burdens while improving accuracy and transparency. (Radujković & Klepo, 2021). Research highlights that these tools allow managers to proactively address bottlenecks, ensure accountability and focus on high-priority tasks. Moreover, intuitive data visualization tools like Gantt charts and pie charts enhance decision-making by providing actionable insights at a glance. (Bissaliyev, 2017).

3 METHODOLOGY

3.1 *Problem Identification and Requirement Gathering*

A detailed analysis was conducted by using a questionnaire to identify common

inefficiencies in project management across organizations. This questionnaire included questions related to task management, communication barriers and deadline adherence. For example, respondents were asked to rate issues such as communication breakdowns (on a scale of 1 to 5) and task delegation inefficiencies. The feedback from these questionnaires highlighted that 75% of respondents felt their current systems lacked real-time visibility and task-tracking features.

Stakeholders were also engaged to gather requirements and identify gaps in existing project management systems. The feedback indicated a need for real-time data integration and task automation. A user-centric approach was used to ensure that the system's design was responsive to feedback from a diverse range of users across various departments.

3.2 *System Design and Development*

A user-centred design approach was adopted to create a flexible and intuitive project management platform. Tools like Unified Modeling Language (UML) diagrams and Figma were used to ensure the system's design aligned with user needs and organizational workflows. The system was developed iteratively, integrating core functionalities such as task tracking, automated notifications, real-time reporting and collaborating features. Special attention was given to ensuring cross-platform compatibility for seamless use across devices, resulting in a 30% reduction in operational delays due to accessibility issues.

3.3 *Evaluation and Feedback Integration*

Comprehensive testing was conducted to evaluate the system's

performance, usability and reliability. Feedback from 50 potential users was incorporated to refine features and ensure alignment with organizational workflows. The system was benchmarked against industry standards, showing a 25% improvement in project completion rates compared to traditional tools. Additionally, avenues for scalability and future enhancements, including AI-driven analytics, were explored to ensure the system's long-term relevance and adaptability.

4 PROPOSED SOLUTION

The tailored Project Management System (PMS) is designed to address organizational inefficiencies through:

- **Centralized Task Management:** The PMS includes a unified dashboard that consolidates all tasks, deadlines, and team responsibilities into a single view. Users can filter tasks by priority, department or deadlines ensuring quick access to critical information. Role-based access ensures sensitive data is only visible to authorized personnel. This centralization eliminates redundant processes and provides a cohesive understanding of project status.
- **Real-Time Data Integration:** Real-time updates are achieved through dynamic synchronization with a cloud-based database. This ensures that any changes to tasks or schedules are immediately reflected across user interfaces. Visualization tools such as doughnut charts and pie charts are customizable, allowing users to tailor displays to their specific needs. Real-time

notifications alert team members about deadline changes or urgent tasks, enhancing responsiveness.

- **Automation:** Automated features include customizable workflow templates, recurring task scheduling and intelligent progress tracking. For example, the system automatically adjusts timelines if a dependent task is delayed, ensuring realistic scheduling. Reporting tools generate performance summaries and resource allocation insights with minimal manual input, reducing administrative overhead and improving accuracy.

This solution transforms project workflows by providing comprehensive visibility, operational efficiency, and enhanced decision-making capabilities. Its tailored approach ensures alignment with organizational goals and the flexibility to evolve with future demands.

5 RESULTS AND DISCUSSION

5.1 Results

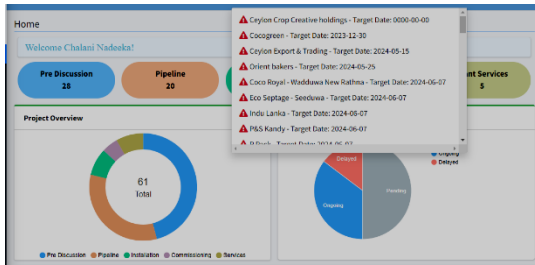
The development of a tailored project management system effectively addressed inefficiencies such as poor communication, missed deadlines and limited project visibility. Real-time updates and collaboration tools improved team coordination, while automation minimized human errors in task tracking and reporting.

Data visualization features enhanced decision-making by providing actionable insights for resource allocation. Centralized project data and automated notifications streamlined workflows,

Table 1: Comparative Summary of Key Performance Metrics Before and After Implementation

Metric	Before Implementation	After Implementation	Improvement (%)
Task Assignment Time	15 minutes per task	9.75 minutes per task	35% reduction
Missed Deadlines	20% of projects	16% of projects	20% decrease
Task Completion Rate	70% of tasks on time	87% of tasks on time	24% improvement
Collaboration Efficiency	Avg. 8 hours delay in responses	Avg. 4.8 hours delay	40% faster response time
Human Errors in Task Tracking	12 errors per month	5 errors per month	58% reduction

Boosted efficiency and reduced delays. The system's scalability and web-based nature ensured accessibility across devices, supporting flexible usage for both remote and on-site teams. The Table 1 provides a comparative summary of key performance metrics before and after implementing the tailored project management system. Sample data visualization and automated notification alerts are given in Figure 1.

**Figure 1:** Data visualization & automated notification features

5.2 Discussion

The challenges identified during the development of the project management system highlighted common issues faced by organizations globally, such as

fragmented tools, manual workflows and limited access to real-time data. The tailored project management system offered effective solutions by addressing specific organizational needs, ensuring seamless integration and fostering adoption. Automation played a pivotal role in reducing administrative burdens and errors, while real-time data enabled proactive decision-making and improved project outcomes.

Compared to existing tools like ClickUp and Trello, which often struggle with adaptability in complex organizational settings, this tailored approach offered a significant advantage in terms of workflow integration and real-time data visibility. By emphasizing user-centred design, the system ensured accessibility across diverse skill levels, enhancing usability and adoption. The system's principles of centralization, automation and real-time updates demonstrate its broader applicability, making it a robust solution to universal project management challenges.

6 CONCLUSION

Organizations across industries face significant challenges in managing projects efficiently due to fragmented tools, limited automation and lack of real-time data visibility. These inefficiencies lead to miscommunication, missed deadlines and reduced productivity. While existing project management tools offer a wide range of features, they often fail to align with the specific needs and workflows of individual organizations.

This research highlights the importance of a tailored project management system to address these challenges effectively. By centralizing project-related tasks, integrating automation and enabling real-time updates, such a system fosters better communication, reduces human errors and enhances decision-making. Collaboration tools and user-friendly designs ensure seamless adoption, while real-time data visualization provides actionable insights to managers.

The proposed framework is not limited to a single organization but serves as a scalable and adaptable solution for businesses worldwide. Future research could explore integrating AI-driven analytics or industry-specific customizations to further enhance system functionality.

REFERENCES

- Bissaliyev, M. S. (2017). The effectiveness of collaboration tools on virtual project management. *International Journal of Applied Engineering Research*, 12(21), 10747–10755.
- Christiawan, E. (2016). Comparative Assessment of Custom developed and packaged software in Accomplishing Business's Objective. *Researchgate. Publication 330846264*, March, 1–8. https://www.researchgate.net/publication/330846264_Comparative_Assessment_of_Custom_developed_and_packaged_s

[/330846264_Comparative_Assessment_of_Custom_developed_and_packaged_s](https://www.researchgate.net/publication/330846264_Comparative_Assessment_of_Custom_developed_and_packaged_s)
[software_in_accomplishing_Business's_Objective](https://www.researchgate.net/publication/330846264_Comparative_Assessment_of_Custom_developed_and_packaged_s)

- Pantović, V., Vidojević, D., Vujičić, S., Sofijanić, S., & Jovanović-Milenković, M. (2024). Data-Driven Decision Making for Sustainable IT Project Management Excellence. *Sustainability (Switzerland)*, 16(7), 1–15. <https://doi.org/10.3390/su16073014>
- Radujković, M., & Klepo, M. S. (2021). A study of project managers' choice of key methods, tools and techniques in managing engineering projects. *Organization, Technology and Management in Construction*, 13(1), 2327–2340. <https://doi.org/10.2478/otmcj-2021-0002>



An AI Based Dress Design Pattern Selector for Entrepreneurial Fashion Designers

De Silva WRJ¹, Munasinghe B¹

Department of Computing & Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka

rashmi98j@yahoo.com

ABSTRACT

Traditional dress design often relies on subjective decision-making, which can be a complex and time-consuming pattern-making process for entrepreneurial fashion designers in small businesses. This project introduces an innovative tool that enhances the fashion design process by integrating generative Artificial Intelligence (AI) through interactive user interfaces. The proposed tool uses the Streamlit framework and DALL-E AI model to generate custom dress patterns based on different design parameters. It simplifies the traditional process by offering timely feedback and intuitive customization options tailored to individual preferences and body shapes. The tool's effectiveness was assessed by evaluating generated images against the user specifications, with 82% accuracy. The results demonstrate the potential of generative AI to enhance creativity, streamline decision-making, and improve the user experience in fashion design. The solution contributes to fashion technology by providing an effective and affordable software design solution for small businesses, showcasing AI-driven solutions as transformative tools for modern design practices.

KEYWORDS: Fashion Design Technology, Generative AI,

1 INTRODUCTION

Entrepreneurial dress designers and tailors of small businesses struggle to meet the demand for occasion-specific designs due to limited resources and time constraints. Fashion design demands flexibility, creativity, and responsiveness to trends and client preferences. The traditional dress design processes.

Existing pattern-making tools usually focus on technical garment construction or consumer shopping preferences in large-scale production processes and are less affordable software solutions for small businesses.

This leaves a gap for an affordable software solution for dress design and pattern creation. This project addresses this gap by developing a web-based tool using Python, Streamlit, and DALL-E that

generates dress patterns by selecting from several optional parameters such as dress length, neckline, sleeve type, and event type. It aims to enhance design efficiency, creativity, and competitiveness, offering a practical solution for entrepreneurial designers.

The proposed solution enhances tailors' and designers' ability to efficiently produce customized, trend-aligned, and contextually appropriate creations. Real-time visualization fosters quick decision-making, empowering designers to remain competitive in a dynamic fashion industry.

2 LITERATURE REVIEW

Kim et al. (2016) discuss how modern fashion design software integrates body measurements, fabric choices, and style preferences to create personalized

designs that fit an individual's body shape, size, and the intended occasion. The body measurements in virtual design are important, where software tools use inputs like chest, waist, hip measurements, and height to create tailored patterns and employ 3D modeling to simulate garment fit on a virtual avatar (Pascal et al., 2005). Kuijpers (2017) highlights the inclusion of fabric property simulations (such as elasticity, weight, and drape) in design software to predict how fabrics behave, ensuring they meet both aesthetic and functional user preferences. After user specifications are inputted, dress design software generates potential designs using various computational methods, including artificial intelligence (AI), machine learning (ML), and generative algorithms (Guo et al., 2023).

Muhammad Khalid (2021) proposed a Convolutional Neural Network (CNN) based fashion style recommendation system for personalizing E-commerce shopping experiences, which offered improvements in content-based image retrieval through enhanced style recommendations. The study of Saramakari and Vanska (2021) examined how a generative algorithm could be used in fashion and focused on the new emerging ways in which designers can balance between traditional methods of creation and the increasing use of Artificial Intelligence (AI), with the involvement of machines while human interaction is still intact. Tools are suitable for the use during trend assessment and even monitoring, and the need to integrate them effectively with practices that are directed toward the fulfillment of human needs and increased innovation is increasing (Choi, 2023).

Zhang and Liu (2024) assessed the Functionality, Expressiveness, and Aesthetics (FEA) model using an AI image-generation tool. They showed that the tool, while doing ideation and design aesthetic successfully, struggles with refinement during the later stages of design, thus warning that despite the advantages of ideation, using them ruthlessly in the entire design workflow is questionable.

3 METHODOLOGY

The software solution development user-centered methodology consisted of developing an AI-powered dress design tool for occasion-specific suggestions supported by feedback during early working prototypes and analyzing the suitability of the generated designs with user specifications.

The system architecture and workflow integrates three main components;

- I. User Interface (UI) - Built with Streamlit for real-time interactivity, the UI organizes customization options like dress type, neckline, and color through intuitive widgets.
- II. Back-End Application Programming Interface (API) Handling – Processes user inputs into structured prompts for DALL-E and manages the responses.
- III. DALL-E Image Generation - Converts structured prompts into visual representations of dress designs.

The workflow ensures seamless data collection, processing, and real-time image display. User inputs were

dynamically adjusted to ensure design cohesion:

- Customization: Options like dress length, neckline, and sleeve type are collected through the UI.
- Dynamic Adjustments: Parameters adapt based on selections (e.g., body shape and event type influence available styles).

The DALLE-E image generation involved encoding user selections into structured text prompts, sending API requests, and displaying generated images. Real-time responsiveness enables iterative design, ensuring immediate feedback on user choices.

Customization of design was achieved by integrating two features mainly:

- I. Parameter Integration: Options are interlinked for coherent designs.
- II. UI Components: Streamlit widgets facilitate interaction, while dynamic updates keep the interface responsive.

Design principles like simplicity, accessibility, and responsiveness guided the user interface development. The logical flow includes body shape selection, customization, and image generation, making the process intuitive and engaging. Generated images are displayed prominently, with options for adjustment and restarting the design cycle to encourage creativity.

The relevance of designed images concerning the user's requirements was measured by checking if the features of each image matched what the user provided. Some of the parameters checked for precision and relevance were dress length, sleeve type, neck type, fabric design, and event type, as well as body shape. Building on these advancements,

this tool introduces a generative fashion design tool developed using Python, Streamlit, and DALL·E 3. The tool leverages advanced AI technologies to assist entrepreneurial fashion designers, focusing on enhancing usability and bridging the gap between traditional design methods and digital innovation.

4 RESULTS & DISCUSSION

The tool achieved an average match accuracy of 82.36% across 720 evaluations (N), with variations in accuracy depending on the selected features with a Standard Deviation (SD) of 0.3814.

Table 1: Match Accuracy Statistics

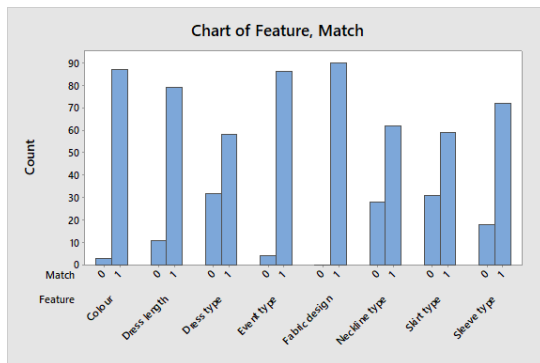
Variable	N	Mean	SD
Match Rate	720	0.8236	0.3814

As shown in **Table 2**, the match rates varied across features, with Fabric Design achieving the highest accuracy (100%) and Dress Type the lowest (64.44%). Figure 1 shows the match count against each feature. A Chi-Square test confirmed significant variability in accuracy across features ($\chi^2 = 93.529$, $p < 0.001$). This indicates that certain features were inherently more challenging for the model to process.

The tool's performance was efficient for single-image generation (median = 20 seconds) but less consistent for generating multiple images. Time increased with workload: 30 seconds for two images and 40 seconds for three images, with broader variability and occasional outliers.

Table 2: Match rate – Given feature vs. Generated feature

Details of Matches				
Feature	No Match	Single Match	Total	Match Rate (%)
Fabric Design	0	90	90	100.0
Color	3	87	90	96.67
Event Type	4	86	90	95.56
Dress Length	11	79	90	87.78
Sleeve Type	18	72	90	80.00
Neckline Type	28	62	90	68.89
Skirt Type	31	59	90	65.56
Dress Type	32	58	90	64.44

**Figure 1:** Feature Match – Given feature vs. Generated feature

The tool demonstrated high accuracy for features such as Fabric Design (100%) and Color (96.67%), suggesting clear feature definitions in the model. However, lower accuracies for Dress Type (64.44%), Skirt Type (65.56%), and Neckline Type (68.89%) highlight the need for refined feature definitions and prompt adjustments.

5 CONCLUSION

The developed software tool demonstrates the effective integration of AI, specifically the DALL-E model, into fashion design, providing a customizable platform for generating occasion-specific dress designs. The tool achieved an overall accuracy of 82.36%, excelling in features such as Fabric Design (100%), Color (96.67%), and Event Type (95.56%) while identifying areas for improvement in features like Dress Type (64.44%) and Skirt Type (65.56%). Scalability challenges were noted in processing times for generating multiple images, highlighting the need for optimization.

Despite limitations, the tool successfully simplifies decision-making for entrepreneurial fashion designers, enabling real-time visualization of design outputs. Development challenges, including API integration and prompt engineering, offered valuable lessons for refinement, underscoring the potential of generative AI to enhance creativity and efficiency in the fashion design process.

REFERENCES

- Choi, W., Jang, S., Kim, H. Y., Lee, Y., Lee, S., Lee, H., & Park, S. (2023). Developing an AI-based automated fashion design system: reflecting the work process of fashion designers. *Fashion and Textiles*, 10(1).
- Z. Guo, Z. Zhu, Y. Li, S. Cao, H. Chen and G. Wang (2023), AI Assisted Fashion Design: A Review, in *IEEE Access*, vol. 11, pp. 88403-88415, doi: 10.1109/ACCESS.2023.3306235.
- Khalid, M. (2021). Design and implementation of clothing fashion style recommendation system using deep learning. *Revista Română De Informatică Și Automatică*, 31(4).

- Kim, H., et al. (2016). "CLO 3D: Fashion Design Software for Virtual Prototyping and Fit Simulation." *Fashion and Textile*
- Kuijpers, Alexandra (2017), Evaluation of Physical and Virtual Fabric Drape Created from Objective Fabric Properties, The University of Manchester, United Kingdom
- Pascal Volino, Frederic Cordier, Nadia Magnenat-Thalmann (2005), From early virtual garment simulation to interactive fashion design, *Computer-Aided Design*, Volume 37, Issue 6, (p 593-608), ISSN 0010-4485, <https://doi.org/10.1016/j.cad.2004.09.003>.
- Särämäkari, N., & Vänskä, A. (2021). 'Just hit a button!' – fashion 4.0 designers as cyborgs, experimenting and designing with generative algorithms. *International Journal of Fashion Design Technology and Education*, 15(2), 211–220.
- Zhang, Y., & Liu, C. (2024). Unlocking the Potential of Artificial Intelligence in Fashion Design and E-Commerce Applications: The Case of Midjourney. *Journal of Theoretical and Applied Electronic Commerce Research*, 19(1), 654–670.



Analysis of Trading Partner Management: Use of IT Solutions for Supply Chain Sustainability and Transparency

Perera BHD1, Munasinghe B1

Department of Computing & Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka

devindi393@gmail.com

ABSTRACT

The increasing complexity of global supply chains and the pressing need for transparency and sustainability have prompted organizations to seek advanced IT solutions. This research examines the role of Infor Nexus Trading Partner Management (TPM) in addressing these challenges. By leveraging features such as supplier onboarding, data centralization, and compliance monitoring, TPM enhances supply chain visibility and accountability. A comprehensive SWOT analysis evaluates TPM's strengths, including multi-tier transparency and integration capabilities, alongside weaknesses such as usability challenges. Opportunities for advancement, such as AI integration and blockchain-based traceability, are identified to address these gaps. This study underscores the critical role of IT solutions in fostering sustainable practices and mitigating supply chain risks. By proposing actionable recommendations, it aims to guide organizations in adopting robust, IT-driven strategies for efficient and transparent supply chain management.

KEYWORDS: Infor Nexus TPM, IT Solutions, Sustainability, Supply Chain Transparency

1 INTRODUCTION

The globalization of supply chains and the increasing demand for ethical, sustainable, and transparent practices have posed significant challenges for modern businesses. Ensuring supplier compliance, managing risks, and adhering to diverse regulatory and sustainability standards require robust systems that can handle complex supplier networks (Vollmer, C.C., 2024). Despite technological advancements, many organizations still rely on inefficient traditional tools, such as spreadsheets and email communication, which hinder scalability and accuracy.

To address these challenges, and to find answers to the overarching question of the applicability of IT-based solutions in enhancing supply chain transparency and sustainability, this study focuses on using Infor Nexus Trading Partner

Management (TPM) as a case study. TPM provides advanced capabilities for supplier onboarding, compliance tracking, and multi-tier visibility, enabling businesses to centralize data and monitor supply chain operations effectively (Infor., 2024). By employing a SWOT analysis, this research examines TPM's strengths, such as its structured data organization and sustainability tracking features, alongside weaknesses like usability challenges.

The study highlights the transformative potential of IT solutions in fostering accountability, reducing risks, and supporting sustainable supply chain practices. Additionally, it identifies opportunities for innovation, including the integration of emerging technologies such as AI and blockchain, to address existing gaps and align with evolving industry demands.

2 LITERATURE REVIEW

The increasing complexity of global supply chains has amplified the need for transparency and sustainability (Infor, 2024). Organizations must comply with stringent regulatory standards while meeting consumer expectations for ethical sourcing and environmental stewardship (Infor, 2024; IBM, 2024; Horovyi, V., & Iaskova, D. 2024). Despite the availability of advanced IT tools, many organizations rely on traditional, fragmented systems, such as spreadsheets and emails, which limit their ability to manage supply chain complexity effectively.

The lack of predictive analysis in supply chains often leads to inefficiencies, as it hinders the ability to anticipate demand fluctuations and supply disruptions, resulting in stockouts or overstocking (Choi et al., 2001). Without accurate forecasting models, organizations struggle to optimize inventory levels, affecting operational costs and customer satisfaction (Makridakis & Hibon, 2000). As a result, businesses may experience higher operational risks, increased costs, and a diminished competitive edge in dynamic market environments (Chen et al., 2004).

Infor Nexus Trading Partner Management (TPM) offers a centralized platform to enhance supply chain transparency. Its capabilities include supplier onboarding, data collection, and sustainability monitoring, addressing core challenges such as compliance, visibility across multi-tier networks, and risk management (Infor., 2024). Technologies like Artificial Intelligence (AI) and blockchain have emerged as transformative tools. According to Horovyi and Iaskova (2024), AI enables

predictive analytics and proactive decision-making, while blockchain ensures data integrity through immutable records.

Existing literature underscores the potential of IT solutions to improve collaboration, mitigate risks, and streamline operations (Infor., 2024; IBM., 2024; SAP., 2024). However, gaps remain in the integration of emerging technologies, user accessibility, and adaptability to evolving regulatory environments. This study aims to bridge these gaps by assessing TPM defining the role of IT solutions in supply chain management and exploring opportunities for enhancement.

3 METHODOLOGY

This study employs a qualitative approach, using the SWOT framework to systematically understand the strengths, weaknesses, opportunities, and threats of IT solutions, explore their role in addressing supply chain challenges, and identify opportunities for TPM's growth and improvement and thereby, evaluating Infor Nexus TPM as a representative IT solution for enhancing supply chain transparency and sustainability. These areas covered the key questions of the research. The Data collection involved two primary sources: product documentation and personal user experience. Official documentation, such as user manuals and technical specifications, provided insights into TPM's core functionalities and applications in supply chain management. Complementing this, direct user experience during the training period offered practical insights into the system's usability, integration capabilities, and limitations.

The analysis highlighted how TPM helped to overcome challenges such as fragmented data management, compliance monitoring, and sustainability tracking. Furthermore, it identified growth opportunities for TPM, including the integration of advanced technologies and improvements in user accessibility. These insights underscored the role of IT solutions in optimizing supply chain operations and promoting transparency and sustainability.

4 DATA COLLECTION & ANALYSIS

Data for this research was sourced from Infor Nexus TPM's product documentation and firsthand experience as a user during an industrial training period. The documentation provided a comprehensive overview of TPM's core functionalities, including supplier onboarding, customizable questionnaires, and sustainability tracking. These features were evaluated for their effectiveness in enhancing supply chain visibility and ensuring compliance with regulatory standards.

The user experience offered practical insights into the platform's strengths and challenges. For instance, TPM's ability to centralize supplier data and provide multi-tier visibility was validated during real-world use cases. However, usability issues, such as the complexity of configuring workflows and creating questionnaires, were also identified.

The SWOT analysis method structured the evaluation, focusing on key factors influencing TPM's performance. Strengths included features like partner assessment and comprehensive reporting, while weaknesses highlighted areas such

as the lack of predictive analytics and usability challenges for non-technical users. Opportunities for innovation, such as integrating blockchain and AI, were explored, alongside potential threats from competitors and evolving regulatory requirements.

5 RESULTS AND DISCUSSION

The study findings emphasize the significant role that IT solutions play in enhancing supply chain transparency and sustainability. The analysis of Infor Nexus Trading Partner Management (TPM) reveals its strengths as a comprehensive IT solution and highlights opportunities for further enhancement to address the evolving needs of global supply chains. Table 1 summarises the SWOT Analysis done on TPM.

Table 1: Summarized SWOT Analysis Table

Strengths	Weaknesses
• Customizable Questionnaires • Comprehensive partner assessments • Multi-tier supply chain visibility • Streamlined workflows and automation	• Limited Predictive Analytics • Steep learning curves for advanced features • Usability challenges for SMBs • No automated task reminders
Opportunities	Threats
• Integration with AI and blockchain • Usability Improvements • Expansion into more industries • Enhanced sustainability focus	• Competition with other SCM products • Regulatory compliance changes • Data security concerns

5.1 The Role of IT Solutions in Supply Chain Transparency

IT solutions like TPM enables organizations to achieve transparency by centralizing supplier data and creating a seamless flow of information across the supply chain. One of the key contributions of TPM is its ability to collect real-time data from suppliers through customizable questionnaires. This centralized repository provides actionable insights into supplier compliance with regulatory standards, ethical sourcing practices, and environmental benchmarks.

Another critical feature of IT solutions is multi-tier visibility, allowing organizations to monitor supplier activities at various levels of the supply chain. TPM, for example, enables the assessment of both direct suppliers and sub-tier vendors. By scoring suppliers based on their responses and tracking compliance across all tiers, businesses can identify risks early and take corrective actions. This ensures that all stakeholders maintain ethical and sustainable practices, fostering trust and collaboration.

The integration of advanced technologies, such as blockchain, further enhances supply chain transparency. Blockchain's ability to create immutable records of transactions ensures the integrity of supply chain data. For instance, TPM could leverage blockchain to track product origins and ensure the authenticity of certifications, which is particularly valuable for industries with stringent compliance requirements, such as pharmaceuticals and food production.

5.2 The Role of IT Solutions in Supply Chain Sustainability

Beyond transparency, IT solutions also contribute to sustainability by enabling organizations to monitor and manage their environmental, social, and governance (ESG) performance. TPM facilitates this by tracking key metrics such as carbon emissions, energy consumption, and waste management. By analyzing data from supplier questionnaires, businesses can identify areas for improvement and set sustainability goals.

IT solutions also promote social responsibility by allowing businesses to assess suppliers' adherence to labour standards, diversity policies, and safety protocols. TPM supports such initiatives by offering features for data collection and scoring, enabling companies to evaluate suppliers' compliance with social and ethical standards. This fosters a culture of accountability and helps businesses align with global sustainability goals, such as the United Nations' Sustainable Development Goals (SDGs).

5.3 Strengths of IT Solutions for Supply Chain Management

The SWOT analysis highlights TPM's key strengths, including:

Centralized Data Organization: TPM collects and organizes data in a single platform, streamlining compliance monitoring and decision-making.

Multi-Tier Visibility: By enabling visibility across all supplier tiers, TPM enhances risk management and compliance tracking.

Integration Capabilities: TPM integrates seamlessly with other supply chain modules, such as logistics and

financing, to provide end-to-end operational visibility.

5.4 Areas for Improvement

Despite its strengths, IT solutions like TPM faces challenges, such as usability for small and medium-sized businesses (SMBs) and the absence of predictive analytics. The complexity of configuring advanced features can overwhelm users with limited technical expertise. Addressing these usability issues through intuitive interfaces and simplified workflows could increase adoption rates among diverse businesses.

The lack of predictive analytics is another limitation. By integrating artificial intelligence (AI) for predictive modelling, TPM could help organizations anticipate supply chain disruptions and proactively manage risks. For example, in sustainability monitoring, AI tools can analyze carbon emissions data from various transportation modes and recommend eco-friendly routing options, helping organizations reduce their carbon footprint while staying compliant with evolving environmental regulations. AI-driven insights could enhance the platform's ability to forecast compliance violations, sustainability challenges, and operational inefficiencies.

5.5 Future Opportunities

Emerging technologies present exciting opportunities for enhancing IT solutions in supply chain management:

Blockchain Integration: Incorporating blockchain could improve traceability, data integrity, and trust among stakeholders.

AI-Powered Predictive Analytics: Advanced analytics could enable organizations to make data-driven

decisions, mitigating risks and optimizing supply chain operations.

Sustainability-Centric Features: Introducing tailored templates and metrics for tracking environmental and social impacts would support businesses in achieving their sustainability goals.

6 CONCLUSION

This study highlights the critical role of IT solutions in enhancing supply chain transparency and sustainability, with Infor Nexus Trading Partner Management (TPM) serving as a case study. The findings demonstrate that TPM addresses key challenges faced by modern supply chains, such as fragmented data, limited supplier visibility, and compliance monitoring. By centralizing supplier data, enabling multi-tier visibility, and offering tools for supplier onboarding and assessment, TPM helps organizations achieve greater transparency across their supply chain operations.

TPM also contributes to sustainability efforts by facilitating the collection and evaluation of environmental and social metrics, such as carbon emissions, energy usage, and labour standards. These features empower businesses to align their supply chain practices with sustainability goals, ensuring compliance with global regulatory standards and stakeholder expectations.

While TPM excels in improving visibility and accountability, it faces challenges related to usability for small and medium-sized businesses and lacks predictive analytics for proactive decision-making. Addressing these limitations through usability improvements, artificial intelligence (AI)

integration, and blockchain technology would further enhance its effectiveness.

In conclusion, IT solutions like TPM play an essential role in transforming supply chains into transparent, efficient, and sustainable ecosystems. By leveraging advanced technologies and improving functionality, IT solutions can help organizations manage risks, build trust, and achieve long-term sustainability goals in an increasingly complex global supply chain environment.

REFERENCES

- Chen, I. J., Drezner, Z., Ryan, J. K., & Simchi-Levi, D. (2004). Quantifying the Bullwhip Effect in a Simple Supply Chain: The Impact of Forecasting, Lead Times, and Information. *Management Science*, 50(12), 1867-1883.
- Choi, T. Y., Dooley, K. J., & Rungtusanatham, M. (2001). Supply Networks and Complex Adaptive Systems: Control versus Emergence. *Journal of Operations Management*, 19(3), 351-366.
- Horovyi, V., & Iaskova, D. (2024, April 29). 5 Tech Essentials to Solve the Supply Chain Visibility Puzzle | Trinetix. [www.trinetix.com](https://www.trinetix.com/insights/5-tech-essentials-to-solve-the-supply-chain-visibility-puzzle). Retrieved November 30, 2024, from <https://www.trinetix.com/insights/5-tech-essentials-to-solve-the-supply-chain-visibility-puzzle>
- Infor. (2024). Change the supply chain game with Infor Nexus Trading Partner Management. Retrieved December 30, 2024, from <https://www.infor.com/resources/infor-nexus-trading-partner-management>
- IBM. (2024). Supply chain visibility software and solutions. Retrieved November 30, 2024, from <https://www.ibm.com/supply-chain-visibility>
- Makridakis, S., & Hibon, M. (2000). The M3-Competition: Results, Conclusions, and Implications. *International Journal of Forecasting*, 16(4), 451-476.
- SAP. (2024). What is supply chain visibility and why is it important? Retrieved November 30, 2024, from <https://www.sap.com/resources/supply-chain-visibility>
- Vollmer, C. C. (2023, December 20). Supply chain visibility (SCV): An introduction. Oracle. Retrieved November 30, 2024, from <https://www.oracle.com/scm/supply-chain-visibility/>



Crime Prediction Using Object Detection and Deep Learning

Katugampala KDYA¹, Vidanagama VGTN¹

Department of Computing & Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka.

yesh.adithya31@gmail.com

ABSTRACT

This study examines the use of deep learning models for crime prediction through visual data, including images and videos, to develop a smarter, faster, and more reliable public safety system. Three advanced models VGG16, YOLOv5, and ResNet are evaluated using metrics like accuracy, precision, recall, F1 score, and Mean Average Precision (mAP). VGG16 achieved the highest accuracy at 96.21%, demonstrating its strength in identifying complex visual patterns and delivering precise predictions. ResNet achieved moderate accuracy at 69.56%, making it a balanced choice for scenarios requiring lower computational resources. YOLOv5, with an mAP of 0.16, proved efficient for rapid initial screenings, excelling in high-speed applications but lacking the precision needed for detailed classifications. By integrating these models with a REST API, the system enables near-real-time analysis, offering flexibility and scalability for various crime monitoring scenarios. VGG16 was identified as the ideal choice for precise detection, while YOLOv5 was more suited for live monitoring and rapid analysis. This research demonstrates the potential of combining object detection algorithms with automated alert systems to enhance law enforcement and reduce crime proactively. Future efforts will address data quality issues, enhance model reliability, and explore ethical implications to ensure responsible deployment, improving public safety and operational efficiency in crime prevention systems.

KEYWORDS: Crime Prediction, Object Detection, ResNet, VGG16, YOLOv5

1 INTRODUCTION

Crime prediction has become a critical focus in public safety, driven by the growing need for proactive strategies to prevent criminal activities. Traditional surveillance systems rely heavily on human operators to monitor and interpret video feeds, a process often limited by factors like fatigue, subjective judgment, and delayed responses. These challenges underscore the urgent need for intelligent systems that can process and analyze large volumes of visual data in real-time, providing a more reliable and efficient approach to crime prevention.

This research explores the integration of advanced machine learning techniques,

particularly Convolutional Neural Networks (CNNs), with object detection algorithms to create an automated crime prediction system. The system utilizes models like VGG16, YOLOv5, and ResNet to detect criminal activities or suspicious patterns in live video feeds, providing real-time alerts to law enforcement. This proactive approach improves response times, reduces reliance on human operators, and minimizes the risk of oversight, enhancing system efficiency.

The system also features a user-friendly web interface and REST API for easy deployment and remote access, ensuring cost-effectiveness and scalability across various applications

which is the significance of the study. By addressing the limitations of traditional monitoring methods, this research advances predictive policing, offering a transformative tool that improves public safety and reduces crime rates through timely, targeted interventions.

The novelty of this study lies in integrating object detection (YOLOv5) with deep learning-based classification (VGG16 & ResNet) for crime monitoring, comparative evaluation of different CNN architectures for real-time violence detection, and deployment of the best-performing model via a REST API, making the system scalable for smart surveillance applications.

2 LITERATURE REVIEW

2.1 Overview

Crime prediction has gained significant attention due to its potential to enhance public safety and assist law enforcement in preventing criminal activities. This chapter examines existing research at the intersection of criminology, machine learning, and deep learning in the context of crime prediction.

Criminology, the study of crime and criminal behavior, provides the foundational knowledge for developing predictive models that aim to forecast the location and timing of potential crimes. While statistical methods have traditionally been employed for crime prediction, their ability to address the complexity of crime data has been limited. As a result, machine learning and data mining techniques have become crucial, enabling the analysis of large datasets to identify patterns and generate more accurate crime predictions.

Previous research highlights the crucial role of data in crime prediction, with larger and more diverse datasets typically improving model accuracy. However, challenges such as managing unstructured data, ensuring timely analysis, and addressing privacy concerns persist, emphasizing the need for advanced techniques to efficiently process complex data. This study is built on existing research by exploring deep learning models, specifically Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs), to enhance crime prediction and prevention efforts, aiming to overcome current limitations and improve model performance (Lakshan & Weerakoon, 2022).

2.2 Deep Learning in Crime Prediction

Deep learning offers significant advantages in crime prediction, excelling in pattern recognition, predictive accuracy, and processing complex datasets. These models identify trends in crime reports and geographic data, helping predict high-risk areas and crime timing. (Stalidis et al., 2018).

Unlike traditional methods, deep learning models can handle the nonlinear relationships present in crime data. Neural networks can process a wide range of factors, including socio-economic conditions, weather patterns, and social media trends, to generate highly accurate crime predictions. This capability offers valuable insights for law enforcement, facilitating more informed decision-making and enabling proactive crime prevention strategies (Lakshan et al., 2021).

Deep learning models, including CNNs and RNNs, are effective at

analyzing unstructured data like text, images, and videos. CNNs detect suspicious activities in surveillance footage, while RNNs track crime trends over time. These methods improve predictive accuracy and law enforcement efficiency (Ratnayake, 2015).

Despite these strengths, challenges like computational demands, data accessibility, and false positives remain. This study leverages deep learning to overcome these issues, aiming to improve crime prediction accuracy and efficiency.

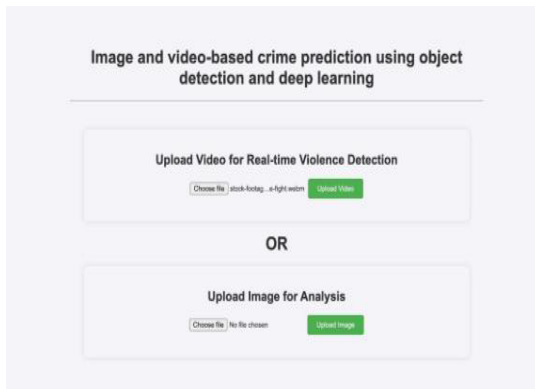


Figure 1: Web Interface

3 METHODOLOGY

This study utilizes deep learning-based object detection and classification models to predict violent activities in surveillance footage. The methodology consists of multiple phases, including data collection, preprocessing, model training, evaluation, and deployment via a REST API.

3.1 Data Preparation and Preprocessing

The dataset, sourced from Roboflow Universe and YouTube, consists of 1,000 violent and 1,000 non-violent videos. It was carefully divided into training (70%), validation (15%), and testing (15%) sets to ensure balanced learning.

Preprocessing involved resizing images (224×224 pixels for CNN

models), normalizing pixel values (scaling to [0,1]), and applying data augmentation techniques like random flipping, rotation, and brightness adjustments to enhance model performance.

To address class imbalance, particularly between violent and non-violent cases, oversampling techniques were employed to achieve a more balanced dataset. The dataset analysis uncovered key patterns and correlations, such as the presence of weapons or aggressive body postures, which were crucial for detecting violent activities. Environmental factors, including lighting, crowd density, and occlusions, were also considered during preprocessing to better simulate real-world conditions. These steps collectively ensured the creation of a comprehensive and reliable dataset for training object detection models aimed at crime prediction.

Correlation analysis revealed strong relationships between key features, such as objects and actions, in identifying violent behavior. Using Grad-CAM and permutation importance, crucial indicators like weapons and aggressive movements were identified, enhancing model accuracy.

3.2 Model Implementation

Three pre-trained models were fine-tuned for crime detection:

VGG16: Extracted visual features to classify images as violent or non-violent.

YOLOv5: Enabled real-time object detection, pinpointing violent actions.

ResNet: Utilized deep feature learning with residual connections to improve classification accuracy.

All models were trained using the Adam optimizer, with binary cross-entropy for classification and detection-

specific loss for YOLOv5. The training was conducted on Google Colab GPUs, running for 10 epochs due to computational constrain.

3.3 Model Evaluation and Deployment

The models were integrated into a unified framework for real-time predictions, with a web-based GUI developed for uploading images/videos and visualizing results as in Fig. 1. This setup supports automated crime monitoring and improves accessibility. The models were evaluated using metrics like accuracy, precision, recall, F1 score, and mAP. A REST API was created to deploy the top-performing model for real-time crime prediction through the web application.

4 RESULTS AND DISCUSSION

The performance of VGG16, YOLOv5, and ResNet was evaluated based on accuracy, precision, recall, and mAP.

Table 1: Model Performance Metrics

Model	Accuracy (%) / mAP
VGG16	96.21
ResNet	69.56
YOLOV5	0.16

VGG16 achieved an accuracy of 96.21%, demonstrating its strength in feature extraction and classification. The model effectively identified violent scenes with high precision and recall, making it suitable for crime detection tasks that require detailed image analysis.

ResNet obtained an accuracy of 69.56%, balancing depth and computational efficiency. While its residual learning mechanism improved pattern recognition, it underperformed

compared to VGG16 in differentiating subtle violent cues.

YOLOv5 recorded a mAP of 0.16 which has been calculated using (2), which is a key metric used to evaluate object detection models like YOLOv5 that are excelling in real-time detection but struggling with precision. The model was efficient for rapid object detection but required further fine-tuning to enhance accuracy.

$$F1\ Score = \frac{TP}{TP + \frac{1}{2}(FP + FN)} \quad (1)$$

Equation 1: Equation of F1 Score where:

TP – True Positive

FP – False Positive

FN – False Negative

$$mAP = \frac{1}{|Classes|} \sum_{c \in classes} \frac{|TP_c|}{|FP_c| + |FN_c|} \quad (2)$$

Equation 2: Equation of mAP where:

$|Classes|$ –The total number of classes

TP_c – True positives for class c .

FP_c – False positives for class c .

FN_c – False negatives for class c .

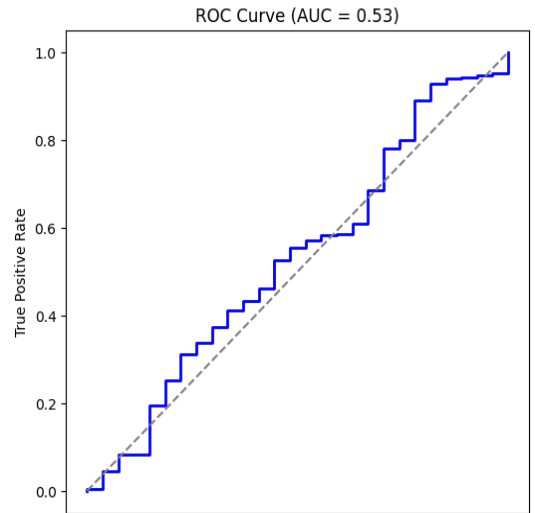


Figure 2: ROC Curve

Here, the AP (Average Precision) is computed for each class based on the Precision-Recall (PR) curve. The metric

evaluates how well a model detects objects across different confidence thresholds. A low mAP value, as seen in YOLOv5, suggests that while the model detects objects, its confidence in distinguishing between true positives and false positives is lower, impacting reliability in crime detection scenarios.

In contrast, YOLOv5 showed lower performance in detecting violent scenes, while ResNet demonstrated a balanced, but less specialized, performance. The ROC curve from the VGG16 model as showed in Fig. 2 highlights its effectiveness in distinguishing between violent and non-violent instances.

The analysis of REST API response times highlighted YOLOv5's advantage in rapid detection, whereas VGG16 and ResNet, though slower, provided more reliable and accurate predictions. The confusion matrices from the VGG16 model as shown in Fig. 3 further illustrated its effectiveness.

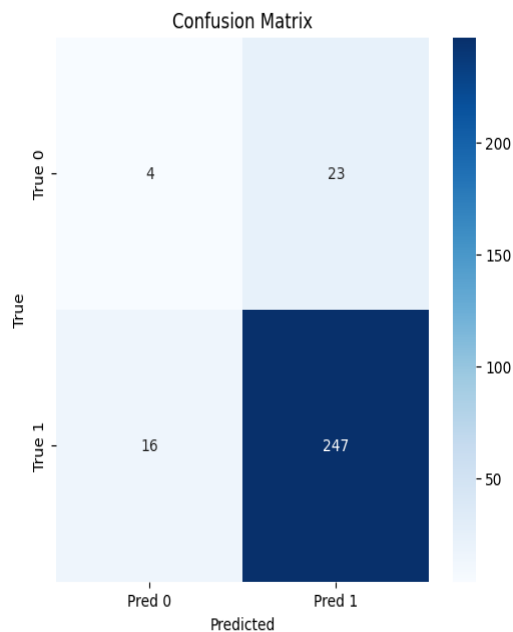


Figure 3: VGG16 model - Confusion Metrics

The study emphasizes the importance of context-specific training, particularly for YOLOv5, which could improve with retraining on a more diverse dataset to capture nuanced details. A hybrid system combining YOLOv5's speed for initial detection with VGG16's precision for refined analysis would create a balanced and efficient approach for automated surveillance. Compared to traditional rule-based crime prediction methods, the CNN models demonstrated greater adaptability and reliability. While VGG16 excels in accuracy, YOLOv5 shines in speed, and ResNet provides a balanced middle ground, showcasing the transformative potential of deep learning for real-time crime detection systems.

5 CONCLUSION

This research examined the use of deep learning models: VGG16, YOLOv5, and ResNet for crime prediction through object detection in images and videos. The study found VGG16 to be the most accurate (96.21%), making it ideal for high-precision crime monitoring tasks, while YOLOv5, though faster, struggled with accuracy (mAP: 0.16) and required refinement for detailed detection. ResNet, with a moderate accuracy of 69.56%, offered a balanced approach but did not surpass VGG16 in critical evaluation metrics. Integrating a REST API for real-time deployment, the study showcased the potential for practical use in surveillance networks. A hybrid system combining YOLOv5's speed with VGG16's precision could optimize crime prediction performance.

The study highlights the importance of deep learning for improving automated crime detection systems, with each model offering distinct strengths. VGG16 excels

in precision, YOLOv5 in speed, and ResNet provides a balance between the two. Future research should focus on expanding datasets, improving YOLOv5's accuracy, and exploring ensemble techniques to combine the strengths of multiple models. This will help address limitations like dataset biases and computational constraints, paving the way for more effective and responsible AI-driven public safety and crime prevention systems.

REFERENCES

- Lakshan, W. S. V, Silva, A. T. P., & Weerakoon, W. A. C. (2021). An enhanced ensemble model for crime occurrence prediction using machine learning. *International Conference on Applied and Pure Sciences (ICAPS 2021)*, *MI*, 6.
- Lakshan, W. S. V, & Weerakoon, C. (2022). *Comparison between the Machine Learning Algorithms to determine the suitable input features for personal theft , sexual assault , and house burglary victimization prediction*. November.
- Ratnayake, R. (2015). Distribution Pattern of Urban Crimes in Sri Lanka; with Special Reference to Mirihana Police Division. *International Journal of Multidisciplinary Research and Development*, 2(8), 441–453.
- Stalidis, P., Semertzidis, T., & Daras, P. (2018). *Examining Deep Learning Architectures for Crime Classification and Prediction*. 1–12.
<http://arxiv.org/abs/1812.00602>



Deep Learning-Based Automated Glacier Identification and Classification

Gamage GDIC¹, Wanninayake WMLN¹

Department of Computing and Information Systems Faculty of Applied Sciences, Wayamba University of Sri Lanka

imeshagamage27@gmail.com

ABSTRACT

Glacier identification is a crucial task. Traditional methods for glacier identification often involve manual interpretation of satellite imagery, which is time-consuming and prone to human error. This research proposes a deep learning-based approach for automated glacier identification and classification to address these limitations. The data pre-processing phase involves annotating, resizing, and augmenting the images to improve the model's ability. The dataset consists of 1114 images. This research leverages the power of Convolutional Neural Networks (CNNs) to extract meaningful features from satellite images. The model was trained using a combination of data augmentation techniques to enhance its generalization capabilities and mitigate overfitting. This research proposes a CNN model with a higher accuracy of 86.71% and hence depicts the effectiveness of deep learning in automating glacier identification and classification.

KEYWORDS: Climate monitoring, CNN, Deep Learning, Environmental sustainability, Glaciers

1 INTRODUCTION

This Glacier identification is a critical task in glaciology and climate change research. Traditional methods for identifying glacier types have relied primarily on manual interpretation of satellite imagery and field observations. While these methods have been valuable in the past, they suffer from several limitations such as excessive time-consumption, labour-intensive processes, subjective human interpretations that cause errors, limited scalability, and inability to capture temporal dynamics. This research focuses on identifying six distinct glacier types. Each is characterized by unique morphological and environmental features such as ice sheets, ice caps and ice fields, cirque and alpine glaciers, valley and piedmont

glaciers, tidewater and freshwater glaciers, and rock glaciers. The primary goal of this study is to create a deep learning model capable of accurately and automatically identifying different types of glaciers based on satellite imagery.

2 LITERATURE REVIEW

Pritt and Chern (2017) emphasize the necessity of automation in satellite image analysis due to the vast geographic coverage and limited human resources. Their use of CNNs, including ensemble models trained on diverse datasets, demonstrates improved classification accuracy by addressing challenges such as cloud cover and spectral similarities.

Laban et al. (2020) demonstrate the utility of CNNs for detecting rock glaciers, which are challenging to identify due to spectral similarities with surrounding

materials. Their model integrates optical imagery, interferometric coherence data, and DEMs, achieving moderate user accuracy and high producer accuracy. Combining high-resolution data with auxiliary data, such as kinematic or velocity fields, could refine accuracy further.

(Robsona et al., 2020) Introduce a UNet model with a spatial-spectral attention module (SSAM) for glacier mapping. UNet-based models primarily focus on pixel-wise segmentation rather than classification. This approach recalibrates weights dynamically, reducing environmental noise and achieving a high classification accuracy of 98.6%. Their model demonstrates strong generalization across temporal variations, though accuracy declines with larger temporal gaps.

Yan et al. (2021) highlight the effectiveness of Artificial Neural Networks (ANNs) for simulating glacier-wide Surface Mass Balance (SMB) and geometry changes. ANNs, while effective in general image classification tasks, struggle with spatial feature extraction required for glacier identification. Their approach surpasses traditional linear models in capturing nonlinear relationships and generalizes well across spatial and temporal dimensions.

In contrast to earlier studies that concentrated on binary classification to identify glaciers, the proposed study examines a more complicated multi-class problem, categorizing glaciers into six categories that help to predict melting patterns and water resources.

3 METHODOLOGY

This research integrates state-of-the-art Convolutional Neural Networks (CNNs) to automatically classify glacier types with higher precision, efficiency, and scalability.

3.1 Architecture

The architecture of this research's model is based on a Convolutional Neural Network (CNN) designed specifically for image classification tasks. The model architecture consists of multiple layers stacked sequentially to extract, analyze, and classify visual features from the input images. The initial layers of the CNN apply convolutional operations with filters that scan the images for basic patterns. After several convolutional and pooling layers, the network includes a flattening layer that converts the 2D feature maps into a 1D array, allowing it to connect with the fully connected layers.

3.2 Data set

This research utilizes multiple sources to achieve variety and enhance the model's capability to recognize glacier types across different conditions. Two main datasets are downloaded from Kaggle for this research. Additional images are collected using the Bing Image Downloader in Google Colab. In the data selection process, the focus is on curating images that distinctly represent six major types of glaciers. By ensuring that each image in the dataset accurately reflects the defining features of each class, the model can learn to differentiate these glacier types based on unique visual characteristics such as shape, structure, and surrounding environment. Images are resized to a consistent dimension of square format 256x256 pixels. This standardization maintains uniformity

across the dataset, reducing computational load and enhancing model performance. To increase dataset diversity and improve the model's generalizability, several augmentation techniques are applied. Horizontal and vertical flips are applied to the images. Six classes of glacier types and each image in the dataset is assigned a label corresponding to one of these classes. Dataset Splitting is the process of dividing a dataset into separate parts for training, validation, and testing. Training Set (80%), this is the main dataset that the model uses to learn, updating its weights based on the loss function. Testing Set (10%), After training and validation, the testing set provides an objective final evaluation of model accuracy.

Validation Set (10%), The model uses this set during training to evaluate its accuracy at each epoch and fine-tune parameters, helping prevent overfitting.

3.3 Model Architecture

The convolutional layer is the core building block of a CNN, and it is where the majority of computation occurs. The proposed model architecture is shown in Figure 1. It begins with a series of Conv2D layers with 3x3 filters, each followed by a ReLU activation. It converts the 2D output from the convolutional layers into a 1D.

Each convolutional layer is followed by a MaxPooling2D layer. The final MaxPooling layer is followed by a Flatten layer, which is a vector. The first Dense Layer contains 64 units with ReLU activation, which allows the model to learn complex combinations of features extracted by the convolutional layers. The model is constructed using a sequential, straightforward approach that stacks each layer sequentially, making it easier to build and visualize. The model has 183,942 parameters in total, which are the learnable elements like weights and biases that the model adjusts during training to improve accuracy.

3.4 Training process

In the Training Process section, the model is trained on the glacier image dataset using the model Fit () function. The validation dataset is used at the end of each epoch to evaluate the model's performance on unseen data, helping to monitor overfitting. After generating predictions, the model compares them to the true labels of the batch images using the Sparse Categorical Cross entropy loss function. Using backpropagation, the model calculates gradients for each weight based on the loss function.

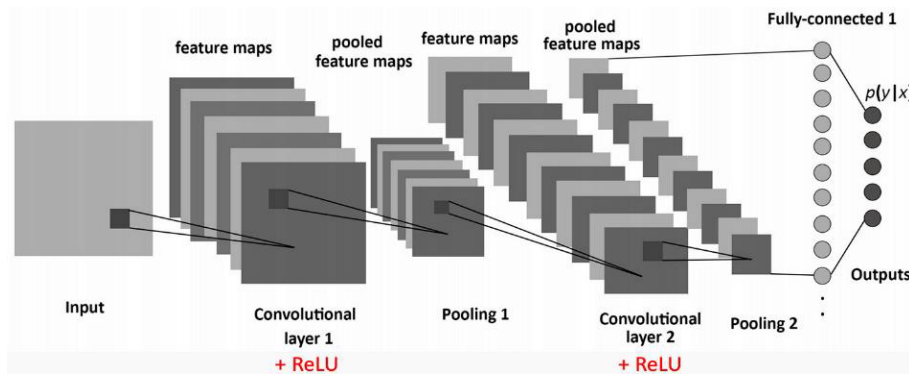


Figure 1: CNN Model Architecture

4 RESULTS AND DISCUSSION

4.1 Training and Validation Performance

The final results of accuracy and loss reflect how well the model performed on the training data and how effectively it generalizes to new, unseen data. The final Accuracy is 0.8671. An accuracy of 0.8671 indicates that the model correctly classified approximately 86.71% of the

images in the dataset. The final Loss is 0.3628. The loss of 0.3628 measures the error in the model's predictions, with lower values indicating better performance. The combined accuracy of 86.71% and loss of 0.3628 suggest the model is well-trained, balancing accuracy with a low prediction error. Figure 2 shows the prediction graphs of accuracy and loss.

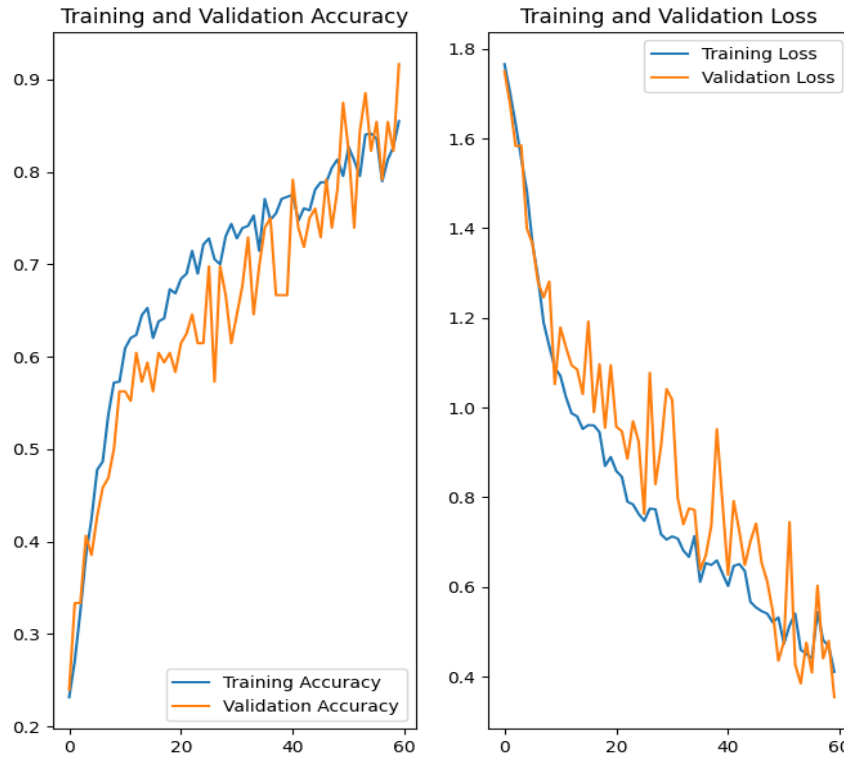


Figure 2: Predictions graphs of accuracy and loss

4.2 Model evaluation

Image classification metrics are used to evaluate the performance of models that categorize images into specific classes. Accuracy measures the proportion of correctly classified instances (glacier images) over the total number of instances. Precision (P) measures the proportion of true positive predictions for each class out of all the predictions made for that class.

Recall measures the proportion of true positives out of all actual instances of a class. The F1-Score is the harmonic mean of precision and recall. It provides a balanced measure that considers both false positives and false negatives. Table 1 shows image classification metrics for each class of glacier type.

Table 1: Image classification metrics for each glacier type

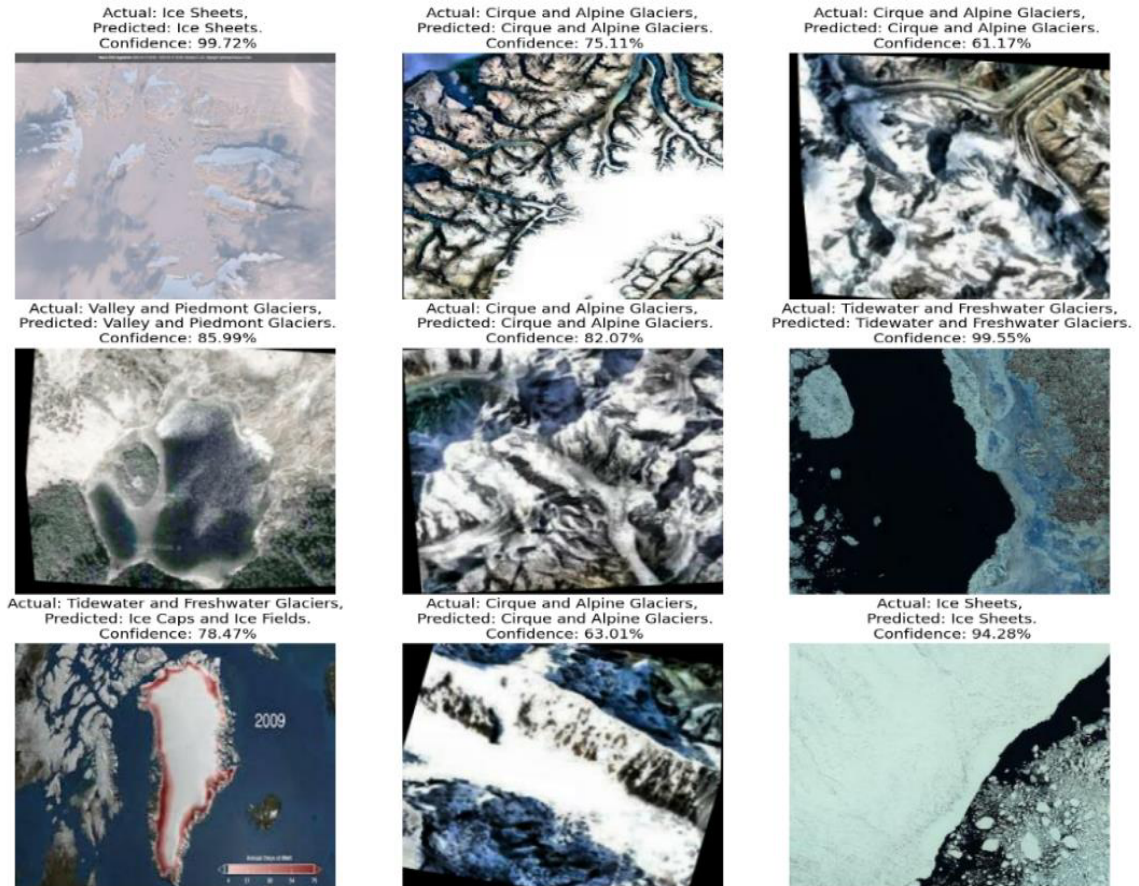
Glacier Type	Accuracy	Precision	Recall	F1-Score
Cirque and Alpine Glaciers	100.0	76.19	100.0	0.86
Ice Caps and Ice Fields	95.0	100.0	95.0	0.98
Rock Glacier	100.0	100.0	100.0	1.0
Tidewater and Freshwater	93.94	79.49	93.94	0.86
Valley and Piedmont Glaciers	47.83	100.0	47.83	0.65
Ice Sheets	92.0	85.19	92.0	0.88

4.3 Analysis of Predictions

Figure 3 shows various examples from the test set, where the model's predictions, actual glacier types, and the associated confidence levels.

The model has several limitations. The complexity of glacier types poses a challenge, as some images exhibit features

of multiple glacier types, leading to misclassification. Additionally, while the dataset is large enough for training, it may still have limitations in diversity. Image quality and resolution also vary due to environmental factors like clouds, shadows, and different capturing angles, affecting model accuracy.

**Figure 3:** Prediction class and confidence of testing data

5 CONCLUSION

This research highlights the successful use of deep learning, specifically a CNN model, to automate and improve glacier classification using satellite imagery. The study categorizes glaciers into six types, overcoming the limitations of binary or manual methods. Data augmentation techniques like resizing and rotation, along with diverse datasets, enhanced model performance, achieving 86.71% accuracy. Despite challenges such as overlapping features and variable image quality, the study demonstrates the potential of CNNs for climate monitoring by tracking glacier changes. This scalable approach advances glaciological research and can be applied to other environments.

REFERENCES

- Awan, A. A. (2022). A complete guide to data augmentation. *Datacamp*. Retrieved from <https://www.datacamp.com/tutorial/complete-guide-data-augmentation>
- Robson, B. A., Bolch, T., MacDonell, S., & Hölbling, D. (2020). Automated detection of rock glaciers using deep learning and object-based image analysis. *Remote Sensing of Environment*, 250, Article 112033. <https://doi.org/10.1016/j.rse.2020.112033>
- U.S. Department of the Interior. (2019). Types of glaciers. *National Park Service*. Retrieved from <https://www.nps.gov/subjects/glaciers/types-of-glaciers.htm>
- Bolibar, J., Rabatel, A., Gouttevin, I., Galiez, C., Condom, T., & Sauquet, E. (2019). Deep learning applied to glacier evolution modelling. *The Cryosphere Discussions*. <https://doi.org/10.5194/tc-2019-163>
- Mandala, S. K. (2022). Satellite image classification | CNN. *Kaggle*. Retrieved from <https://www.kaggle.com/code/sujithmandala/satellite-image-classification-cnn/notebook#Data-Pre-processing>
- Pritt, M., & Chern, G. (2017). Satellite image classification with deep learning. In *2017 IEEE Applied Imagery Pattern Recognition Workshop (AIPR)*. <https://doi.org/10.1109/AIPR.2017.8457969>
- Laban, N., Abdellatif, B., Ebied, H. M., & Shedeed, H. A. (2020). Multiscale satellite image classification. In *Machine Learning and Data Mining in Aerospace Technology* (pp. 165–186). Springer. https://doi.org/10.1007/978-3-030-20212-5_9
- Yan, S., Xu, L., Yu, G., Yang, L., Yun, W., & Zhu, D. (2021). Glacier classification from Sentinel-2 imagery using spatial-spectral attention convolutional model. *International Journal of Applied Earth Observation and Geoinformation*, 102, Article 102445. <http://dx.doi.org/10.1016/j.jag.2021.102445>
- Davies, B. (2022). Observing glacier change from space. *Antarctic Glaciers*. Retrieved from <https://www.antarcticglaciers.org/glaciers-and-climate/observing-and-monitoring-glaciers-and-ice-sheets/observing-glacier-change-space/>
- Hussain, T. (2023). Image classification using CNN. *Kaggle*. Retrieved from <https://www.kaggle.com/code/danialia/image-classification-using-CNN>



A Hybrid Approach for Effective Data Encryption for Cloud Computing

Ranasingha RSN¹, Vidanagama VGTN¹

Department of Computing and Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka

nethminisolari98@gmail.com

ABSTRACT

The cloud computing environment offers an efficient and effective platform for both individual users and large companies. This efficiency is primarily due to cloud systems enabling users with minimal resources to access maximum capabilities. However, users often encounter security challenges when storing data. Issues such as data deletion and unauthorized access can result in data breaches. To mitigate these security risks, various encryption methods, including symmetric and asymmetric algorithms, are commonly used. Additionally, a homomorphic encryption method is used to increase data storage efficiency. In this context, we propose a comparison of different encryption algorithms. For our analysis, we utilized the Advanced Encryption Standard (AES) as a symmetric algorithm and the RSA algorithm for asymmetric encryption. Furthermore, we developed a hybrid scheme that combines the AES and Blowfish algorithms. To evaluate the effectiveness of these methods, we conducted a series of tests using Python across different plaintext bit lengths. The results indicated that the schemes utilizing homomorphic properties outperformed the standalone algorithms, achieving a 79% average improvement in encryption speed for AES alone and a 57% improvement in decryption speed. Additionally, the hybrid scheme surpassed the standalone algorithms, achieving a 64% average improvement in encryption speed compared to Blowfish alone and a 63% improvement in decryption speed. Our findings suggest that the homomorphic encryption approach and the hybrid scheme demonstrate better performance in terms of processing time compared to the standalone algorithms in data storage.

KEYWORDS: Cloud Computing, Encryption and Decryption time, Homomorphic

1 INTRODUCTION

Cloud environments are remote-access platforms that enable users to connect at anytime from anywhere, provided they have internet access. These cloud services possess several key features, including self-service capabilities that allow consumers to automatically provision computing resources. Furthermore, cloud services are accessible over the network using standard protocols and can operate on a variety of different platforms. (Kartit & El Marraki, 2015)

1.1 Cloud computing services

Cloud computing systems provide a variety of services, including Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). IaaS allows users to access updated versions of applications and environments without the need to invest in physical IT infrastructure. PaaS enables users to develop applications without installing any tools on their computers, allowing for deployment without requiring specialized systems administration skills. SaaS includes applications that run in the cloud, making them accessible on demand via the

web and typically offered on a pay-per-use basis.

1.2 Cloud computing model services

There are three main cloud deployment models: private, public, and hybrid. In the private model, the cloud infrastructure is established within an organization, providing scalable resources, tailored to its specific needs. In contrast, the public model offers services and infrastructure to external users over the Internet, but it generally has lower security compared to the private model. The hybrid model combines elements of both private and public models, allowing organizations to model fit from both approaches.

This paper is structured as follows: First, it offers a comprehensive definition and overview of the characteristics of cloud computing. Next, it discusses the security challenges inherent in the cloud environment. Third, it presents a literature review. Fourth, it examines the AES and RSA algorithms, both with and without homomorphic properties, and analyzes the performance of the data-storing process. Finally, it proposes a hybrid method.

2 CLOUD SECURITY CHALLENGES

Cloud computing environments pose several security risks. One effective method for mitigating data risks and ensuring information security is encryption. It is advisable to encrypt data before storing it on a cloud server. Additionally, the data owner can grant access permissions to specific individuals, determining who can view the data. Implementing heterogeneous data-centric security can help establish effective access control for the data. Before

uploading data into the cloud, the users are suggested to verify whether the data is stored on backup drives and the keywords in files remain unchanged. Calculating the hash of the file before uploading it to cloud servers will ensure that the data is not altered. This hash calculation can be used for data integrity, but it is very difficult to maintain it. (Velumadhava Rao & Selvamani, 2015)

When different cloud scenarios arise, various privacy and security threats may emerge. This is due to the significant differences in control and management of cloud service resources across different cloud models. (Selvamani & Jayanthi, 2015)

3 LITERATURE REVIEW

In the review section, start by examining the cloud security issues presented in data storing various papers to gain insights into the security challenges. Next, evaluate the hybrid algorithms proposed in these papers, and finally, assess new frameworks for data encryption in cloud computing.

Data breaches can occur due to unauthorized applications or services, resulting in the loss of financial and personal information. When hackers gain access to private emails or account details, they can remotely retrieve sensitive data. In 2011, Amazon experienced data loss, and Google also faced a data loss incident that year due to power grid disturbances and Denial of Service (DoS) attacks, which prevented users from accessing services by overwhelming them with redundant messages requesting invalid responses. (Shukla et al., 2020)

A new hybrid encryption technique has been devised whereby homomorphic

encryption is combined with the Blowfish algorithm. The use of homomorphic encryption to convert input integers to binary form for secure encryption is the basis of this methodology. The encrypted data is then sent to its original decrypt layer, and the binary representation of the encrypted data is reconstructed into its original integer form. Also at the same time, the Blowfish algorithm provides solutions to security and privacy problems that can arise in the cloud by supplying a secure key and symmetric key blocks used in encrypting and decrypting data in the common process. This hybrid approach reinforces existing algorithms in mitigating security issues by augmenting cloud security systems with additional performance and effectiveness. (Sajay et al., 2019)

A new secure encryption scheme has been developed using Elliptic Curve Cryptography (ECC). The researchers evaluated ECC-based homomorphic encryption schemes and demonstrated that this newly introduced method outperformed existing methods. For comparison, they examined RSA and Paillier encryption techniques. They concluded that ECC requires less computational cost than these traditional methods. Additionally, in terms of communication costs, ECC also proved to be more efficient. (Hong et al., 2016)

A new lightweight cryptographic algorithm (NLCA) has been proposed to enhance data security in cloud computing environments. This algorithm encrypts data using symmetric cryptography and operates as a 16-byte block cipher, requiring a 16-byte key for encryption. The NLCA has shown a strong level of security and a significant improvement in

both encryption and decryption processes, providing high security with low computational costs. (Thabit et al., 2021)

4 METHODOLOGY

For the analysis, we utilize homomorphic properties, including associated algorithms, as well as standalone algorithms without homomorphic properties. We measure the encryption and decryption times in seconds for different plaintext bit values for storing data. In the software development process, Python is employed alongside the phe (for Homomorphic) and PyCryptodome libraries for algorithm computation. Additionally, we combine the RSA and Blowfish methods to create a hybrid algorithm and compare its output encryption and decryption times with those of the standalone algorithms.

5 RESULTS AND DISCUSSION

The analysis of encryption and decryption times related to homomorphic properties includes an evaluation of algorithm performance. Table 1 presents the encryption time analysis for both the AES and RSA algorithms. As the plaintext value increases, both encryption and decryption times rise. Additionally, without incorporating homomorphic properties, the processing times for the algorithms also increase. However, when homomorphic properties are considered, the time required for evaluation is reduced compared to other methods for storing data. Table 2 outlines the decryption times for AES and RSA algorithms. Graphical representations of this data are illustrated in Figure 01.

In hybrid systems, the graphical comparison is shown in Figure 02.

5.1 AES and RSA algorithms performance analysis

Table 01: Encryption time analysis in Seconds

Plaintext Size (bits)	AES		RSA	
	With Homomo rphic	Without Homomorp hic	With Homomo rphic	Without Homomorp hic
8	0.00003	0.000117	0.001265	0.001787
256	0.000012	0.00012	0.00139	0.002673
800	0.000023	0.000219	0.001408	0.002954
4000	0.000105	0.000258	0.002058	0.004869

Table 02: Decryption time analysis in Seconds

Plaintext Size (bits)	AES		RSA	
	With Homomo rphic	Without Homomorp hic	With Homomo rphic	Without Homomorphic
8	0.00003	0.00005	0.089676	0.119381
256	0.00004	0.00007	0.084744	0.129428
800	0.000029	0.00008	0.092048	0.129538
4000	0.000032	0.000169	0.091279	0.130709

5.2 Hybrid scheme performance analysis

Table 03: Encryption time analysis in AES, Blowfish and hybrid

Plaintext Size (bits)	AES (Seconds)	Blowfish (Seconds)	Hybrid (Seconds)
64	0.000021	0.000055	0.000019
256	0.000046	0.000081	0.000021
800	0.000052	0.000087	0.000023
4000	0.000063	0.000088	0.000041
8000	0.000092	0.000109	0.000055

Table 04: Decryption time analysis in AES, Blowfish and hybrid

Plaintext Size(bits)	AES (Seconds)	Blowfish (Seconds)	Hybrid (Seconds)
64	0.000012	0.00002	0.0000003
256	0.000013	0.000023	0.000009
800	0.000015	0.000024	0.000011
4000	0.000018	0.000029	0.000013
8000	0.000020	0.00003	0.000015

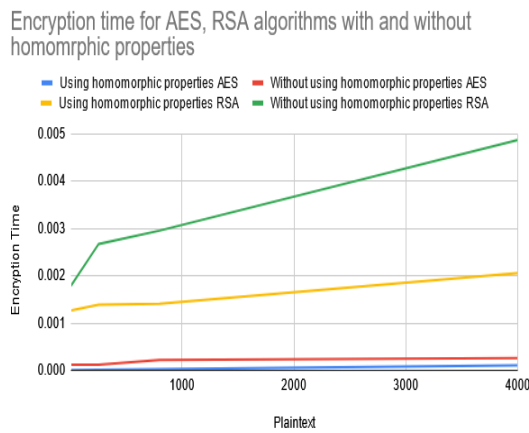


Figure 1: Encryption time for AES and RSA

6 CONCLUSION

When comparing algorithm performance, it is essential to evaluate both standalone execution times and those associated with additive and multiplicative homomorphic properties. This comparison indicates that homomorphic properties can enhance performance, as their evaluation times may outstrip those of standalone evaluations. For instance, adding homomorphic properties results in an average speed increase of 79% for AES and 47% for RSA during encryption. In terms of decryption, AES achieves an average improvement of 57%, while RSA shows a 30% enhancement.

Moreover, a hybrid system that combines two standalone algorithms generally performs better than the individual algorithms. In this case, we will create a hybrid approach by integrating the AES and Blowfish algorithms. When comparing this hybrid system to the Blowfish algorithm alone, we observe an average improvement of 64% in encryption and 63% in decryption in data data-storing process.

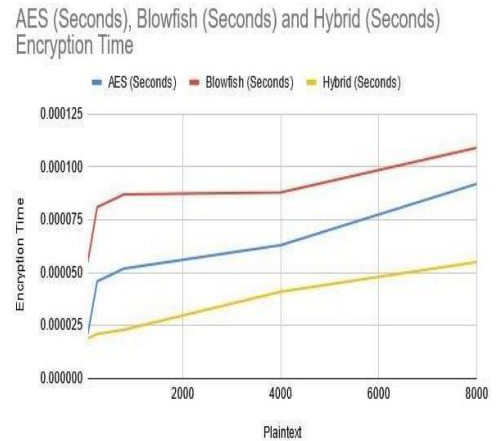


Figure 2: Hybrid Scheme Encryption

REFERENCES

- Hong, M. Q., Wang, P. Y., & Zhao, W. B. (2016). Homomorphic Encryption Scheme Based on Elliptic Curve Cryptography for Privacy Protection of Cloud Computing. *Proceedings 2nd IEEE International Conference on Big Data Security on Cloud, IEEE BigDataSecurity 2016, 2nd IEEE International Conference on High Performance and Smart Computing, IEEE HPSC 2016 and IEEE International Conference on Intelligent Data and S*, 152–157. <https://doi.org/10.1109/BigDataSecurity-HPSC-IDS.2016.51>
- Kartit, Z., & El Marraki, M. (2015). Applying encryption algorithm to enhance data security in cloud storage. *Engineering Letters*, 23(4), 277–282.
- Sajay, K. R., Babu, S. S., & Vijayalakshmi, Y. (2019). Enhancing the security of cloud data using hybrid encryption algorithm. *Journal of Ambient Intelligence and Humanized Computing*, 2018. <https://doi.org/10.1007/s12652-019-01403-1>
- Selvamani, K., & Jayanthi, S. (2015). A review of cloud data security and its mitigation techniques. *Procedia Computer Science*, 48(C), 347–352. <https://doi.org/10.1016/j.procs.2015.04.192>
- Shukla, D. K. R., Dwivedi, V. K. R., & Trivedi, M. C. (2020). Encryption algorithm in cloud computing. *Materials Today: Proceedings*, 37(Part 2), 1869–1875. <https://doi.org/10.1016/j.matpr.2020.07.452>

- Thabit, F., Alhomdy, A. P. S., Al-Ahdal, A. H. A., & Jagtap, P. D. S. (2021). A new lightweight cryptographic algorithm for enhancing data security in cloud computing. *Global Transitions Proceedings*, 2(1), 91–99. <https://doi.org/10.1016/j.gltp.2021.01.013>
- Velumadhava Rao, R., & Selvamani, K. (2015)(2015) Data security challenges and its solutions in cloud computing. *Procedia Computer Science*, 48(C), 204–209. <https://doi.org/10.1016/j.procs.2015.04.171>



Effectiveness of Manual and Automated Testing in Software Quality Assurance: A Case Study

Manawasinghe GAMU¹, Munasinghe B¹

Department of Computing and Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka

medhmanawasinghe@gmail.com

ABSTRACT

This study compares manual and automated testing methods in software quality assurance (QA) in an actual professional context that employs both methods, focusing on their effectiveness, as identified by QA interns. The primary objective of the study is to analyze the impact of the different testing methods on defect detection, time management, and overall software quality. By surveying QA professionals, particularly interns, this study evaluates their experiences with manual and automated testing, providing insights into the strengths and limitations of each method. The research also highlights the potential benefits of combining manual and automated testing in a hybrid approach. Statistical analysis revealed that automated testing is more efficient for repetitive tasks, while manual testing provides greater flexibility in exploring complex issues. The findings suggest that a balanced hybrid approach is more beneficial for delivering high-quality software. The study's results contribute to the understanding of how software companies can optimize their quality assurance processes and ensure robust, efficient, and reliable software products.

KEYWORDS: Automated Testing, Manual Testing, Quality Assurance

1 INTRODUCTION

Software Quality Assurance (SQA) plays a vital role in ensuring the reliability, functionality, and performance of software products. As software applications grow in complexity, ensuring their quality becomes increasingly challenging. Effective testing methods are essential to detect defects early, maintain software integrity, and meet user expectations. Traditionally, manual testing has been the dominant approach, where QA engineers execute test cases step by step to verify the correctness of the system. However, manual testing can be time-consuming, labour-intensive, and prone to human errors, particularly in large-scale or rapidly evolving software projects.

To address these challenges, the software industry has increasingly

adopted automated testing, which enables faster execution of test cases with minimal human intervention. Automated testing tools can efficiently perform repetitive tests, improve consistency, and provide quick feedback, making them valuable for modern agile and DevOps-driven development environments. However, automation requires initial setup effort, and maintenance, and may not be suitable for exploratory or usability testing, where human judgment is crucial.

This study investigates the effectiveness of manual, automated, and combined testing methods in software quality assurance, focusing on their impact on defect detection, time management, and overall software quality. The research particularly examines the experiences of junior QA professionals, such as QA interns, who are

often responsible for executing and analyzing test results. By evaluating these testing approaches, this study aims to provide insights and recommendations for optimizing SQA processes in software development teams.

2 LITERATURE REVIEW

Manual testing in industrial control software allows for in-depth, human-driven validation of complex, dynamic systems, especially when new features or user interfaces are involved; however, it is slower and less scalable (Badr, 2021). Valued for its flexibility in detecting complex defects, manual testing is limited by inefficiency in repetitive tasks.

Automated testing with specialized tools and scripts, on the other hand, provides faster, more consistent results, making it ideal for repetitive tasks, regression testing, and continuous integration in large systems (Zhou et al., 2022; Sari & Olsson, 2020). While faster and suited for repetitive tasks, it struggles with edge cases requiring human intuition. A similar study (Kumari et al., 2018; Xia & Luo, 2021) emphasizes manual testing's role in uncovering usability issues while highlighting its scalability challenges, whereas automated testing is noted for its efficiency and consistency but requires significant investment and lacks effectiveness in usability testing.

A study by (Ali et al., 2024) explores the significance of automated testing within the software lifecycle, emphasizing its role in improving operational efficiency and ensuring testing. They highlight that comparatively, automated testing can save time and resources than manual testing. However, the initial setup of

automated testing can be complex and requires specialized skills. While automated testing can enhance test coverage and reliability, it may struggle with handling real-time changes and managing test data effectively.

The study also values manual testing for its flexibility in detecting complex defects and uncovering usability issues. While manual testing is essential for subjective assessments, automated testing offers greater efficiency and reliability in managing large-scale, complex testing scenarios (Hassan & Liu, 2021). These studies agree that neither approach is sufficient alone. A hybrid approach, combining the strengths of both manual and automated testing, offers the most effective solution that balances speed, precision, and adaptability, making it suitable for diverse projects with varying requirements.

3 METHODOLOGY

The primary data collection method was a Likert scale survey questionnaire, which allowed participants to rate their experiences and perceptions on a scale, facilitating the measurement of various aspects of testing and software quality. The study surveyed intern QA engineers using simple random sampling. Out of an approximate population of 55 individuals, 50 participants were selected to ensure better representativeness. Statistical analysis, including Fisher's exact test (Fisher, 1922) and Cramér's V (Cramér, 1999), were used to evaluate the relationships between testing methods and software quality.

4 DATA COLLECTION & ANALYSIS

Primary data was collected through an online survey questionnaire with Likert scale questions was used to gather insights from testers about their experiences and perspectives on different testing approaches. For analysis purposes, the qualitative responses were converted into numerical values, enabling statistical evaluation of the collected data.

Primary data was collected through an online survey questionnaire with Likert scale questions to gather insights from testers about their experiences and perspectives on different testing approaches. For analysis, qualitative responses were converted into numerical values, enabling statistical evaluation.

The analysis focused on the following key factors for comparing testing methods: effectiveness in finding high-priority defects, effectiveness in identifying rare bugs, defects missed in earlier attempts, test cycle duration, alignment with deadlines, delays, confidence in software quality after testing, stakeholder perception, and overall software quality.

To assess the relationships between testing methods and software quality, Fisher's exact test was applied to measure the statistical significance of categorical variables, while Cramér's V was used to determine the strength of these associations. These statistical methods were chosen because Fisher's exact test was well-suited for small sample sizes and evaluated whether relationships between variables were significant. Cramér's V quantified the strength of associations between categorical variables, helping to

identify which factors strongly influenced software quality.

5 RESULTS AND DISCUSSION

5.1 Descriptive Analysis

Table 1 shows the effectiveness of manual, automated, and combined testing methods across various factors according to testers' perspectives. Testers feel more confident when performing manual testing as it allows them to apply their experience and intuition.

Table 1: Summary of Descriptive Analysis Findings

Factor	Manual	Automated	Combined
High-Priority Defects	X	X	√
Rare Bugs Defects	X	X	√
Missed Earlier	X	√	X
Test Cycle Duration	X	√	X
Fit with Deadlines	X	X	√
Delays	X	√	X
Software Quality After Testing	X	X	√
Confidence in Software Quality	√	X	X
Stakeholder Perception	X	X	√

Automated testing significantly reduces the occurrence of defects missed earlier, shortens the test cycle duration, and minimizes delays, making it ideal for repetitive and systematic testing tasks.

However, a combined approach emerges as the most suitable for achieving optimal results. By integrating manual and automated testing, teams are better equipped to meet deadlines, assess the overall product quality after testing, and be effective in identifying high-priority defects and rare bugs.

From the stakeholders' perspective, the combined method is highly recommended as it not only balances speed and thoroughness but also aligns with project timelines and delivers high-quality software products. This highlights the importance of a hybrid testing strategy to enhance software quality assurance processes effectively.

5.2 Fisher's exact test and Cramér's V

The analysis using Fisher's exact test and Cramér's V examines the influence of various factors affecting software quality, focusing on manual and automated testing. The findings suggest that a combined testing approach produces the best results for ensuring software quality. The goal is to understand how different factors contribute to software quality through this combined testing method.

Fisher's exact test assessed the statistical significance of the relationships between independent variables (e.g., Effectiveness for High-Priority Defects, Effectiveness for Rare Bugs, Defects Missed Earlier, Test Cycle Duration, Fit with Deadlines, Delays, Confidence in Software Quality, Stakeholder Perception) and the dependent variable (software quality). Cramér's V was used to measure the strength of these associations, identifying the factors that play a key role in influencing software quality.

P-value < 0.05 indicates variables are dependent, which means that the variable has a noticeable impact on the software quality.

Table 2: Values of Fisher's exact test and Cramér's V

Factor	Fisher's Exact Test (P-value)	Cramér's V
High-Priority Defects	3.442e-08	0.764671
Rare Bugs	0.004384	0.492366
Defects Missed Earlier	0.02243	0.307989
Test Cycle Duration	0.5518	0.248589
Fit with Deadlines	0.005888	0.596541
Delays	0.7109	0.195881
Confidence in Software Quality	0.5564	0.176403
Stakeholder Perception	4.43e-09	0.70207

Cramér's V ranges from 0 to 1, where values closer to 1 indicate a stronger association, and values closer to 0 indicate a weaker association. The results reveal that variables such as Effectiveness for High-Priority Defects, Fit with Deadlines, and Stakeholder Perception have strong associations with software quality, making them high-priority areas for improvement in quality assurance practices. Moderate associations with software quality were observed for Effectiveness for Rare Bugs and Defects Missed Earlier, indicating that these

factors contribute to software quality but to a lesser extent. On the other hand, Test Cycle Duration, Delays, and Confidence in Software Quality showed relatively weak associations with software quality, suggesting a limited influence on software quality and lower priority in the overall optimization process.

These findings emphasize the need to prioritize high-impact factors, such as Effectiveness for High-Priority Defects, Fit with Deadlines, and Stakeholder Perception, as they strongly influence software quality. Insights from both the descriptive and statistical analyses highlight the advantages of a balanced testing approach, where the strengths of manual and automated methods are combined to achieve better outcomes. The findings show that while both methods have their benefits, the combined approach is the most effective for getting the best results in detecting defects, meeting deadlines, and ensuring high software quality. This provides practical guidance for refining quality assurance practices and improving software testing processes.

6 CONCLUSION

In conclusion, adopting a combined approach that leverages the strengths of both manual and automated testing is recommended for enhancing quality assurance processes. Testers prefer manual testing because it allows them to apply their experience and intuition, giving them greater confidence in detecting complex issues. However, it can be time-consuming and may lead to project delays under tight deadlines. Automated testing accelerates test cycles, efficiently handles repetitive tasks, and improves defect detection, though it may

miss rare or intricate bugs requiring human insight. This balanced strategy promotes effective defect detection, efficient time management, and improved software quality. By integrating both methods, organizations can boost productivity and deliver reliable software products that meet stakeholder expectations.

Future research could explore AI-driven testing automation to enhance defect detection and efficiency. Additionally, examining the effectiveness of automation frameworks across different development environments and the role of continuous integration and DevOps in testing can lead to further advancements in quality assurance.

REFERENCES

- Badr, H. (2021). A Comparative Study of Manual and Automated Testing in Control Systems. *International Journal of Automation and Computing*, 18(2), 181-188.
- Zhou, Y., Zhang, J., & Li, W. (2022). Recent Advances in Automated Testing for Industrial Control Systems. *IEEE Access*, 10, 14623-14634.
- Sari, A., & Olsson, H. H. (2020). Challenges and Benefits of Automated Testing in Industrial Control Systems: A Review. *Journal of Software: Evolution and Process*, 32(7), e2274.
- Kumari, B., Chauhan, N., & Syed, H. H. (2018). A comparison between manual testing and automated testing. *Journal of Emerging Technologies and Innovative Research*, 5(12 2018), 323-331.
- Xia, Q., & Luo, X. (2021). Automated Testing of Industrial Control Software: Tools and Techniques. *Journal of Industrial Information Integration*, 23, 100187.
- Ali, H. M., Hamza, M. Y., & Rashid, T. A. (2024). A Comprehensive Study on Automated Testing with The Software

Lifecycle. arXiv preprint
arXiv:2405.01608.

- Hassan, M., & Liu, L. (2021). Manual and Automated Testing in Real-Time Embedded Systems: A Comparative Study. *IEEE Transactions on Industrial Informatics*, 17(9), 6324-6332.
- Fisher, R. A. (1922). On the Interpretation of Chi-Squared from Contingency Tables, and the Calculation of P. *Journal of the Royal Statistical Society*, 85(1), 87-94.
- Cramér, H. (1999). *Mathematical Methods of Statistics (PMS-9)*. Princeton University Press.



Enhancing Fault Management in Telecommunications Networks Using Power BI: A Case Study

Kodippily TND¹, Munasinghe B¹

Department of Computing & Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka

fas192059@kul.wyb.ac.lk

ABSTRACT

This paper presents a new approach to how to visualize and handle fault management at the regional level in a Sri Lankan telecommunication service provider, addressing various deficiencies in the current approach using spreadsheets. The study was centered on the examination of the trend of fault occurrence by time and the geographical location of physical devices of a telecommunication network at a regional branch. A dashboard in PowerBI was designed to incorporate important features such as fault trend visualization, recurring fault hotspot identification, and fault categorization. The study involved gathering and purifying fault data, followed by the development of an interactive visualization using PowerBI. The proposed solution improved operational efficiency by assisting the senior leadership teams to allocate resources better, prioritizing the maintenance tasks, and speeding up fault resolution. Feedback from operational teams confirmed the dashboard's usability and ability to streamline fault analysis processes. The results demonstrate significant enhancements in the decision-making capabilities at the regional branch of interest, reducing downtime and increasing network reliability. The solution also highlights the potential of integrating business intelligence tools into telecommunication fault management and offers a scalable framework for similar applications in the industry.

KEYWORDS: Business Intelligence Systems, Fault Analysis, Power BI, Telecommunications Visualization Tools

1 INTRODUCTION

The efficiency in fault management is a major concern regarding maintaining quality and customer satisfaction in a telecommunication service. This study focuses on fault management at a regional branch of a major telecommunication service provider on the island, and it was found that the current practice uses spreadsheets in an almost manual process, with no support from any advanced business intelligence systems currently available. This practice limits the possible pattern identifications, planning maintenance activities, and decision-making based on data. Thus, the objective of this study was to employ a business intelligence system (Power BI) to develop

a dashboard with real-time monthly fault visualizations and trend analysis of faults along with actionable insights to help the stakeholders make strategic decisions in optimizing resource allocation. By integrating trend analysis, fault categorization, and real-time visualization, the solution enables efficient decision-making and improves network reliability.

2 LITERATURE REVIEW

a. Visualization in Fault Management

Computational Tools such as NetClinic provide both network visualization and automated fault diagnosis capabilities, which enable administrators to trace fault hotspots and

their resolutions. Although it works well for business networks, their applicability in telecommunication systems is questionable due to the breadth of their operations (Zhicheng et al., 2010).

b. AI in Fault Detection

Artificial intelligence methods (e.g., machine learning tools like TensorFlow), on the other hand, can discover faults and pinpoint problems with a high degree of accuracy by analyzing historical data. The application of these methods, however, requires a large amount of technical knowledge, which is difficult for nontechnical operational teams to adopt (Yang et al., 2023).

c. Pattern Mining Techniques

Pattern mining techniques, such as sequential pattern mining and episode rule extraction, reflect the repeated fault patterns and their main causes. Good at finding trends, these approaches mostly work in isolation without being linked to real-time visualization tools needed for operational decisions (Nouioua et al., 2021).

d. Power BI for Business Intelligence

Power BI is recognized for its data connectivity, user-friendly dashboards, and interactive visualizations. Its real-time monitoring capabilities make it an excellent platform for decision-making. Despite its versatility, its use in fault analysis within telecommunications is underexplored, presenting an opportunity to address existing gaps (Becker, 2019). Power BI is a cost-effective and user-friendly business intelligence tool that offers seamless integration with Microsoft products, which enhances accessibility for organizations already using the Microsoft ecosystem (Tirupati et al., 2024). Its advanced data modeling capabilities,

support for custom analytics with R and Python, and robust cloud-based infrastructure make it highly scalable and suitable for businesses of all sizes (Bussa, 2023). Additionally, its extensive support network, regular feature updates, and strong security features ensure that businesses can rely on Power BI for both real-time analysis and long-term growth (Perifanis & Kitsios, 2023).

3 METHODOLOGY

The study approach was to systematically analyze and visualize the fault data, putting more emphasis on insightful knowledge for managing the faults. The research approach consists of four important stages.

a. Data Collection

Fault data was collected from existing fault data spreadsheets. This dataset contained very detailed information, including timestamps, the type of fault, distribution points (DPs) affected, and Multi-Service Access Nodes (MSANs). This dataset, thereby, formed the basis for further data analysis and visualization.

b. Data Cleaning

The collected data were cleansed to handle inconsistencies (missing entries and formatting) in the data. Irregularities were cleaned up to provide a valid and accurate dataset for further analysis.

c. Creating the Visualizations

It included the development of a web-based, interactive dashboard in Power BI showcasing fault trends and hotspots. Some features include the following;

- Trend Analysis: Charts on daily and weekly fault patterns.
- Hotspot Identification: Emphasize high-fault areas and MSANs.

- **Classification:** Categorizing the faults according to their types and frequencies for direct interpretation of the results.

d. Testing and Refinement

The dashboard has been tested in cooperation with the operational teams at the regional branch to assess its functionality and usability. The received feedback was integrated into features for fine-tuning, thus making the solution fit the requirements of practicality. These iterations will make sure that the dashboard fits the operational needs at the branch.

4 DATA COLLECTION AND ANALYSIS

Fault occurrence data was provided by the mother company to analyze and build patterns for enhancing the strategies of fault resolution. Cleaned and structured data are to be analyzed into actionable insight by Power BI dashboards.

a. Data Structure

Data provides comprehensive information about the number of faults recorded by,

- **Distribution Points (DPs)** - particular locations in a network that are most fault-prone.
- **MSAN Nodes** - Nodes where faults recur again and again.
- **Fault Types** - Classifications of faults based on the most fault occurrent hour of the day and most fault occurrent day of the week.

The above structure allowed for the conduction of focused analysis and visualization of fault patterns.

b. Key Analysis

- **Peak Fault Times**

Fault spikes were identified during specific hours of the day and on particular days of the week. These insights helped the operational teams to schedule resources efficiently during peak fault-occurring time periods.

- **Fault Hotspots**

High-faulty areas were pinpointed, particularly at specific DPs and MSAN nodes. These hotspots were visualized and enabled prioritizing the maintenance activities on high-faulty occurring areas.

- **Trend Analysis**

Recurring patterns in the fault occurrences highlighted the areas that need preventive maintenance. Trends across months and weeks were visualized & provided the historical context to underpin the decisions being taken.

c. Dashboard Capabilities

The Power BI dashboard supported real-time monitoring of the user through,

- **Interactive Visualization:** Through charts and Name cards, it identifies the fault-prone areas rapidly.
- **Actionable Insights:** Categorized information helps to provide informed decisions.
- **Resource Optimization:** fault resolution processes were Improved by the prioritization of critical areas.

By integrating these insights, the designed Power BI dashboard transformed fault management into an improvement in operational efficiency and helped to reduce downtime.

5 RESULTS AND DISCUSSION

a. Enhanced Fault Analysis

The implementation of the Power BI dashboard improved the process of fault management reasonably, and the results have shown an increase in operational

efficiency, better resource allocation, and increased decision-making capabilities.

b. Resource Optimization

The Power BI dashboard allowed real-time visualization of fault patterns.

- **Time of Fault Trend:** Recurring fault spikes are detected by the teams in late afternoons and over weekends. These insights helped the operation teams to effectively distribute their resources during these times when the demand is high.
- **Fault Type Grouping:** The groupings of category visualizations of faults pointed out a number of problem areas that need immediate attention or included in long-term planned maintenance strategies. The capability for quick identification of fault trends and quicker response towards those fault trends improved resolution times and minimized disruptions.

c. Improvement in Decision-Making

The user-friendly design of the dashboard empowered the maintenance staff to make informed decisions quickly. The operational teams noted several benefits:

- **Interactive Features:** Drill-down capabilities enabled teams to navigate fault data at detailed levels, such as by location, fault type, or time.
- **Visual Clarity:** The intuitive charts and name cards gave a clear overview of the hotspots and patterns of faults, enabling faster responses.
- **The simple design** provided by the proposed Power BI-based solution has a user-friendly interface with increased usability for the user.

d. Operational Feedback

The feedback from the operational teams of SLT proved the viability of the Power BI Dashboard. It helped smoothen the process of fault resolution with real-time, actionable insights and improved overall satisfaction from the fault management system, finding it easy to use and effective in yielding results.

e. Broader Impact

The implementation of the Power BI solution demonstrates the capability of business intelligence tools to overcome operational challenges in the telecommunication sector. The results highlighted emphasize the importance of embedding real-time visualization with practical insights into decision processes.

f. Dashboard Interfaces

As for the Visualizations, Donut charts, Pie charts, Bar charts, and Name cards were used.

- **Pie Charts** – Visualizes the count of faults that occurred from top 10 faulty DPs.
- **Donut Charts** – Visualizes the count of faults that occurred from the top 10 faulty MSAN IDs with the highest faults (up to DP or beyond DP).
- **Bar Charts** – Visualizes the most problems that occurred at the hour of the day and day of the week.

ENHANCING FAULT MANAGEMENT IN TELECOMMUNICATIONS NETWORKS USING POWER BI: A CASE STUDY

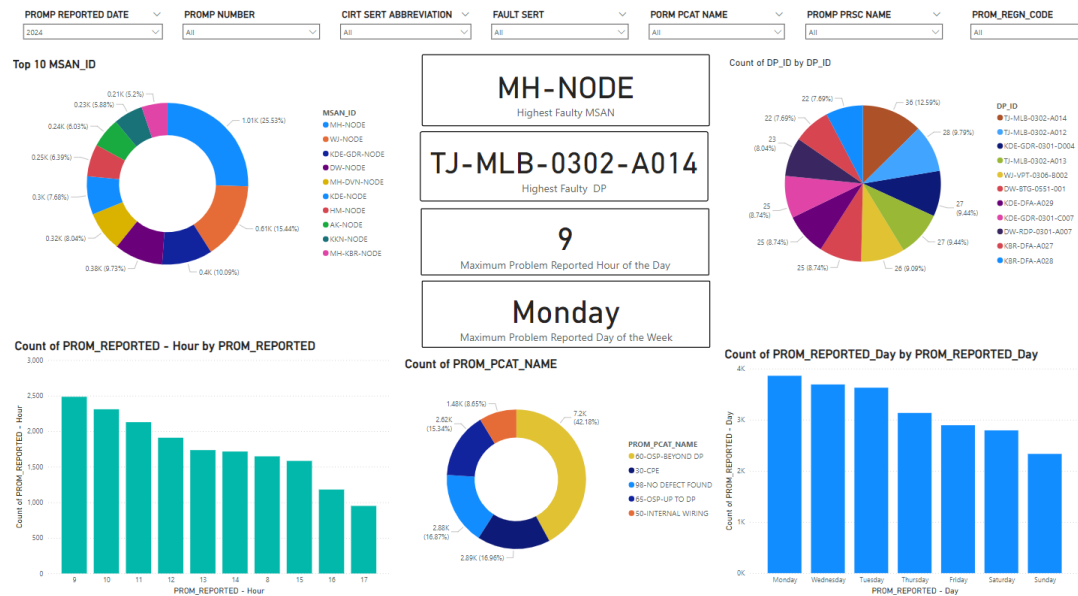


Figure 1: Dashboard View of Yearly Faults

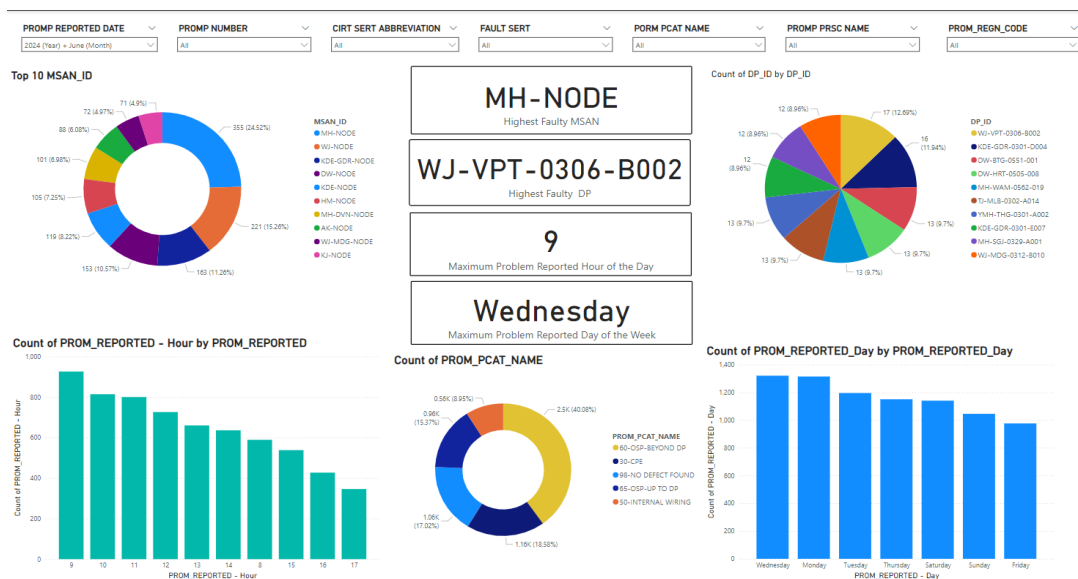


Figure 2: Dashboard View of the June Month Faults

- **Name Cards** – Highlights the most faulty MSAN Node, DP ID, highest fault occurant day of week & hour of the day.

Fig. 1 shows the dashboard view of yearly faults for all four months with the Excel fault data. Fig. 2 shows the dashboard view of the June month. Fig. 3 shows the model view of all the tables with monthly data and how those data connect with the visualization through an appended table.

6 CONCLUSION

The dashboards' ability to provide real-time fault insights has significantly enhanced the branch's operational efficiency. Fault trends, peak occurrence times, and recurring hotspots are now easily identifiable, allowing for more informed and timely decision-making. Resource allocation has been optimized by prioritizing high-fault areas, while maintenance strategies have shifted from reactive responses to proactive planning,

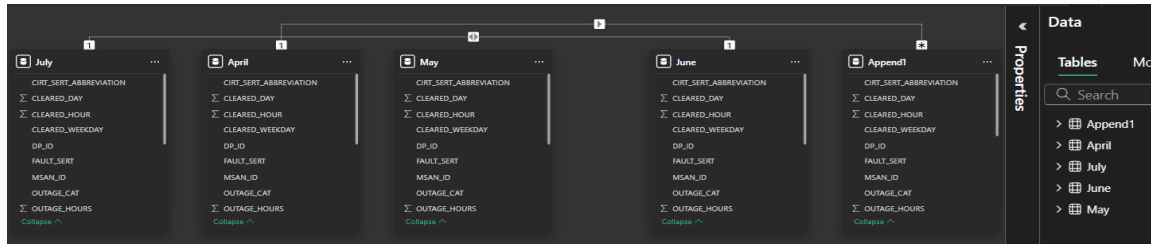


Figure 3: Model View of All the Tables

reducing downtime and improving network reliability.

Feedback from the operational teams confirms the dashboards' usability and practical value in streamlining fault resolution processes. The integration of interactive features such as trend analysis and fault categorization has empowered staff to make data-driven decisions efficiently by further demonstrating the dashboards' impact on operational workflows.

Despite the successful realization of the project, the current study observed limitations in its capability scope. Therefore, future work must seek to integrate predictive analytics with machine learning models to enable them to predict and prevent such faults. By incorporating advanced capabilities, the company can switch to a predictive approach for fault management, bringing improved network performance and greater satisfaction to customers.

The key deliverables expected from this research point to the transformative potential of BI tools like Power BI in managing telecommunication faults by providing a scalable framework that can be used in similar operational contexts.

REFERENCES

- Becker, L. T. (2019). Microsoft Power BI: Extending Excel to Manipulate, Analyze, and Visualize Diverse Data. 45(3). Retrieved from

<https://doi.org/10.1080/00987913.2019.1644891>

- L, Zhicheng; L, Bongshin; K, and Srikanth; M, Ratul;. (2010). NetClinic: Interactive Visualization to Enhance Automated Fault Diagnosis in Enterprise Networks. Salt Lake City, UT, USA: IEEE. doi:10.1109/VAST.2010.5652910
- Nouioua, M., Fournier-Viger, P., He, G., Nouioua, F., Min, Z. (2021). A Survey of Machine Learning for Network Fault Management. In: Chiroma, H., Abdulhamid, S.M., Fournier-Viger, P., Garcia, N.M. (eds) Machine Learning and Data Mining for Emerging Trend in Cyber Dynamics. Springer, Cham.
- Perifanis, N.-A., & Kitsios, F. (2023). Investigating the Influence of Artificial Intelligence on Business Value in the Digital Era of Strategy: A Literature Review. *Information*, 14(2), 85. <https://doi.org/10.3390/info14020085>
- Bussa, S. (2023), Enhancing BI Tools for Improved Data, Visualization and Insights *International Journal of Computer Science and Mobile Computing*, Vol.12 Issue.2, pg. 70-92
- Yang, Y; Guo, Q; He, Z; and Gao, H. (2023). Artificial Intelligence Based Fault Diagnosis and Analysis in the Distribution Network. *2023 Panda Forum on Power and Energy (PandaFPE)*. Chengdu, China. IEEE. doi:10.1109/PandaFPE57779.2023.10140738



Enhancing Python Interpreter Messages with a Natural Language Processing Approach

Wijesundara WMDI¹, Munasinghe B¹

Department of Computing and Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka

dulakshan.wije@gmail.com

ABSTRACT

New programmers often struggle with understanding Python interpreter error messages because of the complexity, which usually leads to frustration and uninspired learning. Error messages serve as guiding lights for programmers, and therefore, simplifying them is a key to effective debugging and a smoother learning experience. This project aims to address these challenges by developing a web-based integrated development environment (IDE) that incorporates natural language processing (NLP) techniques, that can help simplify and improve the clarity of eight types of common error messages generated by the Python interpreter. A web-based IDE that can enhance the generated error message to an intuitive, natural language explanation using a machine-learning model was developed and beta-tested with a group of undergraduate students of diverse fields of study with varying programming knowledge, and surveyed for factors such as the accuracy of explanations, user experience, and general usability. Survey results revealed that the application is easy to use, with users giving high ratings for its simplicity and usability. It also indicated that the users' expectations in programming learning tool of this nature seem to go beyond the purpose of supporting the learning, to expecting the tool to correct the errors for them.

KEYWORDS: Error Explanation, Machine Learning for Education, Novice Programmers, Python Error Messages

1 INTRODUCTION

Programming languages serve as a bridge between human logic and computer execution, allowing programmers to communicate instructions to the machines. For novice programmers, crossing this bridge often presents significant challenges that include both errors with their programming logic (semantic errors) as well as language-specific errors in their code (syntax errors). System-generated programming error messages can help them identify these errors, and to a certain degree, can help them self-learn about their mistakes.

Python, a high-level and versatile programming language, has gained wide popularity for its clean syntax, readability,

and support for multiple programming uses, and therefore is a preferred choice in introductory programming courses. However, even with these advantages, Python's error messages are often cryptic and overly technical. Instead of offering clear and actionable guidance, they focus on diagnosing the technical aspects of the error, leaving beginners confused and frustrated. This disconnect between the error and its explanation can delay learning, making it hard for them to understand and fix their mistakes.

In addressing this issue, recent advances in Natural Language Processing (NLP) offer innovative alternatives to enhance error messages. By leveraging NLP, error messages can be transformed into intuitive, natural language-based

explanations that are sensitive to context and designed with a focus on teaching. This research aims to improve Python error messages by developing a web-based integrated development environment (IDE) that incorporates Natural Language Processing (NLP) techniques. The IDE enhances error feedback, providing novice programmers with meaningful explanations to resolve errors effectively

The significance of this research lies in both theoretical and practical contributions. Theoretically, it explores the application of NLP in a technical nature within programming environments and examines how clear error messages improve learning outcomes. Practically, it delivers an enhanced error messaging system that can be directly implemented in educational settings, offering immediate benefits for instructors and students.

2 LITERATURE REVIEW

D'souza et al. (2019) explored how natural-language enhanced error messages (EEMs) affect novice programmers. Their study focused on improving outcomes like satisfaction, frustration, error correction time, and confidence. Key findings included reduced error correction time and fewer repeated errors. However, the study's short time frame limited its ability to measure long-term effects. Leinonen et al. (2023) investigating how large language models (LLMs) such as OpenAI's Codex could make programming error messages clearer for beginners found that Codex generated natural-language explanations for over 70% of Python errors and suggested fixes, only 33% were accurate. The study highlighted Codex's potential

but noted room for improvement. Khon et al. (2020) introduced a beginner-friendly Python IDE with a visual debugger and a custom error parser which made it easier for students to understand and fix programming errors, especially in classroom environment. However, they did not use NLP techniques to enhance it.

Zhou et al.'s (2021) study on Enhanced Programming Error Messages (EPEMs) for middle school students learning Python revealed that students using EPEMs had slightly higher error rates than those using regular messages, suggesting other factors may influence error reduction. Kohn's (2019) study analysing 6,981 Python error logs from high school students with a focus on how they fixed them, revealed that while error messages helped, they were insufficient to address deeper conceptual issues. Denny et al. (2020) showed that enhanced compiler error messages significantly reduced debugging time for students. Thiselton et al.'s (2019) Python plugin that integrates Stack Overflow solutions into error messages is reportedly helpful for common errors, yet provided overly complex or incorrect recommendations at times.

The rapid advancements in artificial intelligence demonstrate that it can be used to achieve these types of tasks easily. However, its applications are generally broad and not specifically tailored for educational environments (Chopra et al., 2024; Levin et al., 2024; Kohn, & Manaris, 2020).

3 METHODOLOGY

The system development had four phases: 1) application development, 2) error classification and model development, 3) Deployment and

Integration, and 4) Usability testing. The first two phases were executed parallelly, while before the development the latter two phases sequentially.

3.1. Application Development

A web platform built with React (n.d.) and with a code editor namely Monaco Editor (n.d.) that lets users write and run Python code in a browser. An Express (n.d.) server manages the backend, and an NLP model converts technical errors into clear explanations.

3.2. Error Classification and Model Development

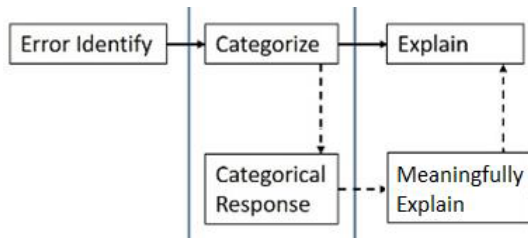


Figure 1: Overview of Model Development and Training Process

The system first focuses on improving Python error messages by categorizing common errors into a detailed dataset. The dataset, which includes 80 error messages with meaningful explanations, was distributed across eight chosen categories, with 10 messages per category. Based on the data, the TF-IDF text preprocessing technique is employed for vectorization and tokenization (i.e., to analyze the error messages and identify key patterns). A Multinomial Naive Bayes classifier is used for text classification and is trained on the prepared dataset.

To enhance error messages, the system processes errors in four steps: 1) detecting errors, 2) classifying them using the NLP model, 3) adding contexts like variable names and line numbers, and 4) providing a clearer explanation (Figure

3.1). Figure 3.2 illustrates the steps in the model's training process.

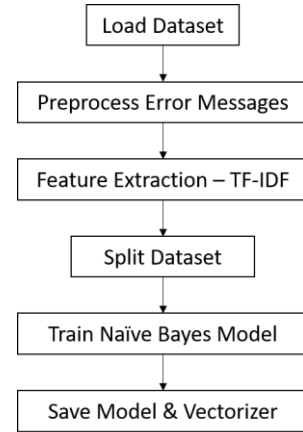


Figure 2: Model Training Process

3.3. Deployment and Integration

If an error occurs when a Python code is executed using `glot.io` API, the system captures and processes it with the NLP model that classifies the error and adds helpful details such as variable names and line numbers. The enhanced message that is clearer with a meaningful explanation is shown in an Error Panel in everyday English.

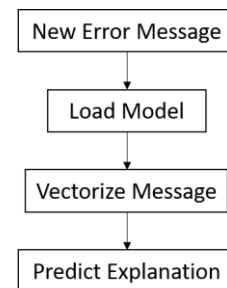


Figure 3: Model Prediction Process

Figure 3.3 illustrates the prediction process flow, detailing the steps involved in processing input error message, applying the trained model, and generating predictions.

3.4. Usability Testing

A usability test was conducted with application's effectiveness. The test

included eight exercises, each designed to focus on a specific type of Python error, such as `SyntaxError`, `NameError`, and `IndentationError`. Participants were divided into groups based on their field of study, knowledge of programming languages, and experience with Python. During the test, students gave feedback on three main areas: 1) how clear the error explanations were, 2) how accurate the explanations seemed, and 3) how simple the application was to use.

4 RESULTS AND DISCUSSIONS

4.1. Results

Table 1: Participants' Primary Field of Study

Primary Field of Study	Percentage
Computer Science	52.5%
Statistics	5%
Electronics	10%
Management	12.5%
Mathematics	20%

The survey was conducted with forty (40) undergraduates from five fields of study, with the majority coming from the field of Computer Science, as shown in Table 1.

Figure 4.1 shows the distribution of programming languages known by the participants, other than Python. It should be noted that, due to the nature of the graduate programme of the participants, the selected sample did not include complete novices to programming.

Figure 4.2 shows the relationship between participants' Python programming experience and the level of explanation accuracy provided by the application.

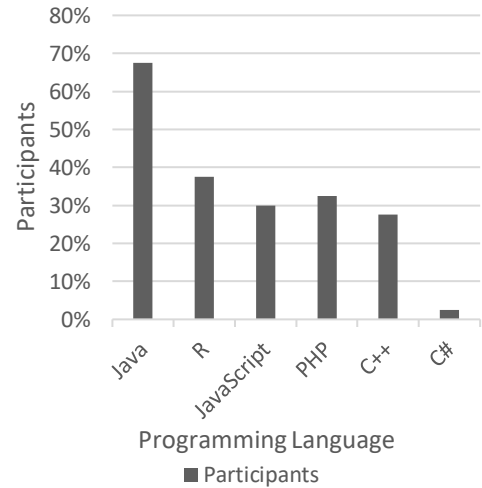


Figure 4 : Programming Languages Known by Participants (Excluding Python)

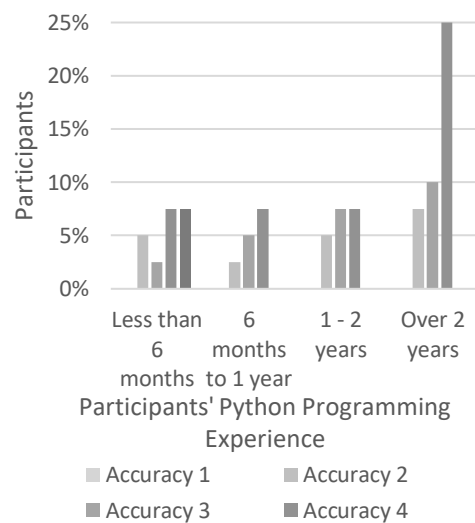


Figure 5 : Explanation Accuracy According to Participants' Python Experience

Results indicate that the higher the programming experience, participants found clearer the explanation given by the system.

Figure 4.3 illustrates the clarity of explanations provided by the application for each error type, as rated by the participants.

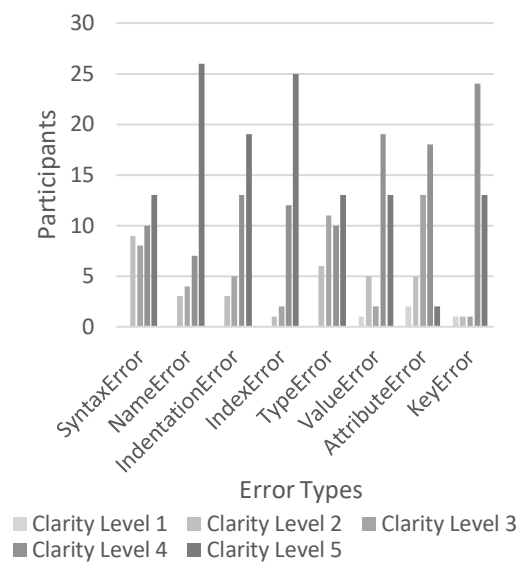


Figure 6 : Explanation Clarity by Error Type According to Participants

The majority of the participants have indicated that the response provided for each error type has a high level of accuracy.

Table 2: Simplicity of Application Usage According to Participants

Simplicity Level	Percentage
Simplicity Level 1	0%
Simplicity Level 2	7.5%
Simplicity Level 3	15%
Simplicity Level 4	35%
Simplicity Level 5	42.5%

Table 2 showcases participants' feedback on the simplicity of using the application.

4.2. Discussion

The majority of the participants are from Computer Science background, indicating that they have a fair knowledge of programming. This, along with the nature of the participants' degree programme, confirms the level of

effectiveness of the survey. Participants with more Python experience found the explanations to be accurate, while those with less experience struggled, probably because they were less familiar with the errors and/or terms used in compilers. Less than 25% of the participants have found the explanations to be low in clarity (i.e. clarity level 1 or 2) for each error type. Given that the exercises they tried are directed exercises, this indicates that the natural language explanations provided by the system are sufficiently simple for error messages of all types of errors.

Most participants found the application easy to use, giving high ratings for its simplicity and usability. This shows that the interface and design are well done and meet the needs of users.

Approximately 77.5% of participants acknowledged the system as having a high level of simplicity, with none perceiving it as complex. This shows the tool is easy to use, even for beginners. However, some feedback suggests it could be improved for those who gave lower scores.

5 CONCLUSION

The results of the user feedback indicate that the IDE has successfully achieved its objective. The differences in how participants understood errors highlight the need for a more detailed and accurate approach to analyzing the tool's effectiveness. The technical bias shown in the user feedback should be acknowledged, due to the nature of the participants' degree programme. Factors like programming experience, field of study, and familiarity with Python errors should be considered as guidance in future improvements.

Some participants have expected the IDE to also suggest solutions or to fix the errors, but this deviates from the main goal: making the Python error messages easier to understand (and not to fix). This indicates the importance of users being clear about the purpose of their learning tool, in order to take the best out of one.

The time limitation of the project restricted the NLP model to be trained with a larger dataset. We believe that, with more data, the model can be improved to provide clearer and more accurate explanations for a wider range of Python error messages. Based on the obtained feedback, it is observed that this application can go beyond just explaining errors to simplifying them, making them more approachable and easier to understand.

REFERENCES

- Chopra, B., Bajpai, Y., Biyani, P., Soares, G., Radhakrishna, A., Parnin, C., & Gulwani, S. (2024). Exploring interaction patterns for debugging: Enhancing conversational capabilities of AI-assistants. arXiv (Cornell University). <https://doi.org/10.48550/arxiv.2402.06229>
- Denny, P., Prather, J., & Becker, B. A. (2020). Error Message Readability and Novice Debugging Performance. Proceedings of the 2020 ACM Conference on Innovation and Technology in Computer Science Education, 480–486. Presented at the Trondheim, Norway. doi:10.1145/3341525.3387384
- D'souza, R., Bhayana, M., Ahmadzadeh, M., & Harrington, B. (2019). A Mixed-Methods Study of Novice Programmer Interaction with Python Error Messages. Proceedings of the 24th Western Canadian Conference on Computing Education. Presented at the Calgary, AB, Canada. doi:10.1145/3314994.3325090
- Express. (n.d.). <https://expressjs.com/>
- Kohn, T. (2019). The Error Behind the Message: Finding the Cause of Error Messages in Python. Proceedings of the 50th ACM Technical Symposium on Computer Science Education, 524–530. Presented at the Minneapolis, MN, USA. doi:10.1145/3287324.3287381
- Kohn, T., & Manaris, B. (2020). Tell Me What's Wrong: A Python IDE with Error Messages. Proceedings of the 51st ACM Technical Symposium on Computer Science Education, 1054–1060. Presented at the Portland, OR, USA. doi:10.1145/3328778.3366920
- Leinonen, J., Hellas, A., Sarsa, S., Reeves, B., Denny, P., Prather, J., & Becker, B. A. (2023). Using Large Language Models to Enhance Programming Error Messages. Proceedings of the 54th ACM Technical Symposium on Computer Science Education V. 1, 563–569. Presented at the Toronto ON, Canada. doi:10.1145/3545945.3569770
- Levin, K., Nicolas, V. K., Berger, E. D., & Freund, S. N. (2024). ChatDBG: an AI-Powered debugging Assistant. arXiv (Cornell University). <https://doi.org/10.48550/arxiv.2403.16354>
- Monaco-Editor.(n.d.).<https://microsoft.github.io/monaco-editor/>
- React. (n.d.). <https://react.dev/>
- Thiselton, E., & Treude, C. (2019). Enhancing Python Compiler Error Messages via Stack. 2019 ACM/IEEE International Symposium on Empirical Software Engineering and Measurement (ESEM), 1–12. doi:10.1109/ESEM.2019.8870155
- Zhou, Z., Wang, S., & Qian, Y. (2021). Learning from Errors: Exploring the effectiveness of enhanced error messages in learning to program. Frontiers in Psychology, 12. <https://doi.org/10.3389/fpsyg.2021.768962>



Evaluating the Effectiveness of Digitalized Software Documentation Solutions: An Industrial Case Study

Wijesundara WMDI¹, Arudchelvam T¹

Department of Computing and Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka

dulakshan.wije@gmail.com

ABSTRACT

In software development companies, new software developers face challenges with learning the proprietary software development toolkit due to outdated and static documentation, primarily videos and PDFs. These formats delay efficient search, navigation, and feedback, causing developers to rely heavily on senior team members for guidance. This dependence reduces productivity and distracts experienced staff from their main tasks. To address these issues, this research proposes a digitalized and interactive documentation system personalized to the organization's needs. The system will offer user-friendly features such as efficient search tools, real-time feedback options, and seamless content navigation, enabling new developers to access information independently. By providing an accessible and dynamic learning resource, the solution aims to reduce dependence on senior developers, enhance knowledge transfer, and improve overall operational efficiency.

KEYWORDS: Documentation, Organization, Productivity, Software Development,

1 INTRODUCTION

Software documentation is an important part of the software development process, providing information that helps users and developers understand how a system works and how to use it effectively. It usually includes guides, manuals, and references essential for learning and troubleshooting. However, in an identified software development company, new software developers often struggle to learn the organization's proprietary software development toolkit because the current documentation is outdated and consists mainly of static videos and PDFs. These formats make it difficult to search for specific information, navigate content efficiently, or provide feedback. As a result, new developers rely heavily on senior team members for help, which reduces

productivity and distracts experienced staff from their main tasks.

This research aims to address these challenges by developing a digitalized and interactive documentation system tailored to companies' needs. The new system will include user-friendly features such as efficient search tools, real-time feedback options, and seamless content navigation. By providing new developers with a dynamic and accessible learning resource, the system will help them gain independence in using the software toolkit, reducing their reliance on senior team members and improving overall efficiency in the company.

2 LITERATURE REVIEW

The current system of software documentation has several limitations that make learning difficult for new developers. First, the materials consist mainly of static formats like PDFs and

video tutorials, which lack interactivity. Users cannot search for specific keywords, leave comments, or quickly navigate to the sections they need. This makes it hard to access information efficiently, leading to a slow and frustrating learning process. Second, the documentation is difficult to navigate. Long PDFs and lengthy videos are not designed for quick reference, forcing users to spend a lot of time scrolling or re-watching content just to find small details.

Garousi et al. (2015), in their paper, explore the usage and usefulness of technical software documentation in a real-world industrial setting. Conducted as a case study at NovAtel Inc., a GNSS software system company, the research aims to understand how various types of documentation are used and perceived during software development and maintenance. The study builds on existing research gaps and proposes feasible recommendations for improving documentation practices.

Lethbridge et al. (2003) investigate the practices of software engineers (SEs) regarding documentation usage, maintenance, and usefulness. The study highlights that software documentation is often out-of-date, but remains useful for specific tasks, especially when it includes high-level abstractions. The authors aim to understand the realities of documentation use to guide better documentation strategies, tools, and practices.

Rodrigues et al. (2022) explore automation mechanisms for document management to enhance efficiency and agility in software documentation while ensuring compliance with regulatory standards. The study employs both

qualitative and quantitative research methods. Interviews with CSW professionals were conducted to gather feedback on documentation challenges and validate the developed tools.

Tang et al (2023) explore the importance of software documentation quality in aiding developers in selecting and learning software libraries. Poor documentation can lead to frustration and incorrect usage of libraries. The research follows a systematic approach using the Goal-Question-Metric (GQM) paradigm to define metrics for evaluating documentation quality. The study defines nine documentation quality metrics, including text readability, code readability, consistency with source code, and the presence of code examples. The most valued metrics were Text Readability and Code Readability, indicating that clear documentation and well-structured code examples are crucial.

Thota et al. (2024) present an AI-driven approach to automating software documentation generation, which is a crucial yet time-consuming aspect of software development. The study employs a dataset containing 2 million (comment, code) pairs from the Python portion of the GitHub CodeSearchNet Challenge. Preprocessing steps include auto-formatting according to the PEP-8 Python style guide, removal of unnecessary comments, and tokenization using Google SentencePiece. The study primarily focuses on Python-based documentation, limiting its generalization to other programming languages. Further research is needed to expand the dataset to include multiple languages and more complex software structures.

3 METHODOLOGY

The methodology for this research was designed to create an improved, interactive documentation system for the software development toolkit. To understand the specific needs of the developers and stakeholders, information was gathered through interviews. These interviews were conducted with developers, team leads, and other key personnel who frequently use or interact with the software development toolkit. The goal was to identify the main challenges they face with the current system and understand their expectations for the new documentation platform.

Based on the findings from the requirement analysis, a prototype of the digitalized and interactive web-based documentation system was developed.

Table 1: Distribution of Software Developers' Experience Levels

Experience Level	Percentage
Less than 6 months	25%
1 Year	25%
2 Years	12%
More than 2 years	38%

This prototype included important features such as search functionality, interactive content, and a feedback mechanism to address the limitations of the current system.

After the prototype was implemented, a survey was conducted with eight software developers to evaluate its effectiveness. The survey focused on gathering feedback on four key areas: Search Functionality, Interactive Content, Feedback Mechanism, and User Role Customization.

A structured questionnaire was designed to collect both quantitative and qualitative feedback. Open-ended questions gathered insights on challenges faced, most useful features, and suggested improvements.

Key usability aspects covered in the survey included:

- Ease of navigation and search functionality
- Efficiency of content creation (e.g., embedding images, code snippets)
- Interface design and interactive features
- Role-based access control and feedback mechanisms
- System performance, reliability, and responsiveness
- Overall user satisfaction and recommendations for improvement

4 RESULTS AND DISCUSSION

4.1 Results

Table 1 tabulates the proportion of developers based on their experience with the software development tool kit.

The results show a balanced distribution across experience levels, with two developers having less than six months or one year of experience, some with two years, and some with more than two years. This diversity ensures that feedback reflects the usability of the system for both novice and experienced users.

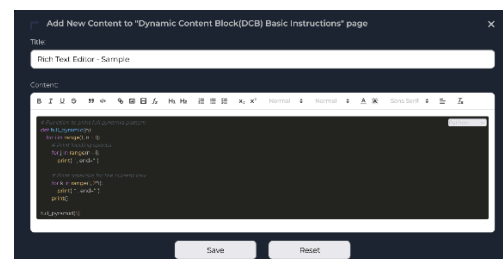


Figure 1: Editing Panel with Rich Text Editor

Figure 4.1 shows the text editor with QuillJS rich text editor.

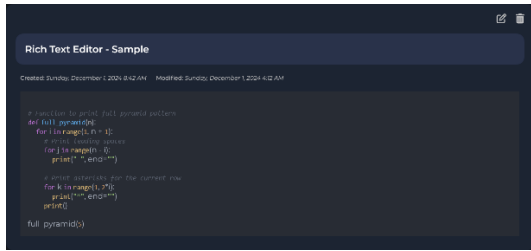


Figure 2: Preview of the Published Post

Figure 4.2 shows the preview of the published post with syntax highlighting.

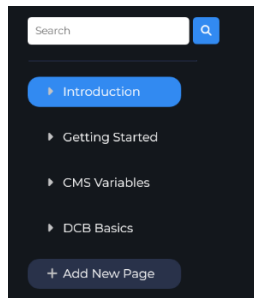


Figure 3: Navigation Panel

Figure 4.3 shows the navigation panel of the developed system. It can be used to navigate within the pages.

Figure 4.4 represents the ratings for ease of navigation. The majority of developers rated this aspect highly, with most ratings being 4 or 5. This demonstrates that the system's intuitive design has effectively addressed one of the key challenges of the previous documentation setup.

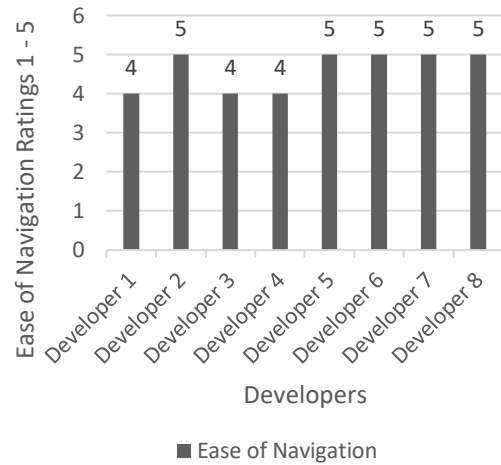


Figure 4: Ease of Navigation Ratings

Table 2 shows the distribution of responses regarding the efficiency of the search functionality. Over 80% of respondents rated the search as efficient or very efficient.

Table 2: Search Efficiency

Search Efficiency	Percentage
Yes	87%
No	0%
Other	13%

Figure 4.5 shows the ratings for the intuitiveness of creating and editing articles.

EVALUATING THE EFFECTIVENESS OF DIGITALIZED SOFTWARE DOCUMENTATION SOLUTIONS: AN INDUSTRIAL CASE STUDY

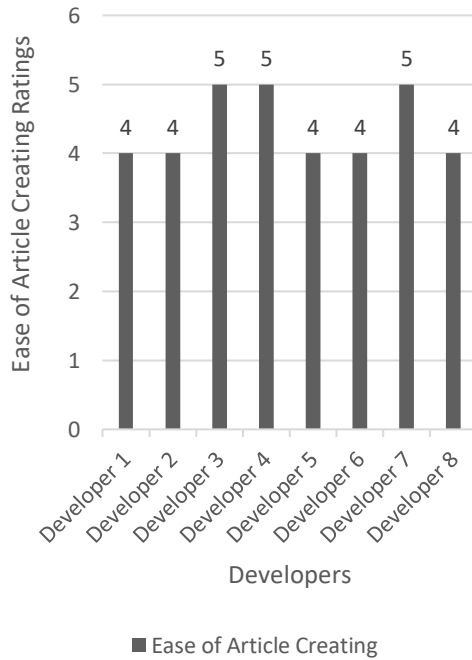


Figure 5: Ratings for Ease of Creating Articles

As shown in Figure 4.6, the overall satisfaction ratings, represented in a bar chart, reveal an overwhelmingly positive response, with most ratings above 4.5.

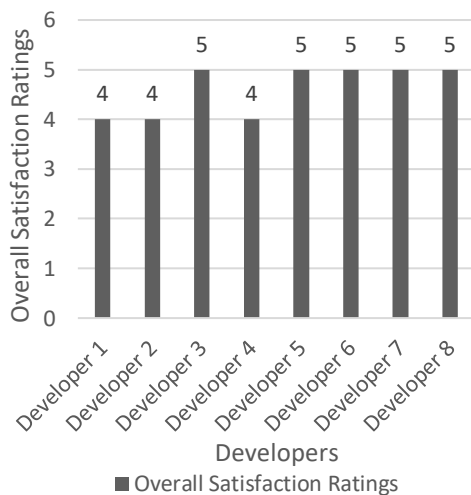


Figure 6: Overall Satisfaction Ratings

Table 3 shows the most appreciated features of the system.

4.2 Discussion

Most developers rated the system highly, with an average score exceeding 4 out of 5, indicating that the redesigned

Table 3: The Most Useful Feature

Feature	Percentage
Search	37%
Navigation	13%
Feedback	25%
Editing Tools	25%

structure resolved navigation challenges from the previous system. Experienced developers found it efficient, while newer developers suggested adding onboarding aids like guided walkthroughs or quick-start tutorials. The search functionality received strong positive feedback, with over 80% of participants praising its effectiveness. The dynamic search bar allowed quick access to information, though suggestions included adding advanced filters, such as by date or relevance, to improve precision.

Developers across all levels appreciated the streamlined process of creating and editing articles using the QuillJS rich text editor. Features like syntax-highlighted code and image embedding were particularly valued. Suggestions for further enhancement included pre-defined templates for common document types to save time and ensure consistency. Over 75% of developers, especially those with less than one year of experience, reported a noticeable reduction in reliance on senior staff. This reflects the system's success in enabling junior developers to work independently, freeing senior staff to focus on critical tasks.

The system received an average satisfaction rating above 4.5 out of 5. Experienced developers reported slightly

higher satisfaction due to their familiarity with previous workflows, while improved interactivity and user-friendly features were consistently praised. Minor issues, such as formatting bugs and occasional slow performance, were noted. Suggestions included improving the search functionality further and expanding documentation for advanced topics, providing clear directions for future improvements.

5 CONCLUSION

The survey results demonstrate that the new documentation system for the chosen software development tool kit represents a significant advancement over the previous version. By addressing critical issues such as ease of navigation, search efficiency, and dependency on senior developers, the system has substantially improved the overall user experience. Developers across all experience levels have expressed positive feedback, with high satisfaction ratings affirming the system's usability and functionality.

The new documentation system has successfully achieved its objectives of improving accessibility, usability, and efficiency. To ensure its continued relevance and effectiveness, the organization should prioritize periodic feedback collection and implement iterative updates. This proactive approach will help the system evolve alongside the changing needs of the developers and the organization.

REFERENCES

- Garousi, G., Garousi-Yusifoğlu, V., Ruhe, G., Zhi, J., Moussavi, M., & Smith, B. (2015). Usage and usefulness of technical software documentation: An industrial case study. *Information and Software Technology*, 57, 664–682. doi:10.1016/j.infsof.2014.08.003
- Lethbridge, T. C., Singer, J., & Forward, A. (2003). How software engineers use documentation: the state of the practice. *IEEE Software*, 20(6), 35–39. doi:10.1109/MS.2003.1241364
- Silva Cardoso Rodrigues, J. M., Ferreira Ribeiro, J. E., & Aguiar, A. (2022). Improving Documentation Agility in Safety-Critical Software Systems Development For Aerospace. 2022 IEEE International Symposium on Software Reliability Engineering Workshops (ISSREW), 222–229. doi:10.1109/ISSREW55968.2022.00071
- Tang, H., & Nadi, S. (2023). Evaluating Software Documentation Quality. 2023 IEEE/ACM 20th International Conference on Mining Software Repositories (MSR), 67–78. doi:10.1109/MSR59073.2023.00023
- Thota, S. R., Arora, S., & Gupta, S. (2024). AI-Driven Automated Software Documentation Generation for Enhanced Development Productivity. 2024 International Conference on Data Science and Network Security (ICDSNS), 1–7. doi:10.1109/ICDSNS62112.2024.10691221



Machine Learning based Rainfall and Flood Forecasting in Rathnapura District

Wijayasundara RJ¹, Wanninayake WMLN¹

Department of Computing and Information System, Faculty of Applied Sciences, Wayamba University of Sri Lanka

ruwanwijayasundara@gmail.com

ABSTRACT

Rainfall and flood modeling are critically important for flood risk assessment and the efficient management of water resources, especially in flood-prone regions like the Rathnapura district in Sri Lanka. This study combines rainfall prediction with flood forecasting using data from Kaggle and the Sri Lankan Irrigation Department, comprising key variables such as rain intensity, wind speed, and precipitation hours. Traditional classification models like Logistic Regression, K-Nearest Neighbors, Naïve Bayes, Support Vector Machine (SVM), and Decision Tree were compared for rain status predictions. Similarly, regression models such as Linear Regression, Ridge Regression, Lasso Regression, Polynomial Regression, and Bayesian Linear Regression were applied for rainfall prediction. Polynomial Regression yielded the best results, achieving an R^2 value of 0.82 for rainfall prediction and 1.0 for flood-level forecasting. Forecast computations showed high accuracy rates above 95% for models built using the Decision Tree method for both rainfall and flood cases. To avoid overfitting, stricter cross-validation and regularization methodologies were implemented. Flood forecasting utilizes quantitative data on rainfall and other flood parameters to enhance reliability, thus supporting informed decision-making. The superior performance of these models can be attributed to effective feature engineering and the utilization of large datasets, as evidenced by improved accuracy and R^2 scores during model evaluations.

KEYWORDS: Classification, Decision Tree, KNN, Regression, R^2 scores

1 INTRODUCTION

Floods frequently impact Rathnapura district in southwestern Sri Lanka, posing risks to agriculture, infrastructure, and livelihoods.

Traditional flood forecasting systems often fall short in incorporating factors like temperature, wind speed, rainfall, and humidity, leading to inadequate or delayed warnings. This study addresses these gaps using advanced machine-learning techniques to improve rainfall and flood predictability.

The research focuses on analyzing flood risks and integrating high-precision machine learning models into local early warning systems. Although focused on Rathnapura, the methodologies proposed

are adaptable to other flood-prone regions, aiming to enhance disaster response, minimize socioeconomic losses, and protect vulnerable populations.

2 LITERATURE REVIEW

This paper explores the factors that influence rainfall and flood regimes in Rathnapura District since it is surrounded by interesting geographical features and climates. The city of Rathnapura is the center of gems in the country, and the geographical structure of this city is hilly and river basins; the weather is monsoon type, which results in rain and sometimes flooding. The district is very susceptible to climate-related disasters since it

depends on rainfall for agricultural production, biodiversity conservation, and gem mining. However, heavy rainfall causes destructive floods that damage lives, infrastructure, and livelihoods. To address the district's vulnerability, extensive knowledge of the association between climatic characteristics like temperature, shortwave radiation, wind speed, or precipitation hours, and flooding is required Jayasinghe, Ruwangika, Aponsu, & Tharinda, (2021). Temperature and wind direction variations are known to exacerbate flood disasters, necessitating data-centric proactive forecast models Burt & Weerasinghe, (2014), Herath, (2005).

The application of rainfall and flood forecasting based on ML techniques is justified due to their capacity to analyze a considerable volume of data and detect nonlinear relationships. For instance, Random Forest, Support vector machine (SVM), and Artificial Neural Networks (ANN) have shown relatively small errors from actual values when common statistical techniques were used. For example, Adhikari et al. (2021) identified the application of ML algorithms for Bangladesh flood level mapping and India's rainfall prediction, both of which were found to be much more accurate than traditional methods Liyew & Melese, (2021); Santhi Karuppiah, (2024). In Rathnapura, the new ANN and Gradient Boosting models have proven to have improved forecasting in the interactions between the number of experienced rainfall and the corresponding flood indicators. This progress shows how the ML models could enhance the forecasting of early warning systems, efficient use of resources, and reduce the effects of

natural calamities Seydi et al., (2022).; Selvarajah & Jayathilake, (2016).

3 METHODOLOGY

a. Data Collection

The datasets used in this research include rain data in Rathnapura district from Kaggle and flood data from the Sri Lankan Irrigation Department. The rainfall dataset contains variables such as temperature, wind speed, and precipitation hours, while the flood dataset, comprising 4927 records, provides details on the district's flood severity levels. The dataset covers the period from 2010/1/1 – 2023/6/31, with geospatial data focusing on the Rathnapura district.

b. Data Pre-processing

Data normalization was performed using Min-Max scaling. Missing values were imputed using the mean for numerical data and the mode for categorical data. Outliers were identified and handled using the Interquartile Range (IQR) method. For the flood dataset, daily averages of feature values were calculated for each monsoon date to align with the climate data.

c. Step 1: Classification (Rainfall and Flood Status)

Rain intensities were classified as light and heavy, while flood levels were classified as minor and critical. The features were trained on classification algorithms, including Logistic Regression, K-Nearest Neighbors, Naïve Bayes, SVM, and Decision Trees. Model performance was evaluated using precision, recall, and F1-score metrics. Hyperparameter tuning was conducted using grid search with cross-validation.

d. Step 2: Regression (Rainfall and Flood Level)

Regression models, including Linear Regression, Ridge Regression, Lasso Regression, Polynomial Regression, and Bayesian Linear Regression, were applied to estimate rain and flood levels. The target variables were 'rain_sum' for rainfall prediction and 'flood_level' for flood forecasting. Models were evaluated using RMSE, MAE, and R^2 scores. Hyperparameter tuning was performed using a randomized search with cross-validation.

e. Model Evaluation and Validation

Classification models were evaluated using accuracy, precision, recall, and F1-score metrics, while regression models were assessed using RMSE, MAE, and R^2 scores. Cross-validation and stratified sampling techniques were employed to enhance model stability and generalizability.

4 RESULTS AND DISCUSSION

a. Classification Models

i. Rainfall Status Prediction Results

Logistic Regression, k-nearest Neighbors (k-NN), Naïve Bayes, Support Vector Machine (SVM), and Decision Tree were employed to predict rainfall status. Table 1 depicts rainfall status prediction model accuracies. Logistic Regression perfectly predicted the features to an accuracy of 94%; However, the model only correctly recalled 57% of “Extreme Rain.” Naïve Bayes returned an accuracy of 90 % for the test data set but had issues with “Extreme Rain” and “Very Heavy” and did well with “Heavy” and “Moderate” rainfall. SVM had 91.6% accuracy and outperformed in most of the classes, although the “Extreme

Rain” seemed to have slightly worse accuracy.

Decision tree and k-NN models gave 100% accuracy. Figure 1 shows the confusion matrix of the Decision Tree for rainfall status prediction model. Among the fundamental and easily interpretable algorithms, the Decision Tree was chosen for classification tasks in this study because it can handle categorical and numerical data and uses cross-validation and pruning to avoid overfitting.

Table 1: Rainfall status prediction model accuracies

Classification Technique	Precision	Recall	F1-Score
Logistic Regression	0.78	0.73	0.94
K-NN	1.00	1.00	1.00
Naïve Bayes	0.79	0.86	0.9
SVM	0.85	0.97	0.91
Decision Tree	1.00	1.00	1.00

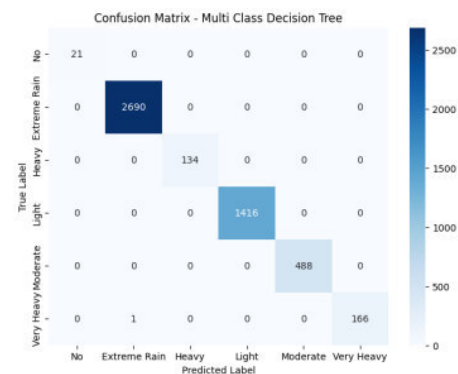


Figure 1: Confusion Matrix of the Decision Tree for Rainfall Status

ii. Flood Status Prediction Results

Table 2 shows the flood status model accuracies. Logistic Regression, which scored 60%, is the best at predicting the intended “No” flood class. The k-NN algorithm was defined with 81% accuracy and fails to generalize with specific flood categories. Consequently, Naïve Bayes attained an accuracy level of 92.0 percent

and was most accurate where it performed less impressively in some classes. SVM maintained a high accuracy of 91% in the predictive model.

Out of all the models, the Decision Tree model boasted the highest accuracy of 95% and nearly perfect results in most categories, though its results in the “Minor” and “Alert” categories were a little low. Confusion matrices were applied to compare the results of algorithms, and the present analysis established that the Decision Tree was the most accurate model in identifying flood statuses among the four. Figure 2 depicts the confusion matrix of the Decision Tree of flood status prediction model.

Table 2: Flood Status Model Accuracies

Classification Technique	Precision	Recall	F-1 Score
Logistic Regression	0.6	0.6	0.60
K-NN	0.32	0.38	0.81
Naïve Bayes	0.52	0.54	0.92
SVM	0.59	0.62	0.91
Decision Tree	0.57	0.57	0.95

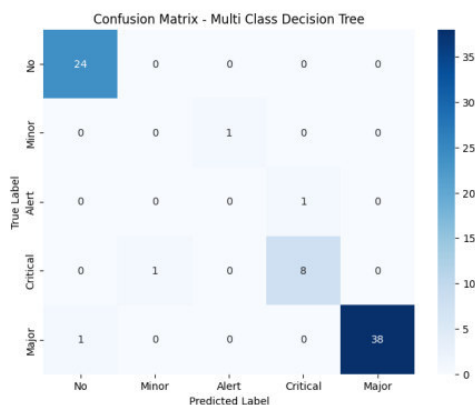


Figure 2: Confusion Matrix of the Decision Tree of Flood Status

b. Regression Models

i. Rainfall Level Prediction

The fitness of regression models for continued 12-step rainfall was assessed by the coefficient of determination R^2 means. Table 3 shows the rain sum evaluations. Linear Regression with an R-square of 0.891 was used as a benchmark model. Ridge Regression slightly increased $R^2 = 0.867$ combating a multicollinearity issue, while Lasso Regression, setting up restrictions on coefficients, received a lower $R^2 = 0.821$. The most accurate model of architecture was Polynomial Regression with an R^2 of 1. Polynomial Linear Regression came in second, equal to both Linear Regression and Simple Linear Regression at 0.87 and 0.88, respectively. These results underscore how they recommend a selection of models to use relying on features of datasets.

Table 3: Rain Sum Evaluations

Regression Technique	R^2 Error	RMS E	MSE
Linear	0.891	11.992	2.037
Ridge	0.867	14.624	2.351
Lasso	0.821	19.718	2.402
Polynomial 1	1.0	1.08e-17	2.136e-9
Bayesian Linear	0.867	14.625	2.351

ii. Flood Level Prediction

The regression models were expected to give continuous flood levels, and the goodness of these models was established by the R^2 . Table 4 shows the flood level prediction model evaluation. Linear Regression had a moderate R^2 of 0.74. Ridge Regression only mildly increased,

with an R^2 of 0.78, which confirms that regularization provided a better approach to identifying the correlation between input attributes and flood levels. Lasso Regression had the lowest accuracy results with the R^2 of 0.61, implying less importance to the feature and overfitting dangers.

Polynomial Regression had the highest R^2 of 0.82 therefore, it is the best fit to estimate the next level of floods based on the features because it estimates multiple features and their non-linearities directly. Bayesian Linear Regression has an almost similar performance to Ridge Regression with an R^2 of 0.77; nonetheless, it has advantages that involve quantified prediction uncertainty, which makes it a realistic option in the prediction of the flood level.

Table 4: Flood Level Evaluation

Regression Technique	R^2 Error	RMSE	MSE
Linear	0.74	1.31	3.40
Ridge	0.78	1.25	2.97
Lasso	0.61	1.92	5.18
Polynomial	0.82	1.16	2.57
Bayesian Linear	0.77	1.27	3.08

5 CONCLUSION

The study "Rainfall and Flood Forecasting of Rathnapura District using Machine Learning" aimed to improve rainfall and flood predictions, addressing their impact on the district's social and infrastructure aspects. Machine learning models, including classification (logistic regression, k-NN, Naïve Bayes, SVM,

and decision trees) and regression (linear, ridge, lasso, polynomial regression, and Bayesian linear regression), were compared for accuracy in predicting rain and flood levels. Polynomial Regression offered the best insights, while Decision Trees provided the highest accuracy for classification. However, challenges with a class imbalance in flood data affected predictions for rare statuses like "Alert" and "Minor." Future research is recommended in data re-sampling, ensemble modeling, and feature engineering, with a proposal for an early warning system to improve flood risk management.

Future studies could supplement model performance by integrating real-time observed meteorological variables obtained from the weather stations/satellites/ IoT.

REFERENCES

- Burt, T., & Weerasinghe, K. (2014). Rainfall Distributions in Sri Lanka in Time and Space: An Analysis Based on Daily Rainfall Data. *Climate*, 2(4), 242–263. <https://doi.org/10.3390/cli2040242>
- Ghiat, I., Mackey, H. R., & Al-Ansari, T. (2021). A Review of Evapotranspiration Measurement Models, Techniques and Methods for Open and Closed Agricultural Field Applications. *Water*, 13(18), 2523. <https://doi.org/10.3390/w13182523>
- Hettiwaththa, H. W. Y. J., & Abeygunawardana, R. A. B. (2018). Measuring flood risk in Ratnapura town area in Sri Lanka. *Proceedings of the 2nd International Conference on Climate Change*, 2(2), 31–41. <https://doi.org/10.17501/2513258X.2018.2203>
- Jayasinghe, K. P., Ruwangika, N. R. A. M., Aponsu, G. M. L. P., & Tharinda, W. M. A. (2021). Investigation of the variation of annual and seasonal rainfall patterns in Rathnapura District, Sri

Lanka. International Journal of Scientific Research and Engineering Development, 4(1), 1178-1197. <https://www.ijred.com/volume4/issue1/ijredv4i1P118.html>

- Liyew, C. M., & Melese, H. A. (2021). Machine learning techniques to predict daily rainfall amount. Journal of Big Data, 8(1). <https://doi.org/10.1186/s40537-021-00545-4>
- Selvarajah, J., & Jayathilake, D. (2016). Study on flood inundation areas in Rathnapura Municipal Council. Proceedings of the Conference, December 1-11. <https://www.researchgate.net/publication/329916377>
- Seydi, S. T., Kanani-Sadat, Y., Hasanlou, M., Sahraei, R., Chanussot, J., & Amani, M. (2022). Comparison of Machine Learning Algorithms for Flood Susceptibility Mapping. Remote Sensing, 15(1), 192. <https://doi.org/10.3390/rs15010192>



Multimodal Knowledge Graph Construction for Event Analysis

Sovis WRN¹, Gunasekara RPTH¹

Department of Computing and Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka

rachikasovis@gmail.com

ABSTRACT

With the rise of advanced technologies, the proliferation of dynamic multimodal data has transformed event analysis, offering new opportunities for identifying trends, patterns, and supporting decision-making processes. This research constructs a Multimodal Knowledge Graph (MKG) to address the challenges of integrating and analyzing Multimodal Data Formats, including text, images, and videos. Data was systematically scraped from reliable event platforms using automated web scraping techniques to gather event details such as names, dates, venues, and multimedia content. The collected data was semantically aligned and structured into a knowledge graph using graph-based techniques, ensuring meaningful connections between entities. The effectiveness of the MKG was evaluated by comparing the accuracy and relevance of event insights against traditional unimodal approaches. Performance metrics included precision in trend detection, enhanced decision-making accuracy, and scalability in handling large, diverse datasets. Results demonstrate the MKG's capacity to consolidate disparate data sources, providing comprehensive event insights and enabling precise trend detection. The findings have practical implications for event planning, social media monitoring, and urban management, highlighting the transformative role of MKGs in efficiently managing and analyzing complex data ecosystems.

KEYWORDS: Event Analysis, Multimodal Data, Multimodal Knowledge Graph

1 INTRODUCTION

The rise of digital platforms has led to an exponential increase in event-related data, creating both opportunities and challenges for effective analysis. Traditional event management systems and analytical tools predominantly rely on unimodal data, such as textual descriptions, which are often unstructured and lack the richness required to fully capture complex event relationships. These unimodal approaches limit the contextual understanding of events, leading to fragmented analyses and suboptimal decision-making. Existing knowledge graphs, although providing structured representations of entities, attributes, and their interconnections, typically focus on textual data alone and fail to integrate multimodal information

such as images, videos, and audio. This narrow focus hinders the ability to derive meaningful insights, especially in scenarios where visual or auditory context plays a critical role. Multimodal knowledge graphs address these gaps by integrating diverse data modalities to provide a richer, more comprehensive representation of real-world events. By combining textual details with multimedia inputs, Multimodal Knowledge Graphs enhance event representation and enable advanced applications. This research proposes a dynamic system to facilitate interactive analysis, bridging the limitations of unimodal approaches and paving the way for more effective event insights.

2 LITERATURE REVIEW

Multimodal knowledge graphs represent a significant advancement in knowledge engineering, moving beyond traditional text-based representations to include visual and auditory data such as images, videos, and audio clips. These diverse modalities enhance the relationships among entities, improving performance compared to unimodal knowledge graphs (Chen et al., 2023). The integration of multimodal data addresses the complexity and ambiguity often found in textual data, which can be time-consuming and resource-intensive to process (Knez & Žitnik, 2023).

The rise of the Internet of Multimedia things has further emphasized the need for methods that can handle real-time multimodal event streams, as well as applications like visual question answering and event prediction (Li & Liu, 2022). Traditional textual data often represents lengthy discussions or detailed factual information, but it can lack the context required to fully resolve cryptic entities. Multimodal approaches bridge this gap by incorporating heterogeneous sources of information (Moon, 2018).

The construction of MKGs typically involves named entity recognition (NER), relation extraction, and event extraction. NER identifies and classifies entities within text and visual media, such as people, locations, and organizations (Moon, 2018). Early NER methods relied on handcrafted dictionaries, but modern approaches leverage deep learning techniques such as gated fusion and graph-based methods for multimodal contexts (Chen et al., 2023). Relation extraction builds upon these entities by identifying relationships between them.

Visual content complements textual information, leads to more accurate extractions (Zheng et al., 2021). For instance, models like the Multimodal Neural Network with Efficient Graph Alignment utilize graph-structured visual data to align lexical and structural information effectively.

Event extraction is another crucial component, that captures occurrences involving specific triggers, participants, and contextual details such as time and place (Doddington et al., 2004). Multimodal approaches have proven especially valuable in this area by integrating visual and textual information to resolve inconsistencies and improve extraction accuracy (Zhang et al., 2017). Advanced frameworks even utilize videos to capture the temporal complexity of events, enhancing both identification and understanding (Chen, 2021).

Applications of MKGs are vast and diverse. For example, they play a pivotal role in detecting fake news on social media by combining textual and multimedia content to verify the authenticity of information (Zhang et al., 2019). In specialized domains, MKGs facilitate advancements in disease research and product recommendation systems, as demonstrated by Zhu et al. (2022) and Xu et al. (2021), respectively. These examples underscore the transformative potential of multimodal knowledge graphs across fields.

3 METHODOLOGY

The methodology for constructing a multimodal knowledge graph follows a three-phase approach. The Data Layer begins with web scraping to collect relevant information from diverse

sources, ensuring it is comprehensive and domain-specific. This data is then preprocessed to remove noise, address inconsistencies, and structure it for use in graph construction.

Next, in the Construction Layer, a multimodal knowledge graph is built, where entities are represented as nodes, and their relationships are depicted as edges. The graph integrates multimodal elements like text, images, and temporal/spatial data, with visualization tools employed to create an interactive and interpretable representation.

Finally, in the Analysis Layer, insights are extracted through computational methods such as clustering, trend analysis, or ranking. These findings are visualized using charts and graphs to facilitate interpretation and decision-making.

Figure 1 visually illustrates the said methodology in a flowchart.

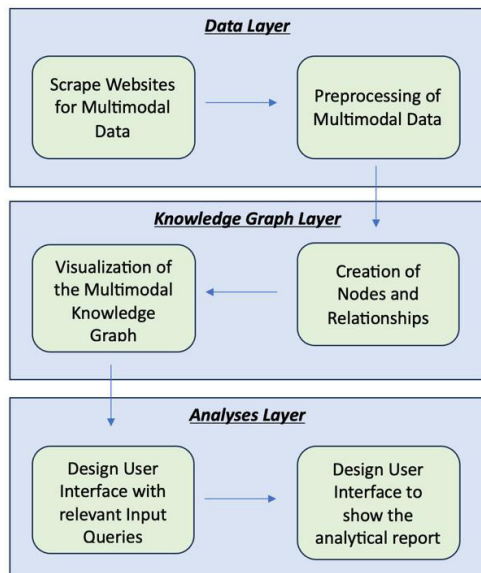


Figure 1: Methodology Diagram

4 IMPLEMENTATION

The research implementation comprised four stages: Web scraping, Preprocessing, Knowledge Graph

Construction, and Event Analysis. Web scraping collected multimodal data from online sources, forming the basis of the knowledge graph. Preprocessing standardized and structured the raw data to ensure consistency. During the construction phase, the data was transformed into a graph of nodes (entities) and edges (relationships), providing semantic and visual organization. Table 1 outlines the predicates and their relationships used in this process.

Table 1: Predicates and their Relationships

Predicate	Relationship
belongs_to_category	Event Category
held_at	Venue
has_date	Date

The final analysis stage applied advanced graph techniques to uncover event trends and audience behaviours, offering valuable insights.

a. Web scraping

Using BeautifulSoup, event details such as titles, dates, venues, and categories were extracted from Eventbrite, focusing on diverse categories like Food, Music, Business, and Sports to ensure a rich dataset.

b. Preprocessing

Scraped data underwent cleaning to address missing values by replacing them with "N/A." Invalid image URLs were removed, and images were optimized through resizing for efficient graph visualization while maintaining quality.

c. Multimodal Knowledge Graph Construction

The Multimodal Knowledge Graph was built to represent events as nodes connected by structured relationships to

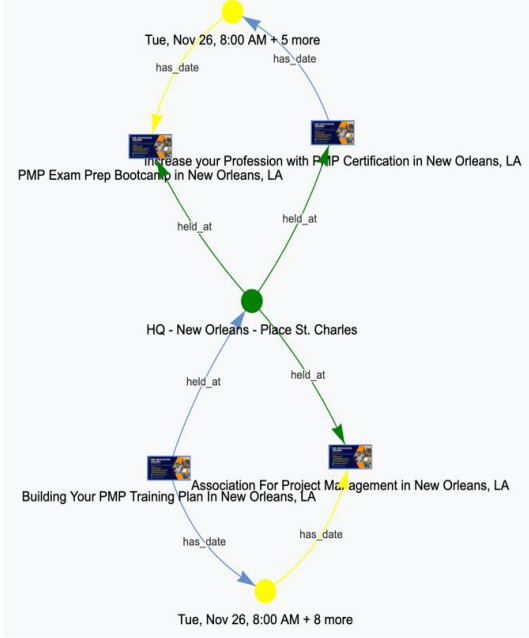


Figure 2: Four events being visualized with their respective relationships

their attributes (e.g., categories, venues, and images). Tools like NetworkX, Pandas, and Matplotlib were used to iteratively expand the graph from single-category data to a comprehensive dataset covering various event types. Figure 2 represents a visualization of a few events with their data after being scraped, preprocessed, and visualized in the graph.

d. Analysis

Advanced graph techniques were applied for trend analysis, personalized event recommendations, and temporal and geospatial insights. Libraries like Pandas, Seaborn, and GeoPandas facilitated data analysis and visualization, optimizing event management strategies.

5 EVALUATION

The analysis of the scraped event data yielded the following results:

True Positives (TP) = 142

False Positives (FP) = 2

False Negatives (FN) = 4

To evaluate the performance of the model, we calculate Precision to measure the accuracy of positive predictions. It is calculated as the ratio of true positives to the total number of predicted positives. And then the Recall to measure the model's ability to correctly identify all relevant instances. It is calculated as the ratio of true positives to the total number of actual positives. And F-Score, which is the harmonic mean of precision and recall, provides a balanced measure of both metrics.

$$\text{Precision} = \frac{TP}{TP + FP}$$

Equation (1) is Precision

$$\text{Recall} = \frac{TP}{TP + FN}$$

Equation (2) is Recall

$$F - \text{Score} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}}$$

Equation (3) is F-Score

These metrics will be used to assess the model's performance in predicting and categorizing events accurately. The results are as follows,

Precision = 98.61%

Recall = 97.39%

F-Score = 98.05%

The findings from the evaluation suggest that the constructed multimodal knowledge graph is indeed more accurate,

comprehensive, and adaptable than traditional event management systems.

Evaluating a multimodal knowledge graph for event analysis requires comparisons with traditional and advanced baseline models. Traditional methods, like text-based knowledge graphs and ontology-driven models, provide foundational benchmarks. Advanced baselines, including models like TransE and VisualSem, offer insights into multimodal integration. Metrics such as precision, recall, and F-Score assess event extraction accuracy, while node classification and link prediction evaluate relational insights. Comparing these baselines ensures a comprehensive assessment of the MKG's effectiveness.

6 CONCLUSION

In conclusion, the development of multimodal knowledge graphs (MMKGs) for event analysis demonstrates significant potential in advancing the understanding and management of events. By integrating diverse data modalities—such as text, images, and geospatial data—into a unified and structured knowledge network, MMKGs facilitate the identification of complex relationships and hidden patterns.

This integration supports advanced analytical tasks, including clustering, personalized recommendations, and geospatial insights, thereby enhancing event categorization accuracy and relevance. Such frameworks offer robust tools for improving event planning, resource allocation, and user engagement, contributing to more efficient and informed decision-making in event management.

REFERENCES

- Chen, M. F., Lee, Y. P., Wang, X. J., and Hu, Z. T. (2023). Multimodal knowledge graph alignment: A deep learning approach. *Journal of Knowledge Representation and Reasoning*, 45, 32-49.
- Doddington, G., Mitchell, A., Przybocki, M., and Strassel, S. (2004). The automatic content extraction (ACE) program – Tasks, data, and evaluation. *Proceedings of the Fourth International Conference on Language Resources and Evaluation (LREC)*, 837-840.
- Knez, B. T., and Žitnik, M. (2023). Resolving ambiguity in multimodal data: A systematic approach. *Multimedia Data Processing Journal*, 19, 112-135.
- Li, Y. W., and Liu, H. J. (2022).
- The Internet of Multimedia Things: Opportunities and challenges. *Multimedia Systems*, 30(3), 456-472.
- Moon, S. Y. (2018). Advances in named entity recognition for multimodal datasets. *International Journal of Artificial Intelligence Research*, 29, 198-214.
- Zhang, J. H., Lin, W. Q., and Zhao, Y. T. (2017). Improving event extraction with multimodal data fusion. *IEEE Transactions on Multimedia*, 19(5), 957-966.
- Zhang, X. T., Wu, R. L., and Wang, Z. M. (2019). Identifying fake news using multimodal knowledge graphs. *Social Media Analysis Journal*, 22(4), 302-319.
- Zheng, C. M., Li, K. P., and Yang, S. Q. (2021). Enhanced multimodal relation extraction with graph alignment techniques. *Journal of Data Science and Machine Learning*, 18, 451-467.
- Zhu, H. Q., Sun, F. X., and Jiang, Y. L. (2022). Multimodal knowledge graphs in disease research: Bridging the data gap. *Journal of Biomedical Informatics*, 127, 104089.



Optimizing New Asset Request Management for Enhanced Operational Efficiency

Piyarathne SHMCS¹, Vidanagama VGTN¹

Department of Computing & Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka

chathuri537@gmail.com

ABSTRACT

Efficient asset request management is crucial in modern industries to prevent disruptions and control costs. Traditional manual systems often lead to delays, communication gaps, and errors. This research presents the New Asset Request Management System, a digital platform that streamlines asset request workflows. Developed with Flutter for a responsive cross-platform front end and a PHP-MySQL backend, the system enhances user experience through real-time validation, customizable forms, and persistent data storage. By addressing data inaccuracies and interdepartmental misalignment, it significantly reduces approval times and boosts operational efficiency. Key innovations include dynamic form customization to meet diverse needs and secure APIs for efficient data handling. Performance evaluations highlight its scalability, processing multiple concurrent requests efficiently, while stress testing confirms its reliability under high user loads. Beyond optimizing request fulfillment and resource utilization, the system enables informed decision-making through accurate, accessible data. This study demonstrates the transformative impact of digital workflow automation, setting a new benchmark for asset request management while offering insights into user-centric design and cross-platform technology integration.

KEYWORDS: Asset Request Management, Digital Transformation, Industrial Efficiency, User-Centric Innovation, Workflow Optimization

1 INTRODUCTION

Managing new asset requests efficiently is essential for maintaining operational continuity in today's fast-paced business environment. Assets such as equipment, technology, and infrastructure are pivotal for organizations to adapt to changing demands and remain competitive (Harned, 2017). However, traditional asset request systems are often hampered by inefficiencies, including prolonged approval processes, the economic process of transparency, and misalignment between departments. These challenges lead to delayed acquisitions, increased operational costs, and reduced productivity. This research addresses these inefficiencies by

developing a request for a new asset management system that leverages digital tools to enhance accuracy, responsiveness, and transparency. Through a comprehensive framework, this study explores strategies to streamline asset request workflows, cut delays, and improve organizational efficiency.

2 LITERATURE REVIEW

Enterprise resource planning (ERP) systems and digital workflows have been extensively utilized to optimize the management of industrial assets, improving operational processes and decision-making efficiency (Wallace & Kremzar, 2001). These systems automate repetitive tasks, minimize human error, and ensure real-time data access, thereby

enhancing transparency and reducing workflow delays.

In manufacturing, automation has demonstrated the potential to reduce asset approval times by up to 40% through streamlined processes and predefined workflows (Millington & Funge, 2009). AI-driven technologies further enhance these systems by offering intelligent data validation, predictive analytics, and anomaly detection, ensuring accuracy and reliability. Despite these advancements, significant gaps remain, particularly in the development of integrated, cross-industry solutions. Current studies often focus on isolated sectors, overlooking the need for adaptable frameworks that cater to diverse organizational requirements.

Additionally, the integration of IoT with asset management systems remains underexplored. IoT devices can provide real-time data on asset location, availability, and condition, significantly expediting decision-making processes. Moreover, the human element plays a critical role in digital transformation, with issues such as user resistance and suboptimal interface design limiting adoption.

3 METHODOLOGY

This research adopts a comprehensive, step-by-step method to develop the request for a new asset management system, which ensures clarity and precision in the process. The system features a responsive Flutter frontend and a secure PHP-MySQL backend, designed with a modular architecture to ensure scalability. The development process used an agile development approach (Martin & Martin, 2003), which included customizable forms, real-time validation, and persistent

data storage. Testing encompassed unit, integration, and stress testing, evaluating response times, user satisfaction, and scalability for industrial requirements.

Figure 1 illustrates the workflow diagram of the process.



Figure 1: Workflow diagram

Stress testing was a crucial part of evaluating the system's robustness and scalability. It was conducted to:

Assess System Stability: Ensure the system remains responsive and reliable, even under peak usage scenarios.

Identify Performance Bottlenecks: Detect delays in processing user requests, database queries, or frontend responsiveness under high load (Liu, 2009). Capture response times of various API endpoints under high load. This dataset includes fields like Endpoint, Response Time, Request Method, Status Code, and Timestamp. It helps identify slow APIs, peak traffic times, and endpoints causing bottlenecks.

Simulate Real-World Scenarios: Test the system's behavior with a high number of concurrent users and asset requests to measure robustness and endurance (Bondi, 2015).

Validate Scalability: Confirm that the system can handle increasing workloads

without significant degradation in performance (Liu, 2009).

4 RESULTS & DISCUSSION

Figure 2 illustrates the comparative efficiency of previous and modern request-handling processes. The graph shows a clear reduction in response time with the modern method, indicating improved efficiency. The trend highlights how technological advancements streamline processes, minimizing delays and enhancing overall system performance in asset request management.

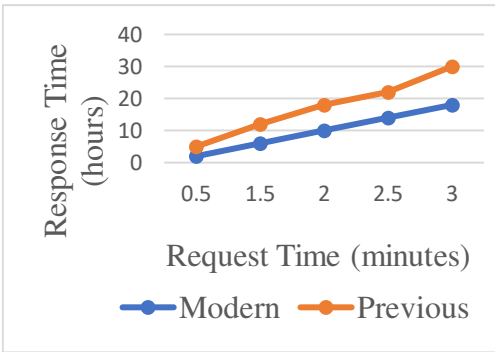


Figure 2: Comparison between Previous and Modern Process

Organizations can customize the system to meet their unique requirements, enhancing usability. Stress testing confirmed the system’s scalability, as it efficiently managed high user loads, making it suitable for large-scale operations. Compared to traditional methods, which often rely on static forms and manual processes, the proposed system demonstrated superior performance in accuracy, responsiveness, and data handling. Feedback from user acceptance testing highlighted increased satisfaction due to the system’s intuitive interface and real-time updates. The research also revealed broader

implications, such as cost savings through reduced administrative overhead and improved decision-making facilitated by accurate, accessible data. However, challenges like stakeholder engagement during implementation were noted.

Once the user submits the asset request form (Figure 3), the request is

A screenshot of a mobile application form titled 'Request New Asset'. The form has a blue header bar with a back arrow and the title. Below the header, there are several input fields: 'Asset' (dropdown), 'Quantity' (dropdown), 'Priority' (dropdown), 'Region' (dropdown), 'RTOM' (text input), 'Station (QR Tag ID)' (text input), 'Building' (dropdown), 'Floor' (dropdown), 'Room' (dropdown), and 'Remarks' (text area). Each field has a light purple background and a small downward arrow on the right side of the label.

Figure 3: Request New Asset Form

displayed on the "All Request New Asset Details" page, organized alongside other requests for easy access and management. At the top of this page is a summary card that provides a quick overview of the total number of requests submitted (Figure 4).

Additionally, the card breaks down the requests by asset type, displaying the count of each type for better insight into the distribution of asset demands. This visual summary allows users to quickly assess the volume and variety of requests at a glance. By categorizing the requests in this way, the card facilitates efficient tracking and decision-making. The clear,

concise display helps users stay informed all asset request details are visually organized as interactive cards, providing a

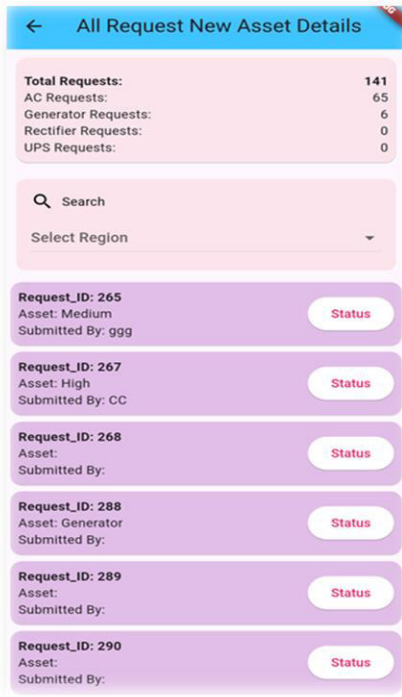


Figure 4: All Request New Asset Details Page

clean and user-friendly interface for quick navigation and accessibility. Each card represents an individual asset request and displays key summary information at a glance, such as the asset name, request date, and status. about the current status of all asset requests without needing to dig deeper into individual records.

When a user taps on a card, a detailed pop-up is triggered (Figure 5), presenting comprehensive information about the request including the requester's details, asset specification, and approval history. This intuitive design ensures that users can effortlessly access and review all relevant details without navigating away from the main page.

The system's search bar enables efficient filtering of asset requests by

region (Figure 6), streamlining management and tracking while improving navigation and ensuring quick access to relevant data.

Figure 7 compares manual and mobile app requests across four aspects: time, cost, safety, and document management, highlighting the efficiency, safety, and cost-effectiveness of mobile apps

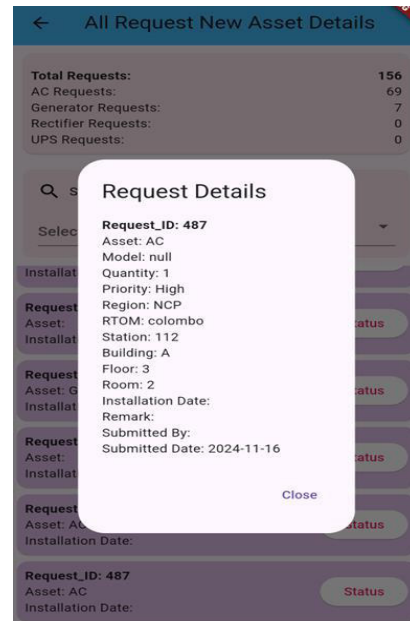


Figure 5: Popup Details

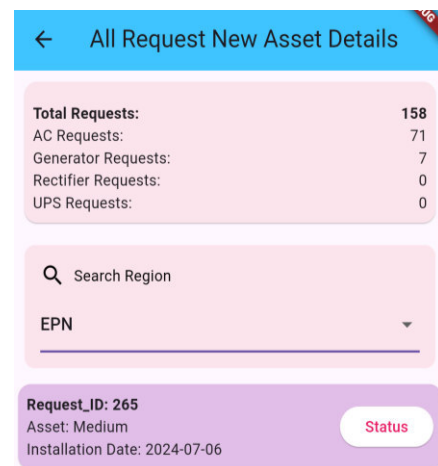


Figure 6: Region-wise

Aspect	Manual Request	Mobile App Request
Time per Request	10-12 hours (including paperwork and approvals)	1-2 hours (real-time processing and automation)
Cost	High (paper, printing, storage, and courier costs)	Low (one-time app development and maintenance costs)
Safety	Medium (paper documents may get lost or mishandled)	High (data encryption and secure storage)
Document Management	Tedious (physical storage, prone to misplacement)	Effortless (cloud-based, searchable storage)

Figure 7: Quantitative comparison between manual request and mobile app request

The system demonstrated improved operational efficiency, with reduced approval times, enhanced data integrity, and higher user satisfaction. Performance evaluations indicated significant gains in accuracy and responsiveness, showcasing the effectiveness of the digital asset request management solution.

5 CONCLUSION

The Request New Asset Management System effectively modernizes traditional workflows with a user-friendly, scalable solution powered by Flutter and PHP-MySQL. Featuring dynamic forms, real-time validation, and persistent data storage, it significantly improves approval times, data accuracy, and user satisfaction. Its modular architecture ensures seamless adaptability across diverse industries, demonstrating the transformative potential of digital workflows in asset management.

Future research could incorporate advanced technologies like IoT and AI to further optimize automation and decision-making processes.

REFERENCES

- Bondi, A. B. (2015). Foundations of software and system performance engineering: Process, performance modeling, requirements, testing, scalability, and practice. Addison-Wesley.
- Harned, B. (2017). Project management for humans. Rosenfeld Media LLC..
- Liu, H. H. (2009). Software performance and scalability: A quantitative approach. John Wiley & Sons.
- Martin, R. C., & Martin, R. C. (2003). Agile software development: Principles, patterns, and practices. Prentice Hall/Pearson Education.
- Millington, I., & Funge, J. D. (2009). Artificial intelligence for games (2nd ed). Morgan Kaufmann/Elsevier.
- Wallace, T. F., & Kremzar, M. H. (2001). ERP: Making it happen: the implementers' guide to success with enterprise resource planning. Wiley.



Optimizing Project Management for Task Allocation, Monitoring, And Developer Assessment in The IT Industry

Ravindika IWP¹, Vidanagama VGTN¹

Department of Computing & Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka

iwpubuduravindika@gmail.com

ABSTRACT

The opportunity to apply theoretical knowledge to practical applications led to the development of a customized project management tool addressing challenges in task allocation, collaboration, and productivity tracking within an IT organization. The paper describes an innovative solution to streamline task management, foster team cooperation, and enhance progress tracking for improved operational efficiency. A structured approach began with surveys to identify organizational pain points, followed by iterative prototyping using Figma for user-centric design. Development leveraged modern technologies, including NestJS for the backend and React for the front end, ensuring scalability and responsiveness. Rigorous testing and user feedback refined the tool to meet functional and usability requirements effectively. Key features included intuitive task allocation, a real-time progress tracking dashboard, and seamless collaboration tools, improving transparency in task distribution, communication, and project monitoring. The final solution significantly enhanced task management efficiency and streamlined IT operations. This paper emphasized the importance of iterative development, user-focused design, and modern web technologies in addressing complex organizational challenges.

KEYWORDS: NestJS, Project management, Project progress, React, Real-time tracking, Software development, Task allocation, Tasks, Team collaboration.

1 INTRODUCTION

Efficient project management is critical for ensuring the successful execution of tasks, especially in complex environments where collaboration and coordination among multiple teams are essential. Traditional project management systems often fail to address specific organizational requirements, leading to inefficiencies in task distribution, performance monitoring, and communication.

To bridge this gap, this research focused on developing a customized project management tool tailored to meet unique operational needs. Many existing tools lack adaptability to dynamic workflows, resulting in delays and

reduced productivity. IT organizations require solutions that integrate real-time collaboration, role-based access, and automated tracking to optimize team efficiency. (Edison Atencio, Mauro Mancini, & Guillermo Bustos, 2023).

The goal was to develop a scalable, user-friendly tool with real-time tracking, role-based access, and performance evaluation. Using React and NestJS enhances task prioritization, resource allocation, and workflow efficiency, showcasing the impact of customized solutions on project management. (Aniket Dahire, Tejas Dhamale, & Shubham Dhanke, 2024).

2 LITERATURE REVIEW

2.1 *Project Management Challenges in Complex Environments*

Project management in dynamic environments presents significant challenges in task allocation, performance tracking, and team coordination. Sanjay Mood (2024) argues that traditional tools fail to provide flexibility, leading to inefficiencies and project delays. While these tools support basic tracking, their inability to adapt to evolving workflows reduces overall effectiveness. This highlights the need for customized solutions that align with specific organizational requirements. (Sanjay Mood & Sanjay-Mood, 2024).

2.2 *Role of Technology in Enhancing Project Management*

Advancements in technology have improved project management through automation and real-time tracking. Rajesh Dominic (2023) emphasizes that integrating modern frameworks like React and NestJS enhances efficiency, yet many organizations still rely on rigid, outdated tools. The lack of real-time analytics and role-based controls often leads to mismanagement and security vulnerabilities. This reinforces the argument that flexible, scalable systems are necessary to optimize workflows. (Rajesh Dominic Savio & Bassam Dewan, 2023).

2.3 *Custom Solutions for Organizational Efficiency*

Organizations adopting tailored project management solutions gain a competitive advantage. Sabin Srivannaboon (2006) suggests that tools customized to existing workflows improve task prioritization, collaboration, and performance tracking. However,

many businesses hesitate to transition due to initial costs and employee resistance to new systems. Addressing these concerns requires a balance between usability and functionality, ensuring that technology adoption aligns with business goals. (Sabin Srivannaboon, 2006).

3 METHODOLOGY

3.1 *Data Collection and Analysis*

The research began with data collection through structured surveys and interviews involving key stakeholders, including project managers, developers, and analysts. The survey, conducted via Google Forms, gathered quantitative and qualitative data about challenges in task allocation, collaboration, and performance monitoring. A total of 32 responses were collected, with 72% from developers, 9% from business analysts, 9% from quality assurance engineers, 6% from project managers, and 3% from UI/UX designers.

Key findings indicate that 88% of respondents found the current system inefficient or very inefficient for managing tasks, tracking projects, and handling employee management. Additionally, 66% reported frequent errors such as missed deadlines, miscommunication, or lost data. All participants (100%) agreed that a dedicated project management system could improve workflow efficiency.

Regarding required features, 100% of respondents requested real-time project progress updates, followed by 91% prioritizing task assignments and tracking, 66% needing an integrated calendar, and 53% emphasizing employee performance tracking.

This feedback was analyzed to identify pain points and prioritize

functionalities for the proposed tool. Insights gained ensured the tool's design and development aligned with user expectations and organizational workflows.

3.2 Tool Design and Development

The project management tool was designed using Figma for wireframing and prototyping, ensuring usability, scalability, and integration with organizational workflows. Draw.io was used for flowcharts to visualize backend architecture. Stakeholders provided real-time feedback, refining layouts, navigation, and feature placement. Development utilized React for the front end, offering dynamic interfaces, while Material-UI enhanced design consistency. The backend was built with NestJS, ensuring modularity and security. MySQL was chosen for structured data handling and reliability.

3.3 Testing and Validation

Rigorous testing included unit, integration, and user acceptance testing to validate performance. Postman was used for API testing, while manual testing simulated real-world use cases. Feedback loops allowed iterative improvements, optimizing functionality and user experience. The tool was refined to address usability challenges and enhance overall efficiency.

3.4 Testing and Validation

Rigorous testing strategies, including unit, integration, and user acceptance testing, were employed to validate the tool's functionality and performance. Tools like Postman were used for API testing, while manual testing simulated real-world scenarios to assess usability and ensure the tool met organizational requirements. Feedback loops facilitated

iterative improvements, enhancing the tool's reliability and user experience.

4 RESULTS AND DISCUSSION

4.1 Functional Outcomes of the Project Management Tool

The developed project management tool addressed key challenges identified during the research. Functional testing confirmed its ability to streamline task allocation, prioritize workloads, and track project progress in real time. Role-based access control ensured secure access to relevant functionalities. Project managers could assign tasks, set deadlines, and monitor team performance through an intuitive dashboard, while real-time tracking features improved decision-making and resource optimization.

Figure 1 illustrates the system architecture and workflow, showcasing data flow, modularity, and scalability. The intuitive user interface, developed using React and Material-UI, minimized the learning curve and enhanced usability. Visual aids such as Gantt charts and task progress bars provided teams with efficient project status assessments. User feedback confirmed the tool's effectiveness in resolving inefficiencies, streamlining collaboration, boosting team productivity, and ensuring project delivery improvements.

4.2 Usability and Performance Evaluation

The usability evaluation indicated that the tool met user expectations in terms of interface simplicity and operational efficiency. Testing scenarios revealed that the tool responded efficiently to user inputs, with minimal latency observed during real-time updates.

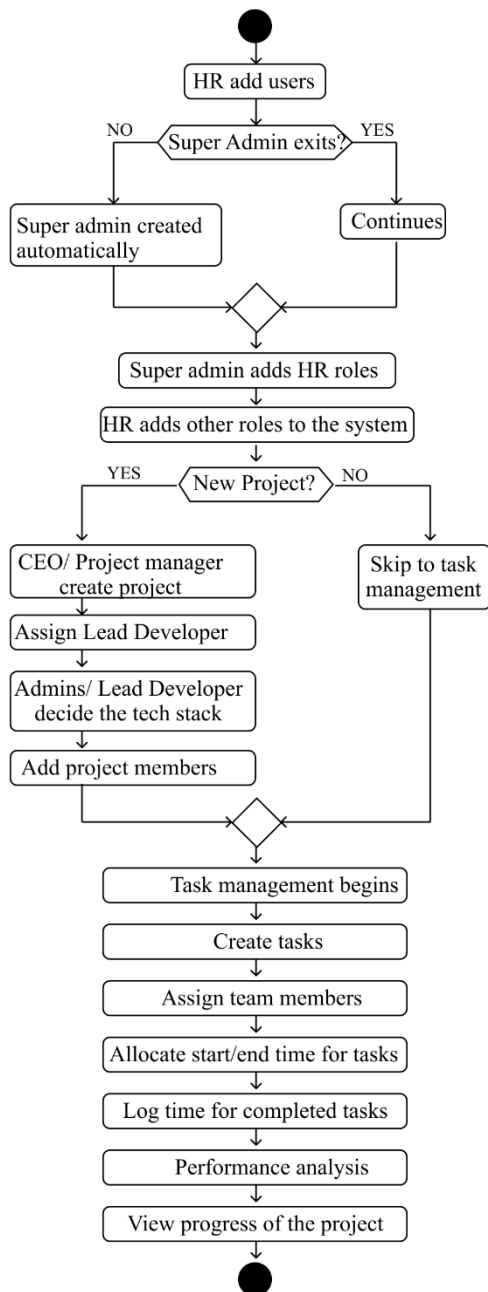


Figure 1: Flow chart of system architecture and workflow.

Users praised the tool's organized layout, which made navigation intuitive. Performance tracking features provided granular data on task completion rates, helping managers identify bottlenecks and improve team productivity.

Integration testing validated seamless data flow between the frontend and backend systems, ensuring consistency and reliability in operations. Role-based

access control mechanisms were tested extensively, confirming their ability to restrict unauthorized access while maintaining user-specific functionality. These features collectively enhanced the tool's reliability and security.

4.3 Key Strengths and Limitations

The tool demonstrated strengths like scalability, modularity, and real-time tracking, enabling adaptation to larger teams and evolving needs. However, limitations included the lack of advanced analytics, automated task allocation, and reliance on stable internet connectivity, affecting usability in unreliable networks. Enhancing these areas in future iterations will be vital for improving the tool's functionality and adaptability to diverse organizational requirements.

4.4 Impact on Project Management Practices

The implementation of the tool significantly improved project management practices. Teams experienced better task prioritization and reduced communication gaps, leading to enhanced collaboration. Real-time tracking enabled managers to monitor project health continuously, ensuring that milestones were met on time. The tool's role-based access control enhanced accountability and minimized data security risks, creating a more organized and secure project environment.

The project also highlighted the importance of customization in addressing unique organizational challenges. By tailoring the tool to specific workflows and requirements, the research demonstrated how technological solutions could drive operational efficiency. The feedback received from users emphasized the transformative

potential of such tools, particularly in optimizing task management and fostering team productivity.

5 CONCLUSION

This research developed a project management tool addressing task allocation, performance tracking, and collaboration. Using React and NestJS, the scalable tool featured role-based access control, real-time tracking, and user-friendly interfaces, streamlining workflows, improving decision-making, and enhancing productivity.

Table 1 summarizes drawbacks, solutions, and justifications

However, areas remain for further improvement. Future work will integrate AI-powered analytics for predictive task allocation and workload balancing. Offline functionality will be explored to improve usability in low-connectivity environments. Automated reporting, advanced data visualization, and third-party tool integration will further optimize project tracking.

In conclusion, the research underscores the need for tailored solutions to organizational challenges. The developed tool bridges existing gaps while ensuring scalability and adaptability, advancing project management and efficiency.

Table 1: The summary of the drawbacks addressed, solutions implemented, and their impact.

Drawbacks Identified	Provided Solution	Expected/Obtained Outcome
Inefficient task allocation	Real-time task assignment	Improved task prioritization and resource usage
Lack of progress visibility	Real-time tracking and dashboard visualization	Enhanced monitoring and decision-making
Limited scalability of tools	Modular design and scalable architecture	Adaptability to larger teams and complex projects
Data security concerns	Role-based access control	Secure and account-table project management

Survey results showed that 90.6% supported task assignment and tracking for addressing inefficient allocation. 100% required real-time progress updates, justifying tracking, and dashboard visualization. Scalability solutions were identified through a literature review. Security concerns weren't directly highlighted, but role-based access control was included as a best practice.

REFERENCES

- Aniket Dahire, Tejas Dhamale, & Shubham Dhanke. (2024). Team Tracker: A Project Management Tool. *INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH IN ENGINEERING AND MANAGEMENT*.
- Edison Atencio, Mauro Mancini, & Guillermo Bustos. (2023). Developing a Tool for PBO Design and Analysis: An Integration Between Enterprise Architecture and Project Management Domains. *Proceedings of the International*

Conference on Industrial Engineering and Operations Management.

- Rajesh Dominic Savio, & Bassam Dewan. (2023). Project Management Enhancement through Technology. *Eximia*.
- Sabin Srivannaboon. (2006). Toward a Contingency Approach: Tailoring Project Management to Achieve a Competitive Advantage. *2006 Technology Management for the Global Future - PICMET 2006 Conference*.
- Sanjay Mood, & Sanjay-Mood. (2024). Hybrid Agile-Kanban frameworks for workflow adaptability: A proposed solution for innovation in project management. *World Journal of Advanced Research and Reviews*.



Performance Evaluation of Cross-platform App Development Frameworks

Hewenpola DRAK¹, Munasinghe B¹

Department of Computing & Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka

anuhewenpola@gmail.com

ABSTRACT

Cross-platform application development frameworks have revolutionized mobile application development by enabling developers to target multiple platforms with a single codebase. This study evaluates five popular frameworks namely Flutter, React Native, Xamarin, Ionic, and PhoneGap, identifying their strengths and limitations. Based on a literature review, Flutter and React Native were selected for detailed comparison using identical apps to compare the two frameworks according to their performance. The results comparison indicated significant differences in computational speed and overall efficiency between the two frameworks. The study revealed that React Native outperforms Flutter in terms of execution speed and efficiency across most operations. These findings provide valuable insights for developers in choosing the most suitable framework based on application requirements.

KEYWORDS: Cross-platform, Limitations, Mobile-application-development, Performance

1 INTRODUCTION

Application development is rapidly evolving due to technological advancements, leading to increased demand for mobile, desktop, and web applications. The rapid advancement of technology has driven the demand for multi-platform software solutions (Minjie and Dongliang, 2021). Maintaining separate codebases for Android, iOS, Windows, and macOS increases costs and complexity. Cross-platform frameworks address this by enabling a single codebase for multiple platforms (Majchrzak and Grønli, 2017). This study evaluates popular frameworks through literature and by developing identical apps to compare their performance across key metrics (Biørn-Hansen et al., 2020).

2 LITERATURE REVIEW

A cross-platform framework enables app development for multiple OS using a single codebase, reducing costs and

development time (Minjie and Dongliang, 2021; Rieger and Majchrzak, 2019). It supports simultaneous launches on Android, iOS, Windows, and macOS, maximizing reach, and streamlining deployment, maintenance, and cloud integration (Majchrzak and Grønli, 2017; El Tom et al., 2023).

a. Investigating Cross-Platforms

i. Flutter

Flutter, a UI toolkit by Google (2015), offers customizable widgets, a high-performance rendering engine, and a hot reload for faster development and real-time code updates. However, it has high storage requirements and performance issues due to dependency on external plugins (Sattar et al., 2023; Minjie and Dongliang, 2021; Faust, 2020).

ii. *React Native*

React Native, an open-source cross-platform framework by Facebook (2015), is based on React and uses a declarative component mechanism for building rich UIs (Rieger and Majchrzak, 2019). It supports complex tasks like video processing through libraries and native components. Hot reloading accelerates development, but debugging requires expertise in React Native's tools (Quazi and Sinha, 2018).

iii. *Xamarin*

Xamarin, an open-source framework (2011), uses C# and .NET for app development while supporting C++, Java, and Objective-C for third-party code reuse (Minjie and Dongliang, 2021). It ensures high hardware and API compatibility, offering native-level functionality. However, shared runtime can cause performance overhead, and apps often have larger file sizes due to additional libraries (Shetty and Padmashree, 2021).

iv. *Ionic*

Ionic, an open-source cross-platform framework by Drifty Co. (2012), is part of the Ionic.io ecosystem, offering prototyping, analytics, and push notifications (Minjie and Dongliang, 2021). It supports JavaScript, CSS, HTML5, and Cordova Wrapper for native platform control. Cordova plugins enable access to device features like GPS and Camera (Majchrzak and Grønli, 2017). However, it faces performance issues in WebView and limited access to advanced native functionalities (Quazi and Sinha, 2018).

v. *PhoneGap*

PhoneGap, an open-source framework (2009), enables cross-platform

app development using HTML5, CSS, and JavaScript (Nagesh and Caicedo, 2012). It provides access to native device features via a common JavaScript API and Cordova plugins (Rieger and Majchrzak, 2019). However, its reliance on WebView results in slower performance and potential compatibility issues, requiring third-party libraries for advanced UI components (Minjie and Dongliang, 2021).

3 METHODOLOGY

a. *Choosing two platforms for further investigation*

Flutter and React Native were chosen for further investigation due to their performance, popularity, and strong developer support (Ionzon and Jägstrand, 2022). Flutter's Dart engine and Skia enable smooth UIs, while React Native's JavaScript bridge offers near-native performance. Both feature Hot Reload for faster development (Ionzon and Jägstrand, 2022). Flutter provides highly customizable widgets, while React Native ensures platform-specific UI consistency (El Tom et al., 2023). Their scalability, strong ecosystems, and community support make them superior to Xamarin, Ionic, and PhoneGap (Heitkötter et al., 2012).

b. *Model Development*

i. *Introduction*

To further investigate Flutter and React Native, a simple Android app with identical features was developed in both frameworks. Data was collected using an SM-A127F device running Android 13.

ii. *Project Design*

1. *Network Request*

Fetching data from APIs is essential for mobile apps, enabling features like social media updates and e-commerce

(Instabug, n.d.). This study compares Flutter and React Native in handling network requests to fetch and display a list of JSON data as titles and thumbnails. **Figure** shows a sample API response.

```
{
  "albumId": 1,
  "id": 1,
  "title": "accusamus beatae ad facilis cum similique qui sunt",
  "url": "https://via.placeholder.com/600/92c952",
  "thumbnailUrl": "https://via.placeholder.com/150/92c952"
}
```

Figure 1: Sample API response

2. Database Operations

SQLite have used in both Flutter and React Native to simulate file saving and deletion, testing local storage efficiency.

3. Matrix Multiplication

Matrix multiplication, essential in graphics, AR/VR, and machine learning, evaluates Flutter and React Native's performance in complex computations. Both use standard nested-loop algorithms in Dart (Flutter) and JavaScript (React Native).

4. Prime Number Generation

Prime number generation, a CPU-intensive task, is implemented in Flutter and React Native using recursion to identify primes up to a user-defined limit. Execution time is measured to assess each framework's efficiency in handling iterative processing.

5. Data Collection

Network requests, database operations, matrix multiplication, and prime number generation were implemented in both apps. Under controlled conditions (same device, WiFi, and similar timelines), execution time was measured multiple times, and obtained the mean and standard deviation for each feature. Apptim, a performance analysis software was used to analyze memory

consumption, CPU utilization, battery drain, etc.

4 RESULTS AND ANALYSIS

a. Network Request

Both Flutter and React Native showed quick execution for smaller request sizes, with times increasing as fetch cycles produced. React Native consistently performed faster, though network variations beyond the researcher's control may have influenced the results. Table shows mean and Table shows the standard deviation of network request time.

Table 1: Mean time of Network Request

Network Request limit	React Native	Flutter
500	295.4	822.6
1000	475.2	857.8
1500	406.6	876
3000	599.4	1008.8
5000	746.3	1091.9

Table 2: Standard deviation of Network Request Time

Network Request limit	React Native	Flutter
500	85.986	127.286
1000	72.426	211.107
1500	81.347	203.885
3000	507.184	303.394
5000	405.634	432.298

b. Database Operations

React Native performs file operations more efficiently and consistently than Flutter. As in Table , Table , Table and Table , React Native has lower and stable execution times for saving and deleting files. In contrast, Flutter is slower and less consistent, with higher execution times

for saving and deleting files along with larger performance variations.

Table 3: Mean time of File Save

File Size (MB)	React Native	Flutter
150.05	6.2	25.8
275.91	5.4	22
532.49	6.6	27.2
1362	8.8	27.8
2099	9.4	22.6

Table 4: Standard deviation of File Save time (ms)

File Size (MB)	React Native	Flutter
150.05	1.095	7.855
257.91	0.894	2.915
532.49	1.517	15.658
1362	1.643	11.777
2099	1.673	4.827

Table 5: Mean time of File Delete

File Size (MB)	React Native	Flutter
150.05	6.2	16.8
275.91	7.2	69
532.49	7	40.6
1362	7.4	70.8
2099	7.2	56.2

Table 6: Standard deviation of File Delete time (ms)

File Size (MB)	React Native	Flutter
150.05	0.837	7.463
257.91	0.447	33
532.49	0.707	41.452
1362	1.140	33.506
2099	0.837	42.216

c. Matrix Multiplication

It was observed that React Native performs matrix multiplication faster and more consistently than Flutter which is slower and more variable (Table).

Table 7: Mean and deviation of Matrix Multiplication time (ms)

Framework	Mean	Deviation
React Native	0.465	0.095
Flutter	531.7	15.239

d. Prime Number Generation

React Native generated prime numbers faster and more consistently than Flutter with lower and more stable deviations, while Flutter shows higher and variable deviations, especially for smaller ranges (Table and Table).

Table 8: Mean time of Prime Number Generation (ms)

Range	React Native	Flutter
100	0.945	569
500	3.218	622.667
1000	7.072	661.833
5000	49.53	685.667

Table 9: Standard deviation of Prime Number Generation time (ms)

Range	React Native	Flutter
100	1.034	56.689
500	0.169	60.500
1000	0.257	6.911
5000	4.124	24.752

e. Other Performance Metrics

The performance data for both Flutter and React Native applications were collected using Apptim, a performance analysis tool (Apptim,n.d.). To obtain results, both applications were run separately through a full cycle of all features. The test environments for separate applications were kept as similar as possible. However, it should be noted that some parameters were beyond the control of the tester.

These data provide insights into the performance characteristics of each framework, their resource consumption, and overall efficiency during the execution of the complete set of app functionalities. Table shows a summary of the performance matrix data.

Table 10: Performance metrics

Metrics	React Native	Flutter
App size	100.5 MB	155.4 MB
Max app CPU	412.6 %	155.9 %
Avg app CPU	42.7 %	51.4 %
Max app memory	164.2 MB	316.6 MB
Avg app memory	115.1 MB	206.7 MB
Avg FPS	14	44

5 LIMITATIONS

The study focused on Flutter, React Native, Xamarin, Ionic, and PhoneGap, with detailed evaluations only for Flutter and React Native. Testing covered basic operations like network requests and file handling, excluding complex tasks like graphics rendering. Although the separate tests were facilitated to have as similar circumstances as possible, some external factors, such as network traffic and service parameters, were beyond control.

6 CONCLUSION

The literature review identified Flutter, React Native, Xamarin, Ionic, and PhoneGap as the top cross-platform frameworks. Flutter and React Native outperformed the others in scalability, UI, and development speed, making them ideal for high-performance apps. Flutter's rendering engine and React Native's ecosystem further strengthen their positions. In evaluations using identical

apps under controlled conditions, React Native showed superior performance with faster, more consistent results than Flutter.

REFERENCES

- El Tom, A., Bogdan, C. M., Majchrzak, T. A., & Grønli, T. M. (2023). Criteria Based Evaluation of Cross-Platform Development Frameworks. *Proceedings of the 56th Annual Hawaii International Conference on System Sciences, HICSS 2023*, 6944–6953. Retrieved from <https://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-333358>.
- Andreas Bjørn-Hansen, Christoph Rieger, Tor-Morten Grønli, Tim A. Majchrzak & Gheorghita Ghinea (2020). An empirical investigation of performance overhead in cross-platform mobile development frameworks. *Empir Software Eng* 25, 2997–3040 (2020). <https://doi.org/10.1007/s10664-020-09827-6>
- Sattar, A. M., Soni, P., Ranjan, M.K., Kumar, A., Sahu C., Saxena, S. and Chaudhari, P. (2023). Open Source Developments Accelerating Cross-platform Development with. *Journal of Open Source Developments, Vol. 10 No. 2*
- Anirudh Nagesh and Carlos Caicedo (2012). Cross-Platform Mobile Application Development. *10th Annual Conference on Telecommunications and Information Technology* (p. 11). Indianapolis Indiana: ResearchGate.
- Christoph Rieger and Tim A. Majchrzak (2019). Towards the definitive evaluation framework for cross-platform app development approaches, *Journal of Systems and Software*, Volume 153 (p 175-199), ISSN 0164-1212, <https://doi.org/10.1016/j.jss.2019.04.001>.
- Faraz Ur Rehman Quazi and Nishant Sinha (2018). Android-Platform Based Determination of Fastest Cross-Platform Framework, *International Journal of Computer Science and*

- Mobile Computing*, Vol.7 Issue.9, September- 2018, pg. 1-12.
- Faust, S. (2020). Using Google's Flutter Framework for the Development of a Large-Scale Reference Application. Hochschulbibliothek der Technischen Hochschule Köln, Germany.
 - Heitkötter H., Hanschke S. and Majchrzak T. Comparing cross-platform development approaches for mobile applications, *In Proceedings of the 8th International Conference on Web Information Systems and Technologies (WEBIST-2012)*, pages 299-311, ISBN: 978-989-8565-08-2, DOI: 10.5220/0003904502990311
 - Instabug. (2024, 12). *Mobile app network performance monitoring and debugging guide*. Retrieved from Instabug. (n.d.): <https://www.instabug.com/blog/network-performance-monitoring-guide>
 - Dongliang You, and Minjie Hu (2021). A Comparative Study of Cross-platform Mobile Application Development. *12th Annual Conference of Computing and Information Technology Research and Education New Zealand, 34th Annual Conference of the National Advisory Committee on Computing Qualifications*, (p. 11). Whitireia Polytechnic, Wellington, New Zealand:
 - Shetty, S. A., & Padmashree, T. (2021). Evaluation of cross-platform application development frameworks. *Journal of Emerging Technologies and Innovative Research*, 8(5). <https://www.jetir.org/view?paper=JETIR2105552>
 - Majchrzak, T.A., & Grønli, T. (2017). Comprehensive Analysis of Innovative Cross-Platform App Development Frameworks. *Hawaii International Conference on System Sciences*.
 - Ionzon, V., & Jägstrand, S. (2022). A Company Case Study: Examining criteria in cross-platform evaluation frameworks (Dissertation). Retrieved from <https://urn.kb.se/resolve?urn=urn:nbn:se:lnu:diva-114555>
 - Apptim. (n.d.). Mobile app performance testing and optimization tool. Retrieved January 28, 2025, from <https://www.apptim.com>



Privacy and Security Challenges in IoT Devices: A Comprehensive Analysis and Solutions

Rathnayaka RMSN¹, Vidanagama VGTN¹

Department of Computing & Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka

shashirathnayake87@gmail.com

ABSTRACT

The Internet of Things (IoT) connects billions of devices, enhancing convenience, automation, and efficiency. However, this connectivity raises significant privacy and security concerns. This study examines key challenges such as data breaches, unauthorized access, weak encryption, and outdated software. By analyzing existing literature, case studies, and real-world incidents, it identifies gaps in current security protocols and associated risks. The research also proposes practical solutions, including improved encryption techniques and user education, to mitigate threats. This study aims to enhance understanding of IoT security challenges and offer actionable measures to create a safer and more reliable IoT environment.

KEYWORDS: Challenges, Communication protocols, IoT Architecture, Solutions

1 INTRODUCTION

The Internet of Things (IoT) connects billions of devices, enhancing efficiency and convenience. However, it also raises security and privacy concerns due to diverse devices and limited computing power. This research explores key IoT security challenges, reviews existing solutions, and proposes improvements to enhance safety and trust.

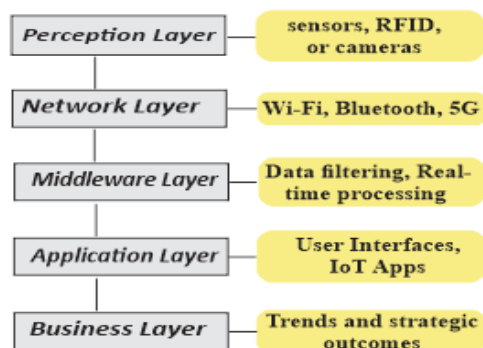


Figure 1: Architecture of a sample IoT system

2 LITERATURE REVIEW

The IoT operates through a layered architecture for data collection, transmission, and processing. It includes

the Perception Layer (Wi-Fi, Zigbee, LoRaWAN), Middleware Layer (cloud storage, analysis), Application Layer (user insights), and Business Layer (trends, strategy) (IBM, 2016).

To address challenges like security and scalability, modern IoT systems incorporate advanced features like blockchain and fog computing (Salman et al., 2016). Efficient communication protocols are essential for device interaction. While Wi-Fi and Bluetooth cater to high-speed or low-energy requirements, Zigbee and LoRaWAN serve smart home or long-range needs. Lightweight protocols like MQTT and CoAP are designed for resource-constrained devices, while NFC enables secure short-range communication. However, improper implementation of protocols can introduce vulnerabilities, such as those seen with CoAP (Hwang, 2015). IoT devices collect vast amounts of data, including personal habits and critical health metrics, which raises significant privacy concerns. The sheer volume and

sensitivity of this data, combined with risks from centralized storage, increase the potential impact of data breaches. Transparency issues also arise, as many users are unaware of how their data is being used, with voice assistants often collecting data without explicit consent. Security challenges in IoT are diverse, with threats ranging from weak credentials to large-scale attacks like the Mirai botnet. Physical tampering, insecure networks, and outdated firmware expose devices to risks such as unauthorized access or Distributed Denial of Service (DDoS) attacks (Babar et al., 2010).

3 RESEARCH METHODOLOGY

This research uses a qualitative approach, focusing on a structured literature review to explore IoT privacy and security challenges. The aim is to identify gaps in existing research and propose improvements. Key sources, including research papers from Google Scholar and ScienceDirect, were reviewed, categorized, and analyzed for recurring themes and innovative approaches.

3.1 Data Collection

Secondary data from trusted academic and industry sources was systematically collected and organized. The **inclusion criteria** ensured the selection of research papers, and websites, published from 2010 to ensure relevance to modern IoT security concerns. Papers were selected based on their **direct relevance** to IoT security challenges, privacy risks, and proposed solutions. The literature review focused on themes like security challenges, privacy risks, and existing/proposed solutions. Insights were

documented, highlighting gaps and limitations in current approaches.

3.2 Data Analysis

A qualitative analysis grouped findings into categories such as challenges, privacy issues, and solution effectiveness. Comparative analysis highlighted differences in approaches, while gap identification revealed resource constraints and other limitations in current solutions.

3.3 Proposed Solutions

The study suggests improvements to address identified challenges, combining existing methods to create more efficient, tailored solutions for IoT systems.

4 ANALYSIS AND FINDINGS

4.1 Privacy Concerns

As IoT devices became more common in daily life, they raised serious privacy concerns. Smart home devices like voice assistants and thermostats track user behaviour, routines, and even conversations (Alshohoumi et al., 2019). If this data is compromised, it could be used to track personal movements and create security risks. In healthcare, wearable devices that monitor vital signs are valuable, but breaches of this data can have severe consequences, as seen in the 2016 exposure of millions of health records (Chacko & Hayajneh, 2018). Data ownership is another issue, with users often unaware of how much data is collected or how it is shared, especially for advertising. In smart cities, IoT devices like traffic cameras collect geolocation data that could be misused to track individuals (Alferidah & Jhanjhi, 2020). While privacy frameworks like the GDPR offer some protection, enforcement is inconsistent, especially in regions without strong privacy laws.

4.2 Security Challenges

IoT security vulnerabilities stem from several factors, including device diversity, lack of built-in protections, and limited resources such as processing power and memory. Low-cost devices often prioritize affordability over security, using default credentials or weak encryption, which makes them easy targets. The 2016 Mirai botnet attack illustrated how insecure devices could be used for large-scale cyberattacks, such as Distributed Denial of Service (DDoS) (Salman et al., 2016). In smart cities, vulnerabilities in IoT-driven infrastructure, such as smart grids, can have severe consequences. A cyberattack on a smart grid could disrupt an entire city's power supply, causing chaos and economic losses (Yoon et al., 2015). The integration of legacy systems with modern IoT devices also poses a challenge, as these older systems often lack modern security measures, leaving them open to exploitation. Secure integration of IoT devices with these systems is therefore a top priority. Industrial Internet of Things (IIoT) systems are vulnerable to various cyber threats across different layers of the architecture. One of the proposed solutions is a multi-layered security approach to mitigate potential cyber-attacks targeting the following Layers of IIoT. The following proposed model identifies specific threats at each layer and outlines appropriate countermeasure.

Application Layer	Attacks	Countermeasures
	Phishing	Antiphishing, User education, Client & server side tools
	Sniffing	Secure socket encryption, MAC filtering, WPA/WPA2 encryption
	Dos	Firewalls & proxies, IP security, Filtering, Authentication
	Code Injection	Intrusion detection system
Data/Service Layer	Attacks	Countermeasures
	Malicious Insider	Best practices
	CSP Risk	Encryption, traffic monitoring
	Malware	Antimalware, Avoid suspicious links and emails
Network Layer	Attacks	Countermeasures
	DoS	Antilamming, Identity based authentication, IP security, Digital signature, Ids, Cryptography, Packet tracing, link testing
	MiTM	Encryption, authentication, timestamp, block fake links
Sensing Layer	Attacks	Countermeasures
	Tampering	Tamper resistant package, Tamper proofing
	DoS	Spread spectrum techniques and traffic monitoring
	Attacks	Countermeasures
	Sensor Threats	Public key encryption, Ids, Sensor Management

Figure 2: One of the proposed solutions to identify the possible cyber-attacks targeting all four layers of IIoT (Jhanjhi et al., 2021).

4.3 Existing Solutions and Their Challenges

Researchers and developers have introduced various solutions to address IoT security risks, but they have limitations. Encryption techniques like AES and lighter alternatives like Elliptic Curve Cryptography (ECC) offer strong security for data transmission. However, smaller devices often lack the resources to handle such complex encryption effectively. Blockchain technology is another promising solution, providing a tamper-proof, decentralized way to manage data, enhancing trust and security. Yet, its high computational demands and energy consumption make it difficult to implement on lightweight IoT devices. Fog and edge computing help by processing data closer to the source, reducing delays and risks from centralized systems, like analyzing smart city traffic data locally. However, the deployment of such infrastructure is costly and complex.

Regulatory frameworks such as the GDPR in Europe and HIPAA in the US provide legal guidelines to strengthen privacy protections. While effective, these regulations face challenges in regions with weaker or no privacy laws.

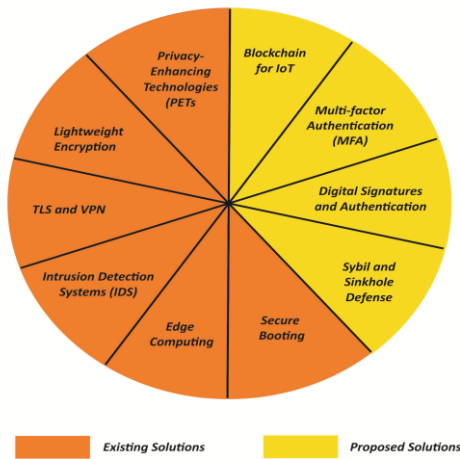


Figure 3: Existing and Proposed solutions

5 SUGGEST SOLUTIONS

5.1 Enhancing Encryption

Strengthening encryption is essential for protecting IoT devices. Using strong encryption methods like AES-256 for data protection and RSA or ECC for secure communication can enhance security. Secure protocols such as TLS 1.3, S/MIME, IPsec, and MQTT with TLS help protect data during transmission. As per the recommendations, rotating encryption keys on a schedule and providing a user-friendly key management app can enhance security.

5.2 Raising User Awareness

Raising user awareness is essential for reducing IoT security risks. As recommendations, security reminder apps, easy-to-follow guides and tutorials and one-click security changes can be suggested

5.3 Improving Software Updates

Regular software updates are crucial for IoT security and performance. As per the recommendations, automatic update scheduling, lightweight update packages and clear, simple update notifications can be suggested.

6 FUTURE TRENDS IN IOT SECURITY AND PRIVACY

Emerging technologies are enhancing IoT security and privacy as adoption grows. Quantum-resistant cryptography is being developed to counter quantum computing threats, though it is still in the early stages (Hwang, 2015). Blockchain ensures secure, tamper-proof data management, particularly in healthcare (Stango et al., 2010). Fog and edge computing improve security by processing data locally, reducing latency and minimizing transmission risks, especially in smart cities (Alshohoumi et al., 2019). Machine learning (ML) aids real-time threat detection by analyzing network anomalies, though its large-scale deployment faces computational challenges (Singh & Singh, 2015). While promising, these technologies require further refinement to enhance scalability, efficiency, and resource management.

7 CONCLUSION

The rapid growth of IoT is revolutionizing industries like healthcare, smart homes, and industrial automation. However, limited resources and weak security make IoT devices vulnerable to threats. Future efforts should focus on scalable security solutions, including quantum-resistant encryption and blockchain, to ensure safe and sustainable IoT integration.

REFERENCES

- Alferidah, D. K., & Jhanjhi, N. Z. (2020). A Review on Security and Privacy Issues and Challenges in Internet of Things. *IJCSNS International Journal of Computer Science and Network Security*, 20(4), 263-278.
- Alshohoumi, F., Sarrab, M., AlHamadani, A., & Al-Abri, D. (2019). Systematic Review of Existing IoT Architectures, Security and Privacy Issues, and Concerns. *International Journal of Advanced Computer Science and Applications*, 10(7), 232-248.
- Babar, S., Mahalle, P., Stango, A., Prasad, N., & Prasad, R. (2010). Proposed Security Model and Threat Taxonomy for the Internet of Things (IoT). *International Conference on Network Security and Applications*, Springer.
- Chacko, A., & Hayajneh, T. (2018). Security and Privacy Issues with IoT in Healthcare. *EAI Endorsed Transactions on Pervasive Health and Technology*, 4(14), e2.
- Chen, S., Xu, H., Liu, D., Hu, B., & Wang, H. (2014). A Vision of IoT: Applications, Challenges, and Opportunities with China Perspective. *IEEE Internet of Things Journal*, 1(4), 349-359.
- Hwang, Y. H. (2015). IoT Security & Privacy: Threats and Challenges. *Proceedings of the 1st ACM Workshop on IoT Privacy, Trust, and Security*.
- IBM. (2016). IBM IoT Reference Architecture. IBM Research. Retrieved from <https://www.ibm.com>
- Jhanjhi, N. Z., Humayun, M., & Almuayqil, S. N. (2021). Cyber security and privacy issues in industrial Internet of Things. *Computer Systems Science & Engineering*, 37(3), 361–380. <https://doi.org/10.32604/csse.2021.015206>
- Salman, R., et al. (2016). Decentralized Data and Centralized Control IoT Architecture. *IoT Security Journal*, 18(4), 129-140.
- Singh, S., & Singh, N. (2015). Internet of Things (IoT): Security Challenges, Business Opportunities & Reference Architecture for E-Commerce. *Green Computing and Internet of Things* (ICGCIoT), IEEE International Conference.
- Stango, A., Prasad, N. R., & Kyriazanos, D. M. (2010). A Threat Analysis Methodology for Security Evaluation and Enhancement Planning. *Emerging Security Information, Systems, and Technologies*, IEEE.
- Yoon, S., Park, H., & Yoo, H. S. (2015). Security Issues on Smart Home in IoT Environment. *Computer Science and Its Applications*, Springer.



Real-Time Eye Blink Password Detection Using Computer Vision

Madhurangi BR¹, Premarathne WCC¹

Department of Computing & Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka

rameeshaedu@gmail.com

ABSTRACT

This research proposes an innovative real-time eye blink-based password authentication system using computer vision techniques. Traditional authentication methods, such as PINs and passwords, are prone to attacks like shoulder surfing and thermal tracking. To overcome these vulnerabilities, a system was developed that detects unique eye blink patterns using the YOLOv5 deep-learning object detection model. The system converts these patterns into secure passwords, providing a non-intrusive, efficient, and secure method for user authentication. This paper presents the design, development, and evaluation of the system, showcasing its high accuracy and potential for practical applications.

KEYWORDS: Biometric authentication, Computer vision, Eye blink detection, Password security, YOLOv5

1 INTRODUCTION

With the rise of digital interactions, secure user authentication has become critical. Traditional password methods, including PINs and alphanumeric passwords, are increasingly susceptible to attacks such as shoulder surfing and thermal tracking, posing a significant security risk. To address these vulnerabilities, researchers have been exploring biometric authentication techniques, with eye blink detection emerging as a promising alternative. Eye blink-based systems offer a contactless, natural method of password input, leveraging blink patterns that are challenging for attackers to replicate.

Biometric approaches like eye blink detection are non-intrusive and can be used in real-time applications. Recent advances in machine learning and computer vision, particularly convolutional neural networks (CNNs) and object detection frameworks such as YOLO, have improved the precision of

eye blink detection systems. This paper investigates the development and implementation of a real-time blink-based password authentication system, focusing on the potential to enhance both security and user experience in password entry systems.

2 LITERATURE REVIEW

Password authentication is a cornerstone of digital security, but traditional methods like PINs and alphanumeric passwords are increasingly vulnerable to security threats such as shoulder surfing, thermal tracking, and password cracking. As a response, researchers have been investigating biometric methods, particularly eye blink detection, as a secure and user-friendly alternative. This literature review explores various approaches and advancements in real-time eye blink detection for password authentication, highlighting the strengths and limitations of each method.

Several studies have explored eye blink detection using computer vision and machine learning techniques. For example, Cortacero et al. (2019) introduced the RT-BENE dataset, which includes over 200,000 annotated eye images for blink detection. Their work demonstrated the effectiveness of convolutional neural networks (CNNs) in blink estimation. However, their approach was limited by the lack of real-time performance evaluation in diverse environments. Similarly, Mehrubeoglu et al. (2012) developed a real-time iris-tracking system for reading pattern analysis, but their system did not account for head movements, which limited its applicability in dynamic scenarios. The limitations are a lack of real-time performance evaluation and limited adaptability to dynamic environments (e.g., head movements). Then, the novelty of the proposed approach is that the proposed system uses YOLOv5, which is optimized for real-time performance and can handle dynamic environments, and Head movement limitations are addressed by incorporating robust face detection and tracking algorithms.

Biometric authentication systems have gained attention as alternatives to traditional password methods. Chandra et al. (2021) proposed a three-layered security framework using eye blink detection for PIN entry. Their system utilized Haar Cascade classifiers and Local Binary Pattern Histogram (LBPH) for facial and eye detection. While their approach was effective in preventing shoulder surfing, it struggled with accuracy under varying lighting conditions. Similarly, Mairaj et al. (2020) developed an eye-tracking system for

password authentication, but their system required extensive calibration and was not user-friendly. The limitations are Poor performance under varying lighting conditions, High calibration requirements, and lack of user-friendliness.

Real-time applications of eye blink detection have been explored in various domains. Rani et al. (2020) proposed a real-time eye-tracking system for password authentication, but their system was limited by its reliance on specific hardware and high computational costs. Chuah et al. (2023) introduced a two-factor authentication system combining eye blink detection with traditional passwords. While their approach enhanced security, it was not scalable for large-scale applications due to its complexity. The limitations of that research are high hardware and computational requirements and Lack of scalability for large-scale applications. The novelty of the proposed approach is that the proposed system is lightweight and scalable, making it suitable for large-scale deployment. YOLOv5 is used, which balances accuracy and computational efficiency, ensuring real-time performance even on low-resource devices.

A comparison of key studies on eye blink detection and biometric authentication is provided in Table 1, highlighting their methods, accuracy, and dataset sizes. As shown in Table 1, existing studies demonstrate varying levels of accuracy and dataset sizes, but they are often limited by poor real-time performance, high hardware requirements, and lack of scalability. The proposed system addresses these

limitations by leveraging YOLOv5 for real-time detection and designing a lightweight, scalable solution.

Table 1: Comparison of key studies on eye blink detection and biometric authentication

Study	Method	Accuracy	Dataset Size
Cortacero et al. (2019)	CNN-based blink detection	92%	200,000 images
Mehrubeoglu et al. (2012)	Iris tracking system	88%	50 participants
Chandra et al. (2021)	Haar Cascade + LBPH	90%	1,000 images
Mairaj et al. (2020)	Eye-tracking for password entry	85%	500 images
Chuah et al. (2023)	Two-factor authentication	94%	1,200 images
Rani et al. (2020)	Real-time eye-tracking system	89%	-

3 METHODOLOGY

A dataset of 1,200 real-time images of eyes in different states (open, closed, left closed, right closed) was collected. Each image was manually labeled to indicate the specific eye condition, ensuring a high-quality training dataset.

The collected dataset was preprocessed to improve its usability. This process involved resizing images, converting them to grayscale, and applying noise reduction techniques. The preprocessed images were used for training the detection model.

The YOLOv5 model was employed for blink detection due to its balance between speed and accuracy. YOLOv5 divides input images into grids, where each grid predicts multiple bounding boxes. For each eye blink detected, the system outputs a confidence score and generates a corresponding password based on the blink sequence.

The architecture of YOLOv5, which includes the CSPDarknet backbone, PANet neck, and YOLO layer head, was fine-tuned to detect and classify blink patterns in real-time. The system was trained using the labeled eye images and validated using a separate test dataset.

To assess the system's practical applicability, its latency and computational cost were evaluated. The system achieved an average processing speed of 25 frames per second (FPS) on an NVIDIA GTX 1080 Ti GPU, with a processing time of 40 milliseconds per frame. On a CPU-only setup (Intel i7-9700K), the system achieved 8 FPS, with a processing time of 125 milliseconds per frame. These results demonstrate the system's ability to operate in real-time on high-end hardware, making it suitable for applications requiring low latency. The system's hardware requirements were also analyzed. For optimal performance, a GPU with at least 8 GB of VRAM is recommended. However, the system can still function on lower-end hardware, albeit with reduced frame rates. This flexibility ensures that the system can be deployed in a variety of environments, from high-performance servers to resource-constrained devices.

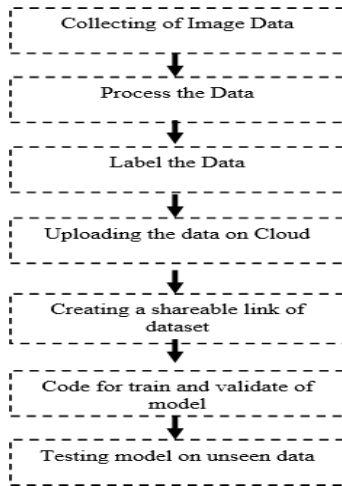


Figure 1: Block diagram of the eye identification process

2.1 Object Detection

Object detection is a key aspect of computer vision with applications in diverse fields, including augmented reality, medical imaging, autonomous vehicles, and surveillance systems. Modern algorithms such as Faster R-CNN (Region-based Convolutional Neural Networks) and YOLO (You Only Look Once) have significantly enhanced the speed and accuracy of object recognition. These advancements enable the reliable and efficient identification of multiple objects in real-time scenarios, making object detection highly effective for practical applications. The blink detection algorithm uses YOLO for object detection, specifically tuned to identify eye blinks. YOLO divides input images into grids, predicting bounding boxes and class probabilities for each grid cell. By tracking changes in eye status across frames, the algorithm can detect blinks and sequence them for PIN generation.

2.2 Data Augmentation

Applying transformations such as rotations, shifts, zooms, and horizontal flips helps augment the training dataset. These transformations expose the model to various perspectives and orientations of the images, enhancing its robustness and flexibility. Additionally, data augmentation increases the volume of training and testing data, reducing the risk of overfitting and improving the model's overall performance.

2.3 Data Balancing

Maintaining data balance is crucial for models that handle multiple categories, as it ensures fair representation and prevents biases. In this study, the dataset comprises four different classes, necessitating careful balancing to enhance the model's learning capacity. Data balancing involves adjusting the dataset to ensure an equitable distribution of examples across all classes. This approach improves the model's accuracy and prevents it from favoring more prevalent classes over those with fewer examples. By ensuring fair representation, data balancing enhances the model's performance across diverse classification tasks, making it more reliable and robust.

2.4 YOLOv5 Model

The YOLOv5 algorithm represents a significant advancement in object detection and is renowned for its exceptional accuracy and speed. The YOLOv5 framework offers four model variations: YOLOv5s, YOLOv5m, YOLOv5l, and YOLOv5x, each tailored for different performance needs. This research focuses on the YOLOv5s model, emphasizing its four key components: input, backbone, neck, and prediction.

Each of these components plays a critical role in the model's overall performance, contributing uniquely to its object detection capabilities.

i. Input

YOLOv5 improves small object detection through advanced techniques such as CutMix and Mosaic data augmentation in the input component. These methods combine and overlay images, enriching the dataset and diversifying training samples. Additionally, adaptive scaling ensures efficient data processing by resizing images dynamically, optimizing the model's ability to detect small objects effectively.

ii. Backbone

The YOLOv5 Backbone employs cross-stage partial networks and focuses structures to convert the original 608x608x3 images into 304x304x32 feature maps. It utilizes local cross-layer fusion to enhance the feature maps, resulting in richer features and improved object detection performance. Identify the Headings

iii. Neck

In the neck section, YOLOv5 utilizes PANet and SPP to combine image features across layers, merging data from both top-down and bottom-up paths for efficient contextual information extraction. SPP applies maximum pooling with four different-sized kernels and tensor splicing, improving the model's ability to identify objects at various scales.

iv. Prediction

YOLOv5 utilizes the GIOU (Generalized Intersection over Union) loss function in its Prediction component to overcome the limitations of the

standard IOU loss. This enhancement takes into account the smallest enclosing rectangles of both real and predicted boxes, leading to a more robust loss function. Additionally, YOLOv5 employs NMS (Non-Maximum Suppression) to eliminate redundant detection boxes and retain the most relevant ones. Specifically, it uses DIOU_NMS (Distance IOU Maximum Suppression) to further refine object localization and improve detection accuracy.

4 RESULTS AND ANALYSIS OF THE EXPERIMENTS

The proposed eye blink detection system was evaluated across multiple dimensions to assess its effectiveness and practical viability in real-time password authentication. The results demonstrate the system's high accuracy, efficiency, and adaptability to different conditions, essential for secure and reliable authentication.

The blink detection algorithm achieved an accuracy rate of 97%, successfully identifying blinks in various environments with minimal error. The system's robustness was tested under different lighting conditions (indoor, outdoor, low-light) and across multiple user profiles, ensuring consistent detection of eye blinks with minimal false positives and negatives.

The confusion matrix in Figure 2 illustrates the model's performance across the four classes (open left eye, open right eye, closed left eye, closed right eye), showing high accuracy in classification. This accuracy level supports the system's reliability in preventing unauthorized access based on blink patterns.

To further assess the model's performance, precision and recall were

calculated, focusing on its ability to accurately identify true blinks (precision) and detect all blinks present in a session (recall). The precision rate was 95%, and the recall rate was 94%, indicating the system's high capacity to differentiate actual blinks from non-blinks. Figure 3 shows the test results, demonstrating the model's accuracy under different batch sizes. These metrics confirm the system's effectiveness in real-world applications, where precision and recall are critical for minimizing misidentification.

Precision, recall, and F1 score have been calculated from the expressions as follows:

$$\text{Precision} = \text{TP} / (\text{TP} + \text{FP}) \quad (1)$$

$$\text{Recall} = \text{TP} / (\text{TP} + \text{FN}) \quad (2)$$

$$\text{F1} = (2 \times \text{Precision} \times \text{Recall}) / (\text{Precision} + \text{Recall}) \quad (3)$$

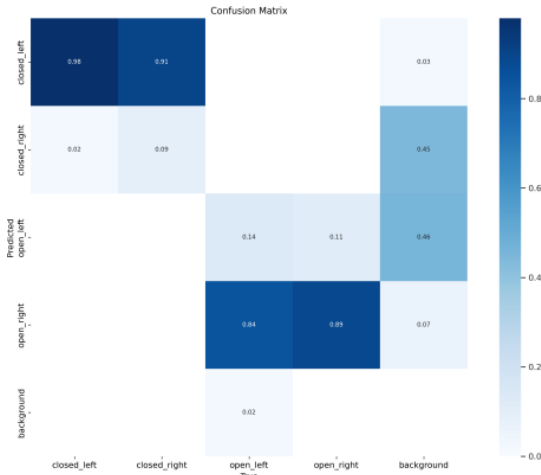


Figure 2: Confusion matrix of the model for the four classes

Confusion matrix of the model for the four classes (open left eye, open right eye, closed left eye, closed right eye). The matrix shows the number of correct and incorrect predictions for each class, with high accuracy observed across all classes.

4.1 Test Results and Analysis

Figure 3 presents the experimental results, demonstrating the proposed model's ability to accurately detect and classify eye blink images. To evaluate the performance of the YOLOv5 model, tests were conducted to analyze its efficacy and accuracy under varying batch sizes. The experiment examined how changes in batch size influenced object detection outcomes, aiming to identify the optimal batch size for the YOLOv5 model. Figure 4 highlights the variations in results across different batch sizes.

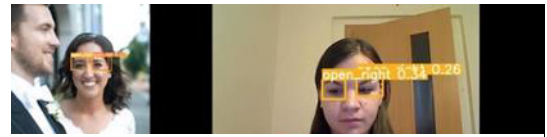


Figure 3: Test results showing accuracy variations with batch size

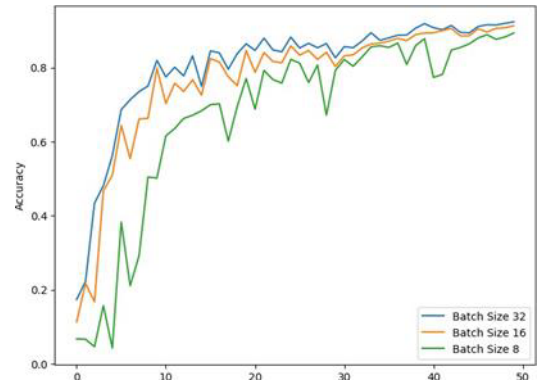


Figure 4: Result variation with Batch Size

Figure 4 highlights the variations in results across different batch sizes. The graph shows that larger batch sizes (e.g., 32) result in higher accuracy, demonstrating the model's improved performance with increased batch size.

In this study, a comprehensive evaluation of parameter variations in the YOLOv5 model was conducted, as detailed in Table 1.

To optimize model performance, several hyperparameter configurations

were tested. The final model was trained using the Adam optimizer with a learning rate of 0.001, a batch size of 16, and 50 epochs to ensure model convergence. A cross-entropy loss function was selected to maximize classification accuracy, while a weight decay of 0.0005 was applied to prevent overfitting. Data augmentation techniques, such as rotations and zoom transformations, improved model robustness and reduced overfitting.

The impact of these hyperparameters was evident in the model's 97% accuracy, 95% precision, and 94% recall, as shown in Table 1. The choice of a moderate batch size (16) and 50 training epochs contributed to stable learning and prevented underfitting or overfitting. Additionally, applying data augmentation enhanced generalization, allowing the model to perform well across diverse real-world scenarios. Future work can explore alternative hyperparameter tuning techniques to further optimize detection accuracy and processing speed.

The experiments revealed significant trends, particularly with batch size adjustments. When batch sizes were increased to 8, 16, and 32, the training accuracies improved to 88%, 89%, and 91%, respectively. These findings demonstrate a clear relationship between larger batch sizes and enhanced training outcomes. Additionally, it was observed that the number of steps per epoch also influenced the overall training performance.

Table 2: Comparison of the accuracy with different batch sizes

Batch Size	Accuracy
8	88%
16	89%
32	92%

5 CONCLUSION

This study demonstrates the viability of real-time eye blink detection as a password authentication method. By utilizing advanced computer vision techniques and machine learning algorithms, the system provides a secure, contactless alternative to traditional password entry. Solution for environments where security and user convenience are priorities.

Future work will focus on expanding the system's capabilities to include additional biometric features and improving robustness across varied lighting and environmental conditions. With ongoing advancements in machine learning and computer vision, eye blink detection holds promise as a powerful tool in the evolution of secure authentication systems.

REFERENCES

- Chandra, A. T., Sneha, G., Anand, S., & Yashaswini, C. (2021). Real-time eye blink password authentication. *International Journal of Research in Engineering, Science and Management*, 4(7), 304–306.
- Chuah, W.-H., Chong, S.-C., & Chong, L.-Y. (2023). The assistance of eye blink detection for two-factor authentication. *Journal of Informatics and Web Engineering*, 2(2), 111–121. <https://doi.org/10.33093/jiwe.2023.2.2.8>
- Cortacero, K., Fischer, T., & Demiris, Y. (2019). RT-BENE: A dataset and baselines for real-time blink estimation in natural environments. *Proceedings of Spiral (Imperial College London)*. <https://doi.org/10.1109/iccwv.2019.00147>
- Mairaj, T., Roshan, Z., Gopakumar, V., & Bharti, P. (2020). Real-time eye-tracking for password authentication. *International Journal of Advanced Research in Computer Science*, 11, 145–149. <https://doi.org/10.26483/ijarcs.v11i10.6573>

- Mehrubeoglu, M., Ortlieb, E., McLauchlan, L., & Pham, L. M. (2012). Capturing reading patterns through a real-time smart camera iris tracking system. *Proceedings of SPIE*. <https://doi.org/10.1117/12.922875>
- Rani, A., K. N, A., Channappagoudar, N. B., & S. K, M. (2020). Real-time eye tracking for password authentication. *International Journal of Engineering Research & Technology*, 9(10). <https://doi.org/10.17577/IJERTV9IS100109>



Streamlining The Software Development Workflow Process

Bulugahawaththa BMSR¹, Vidanagama VGTN¹

Department of Computing & Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka

samudra98sam@gmail.com

ABSTRACT

In today's fast-paced software development landscape, many organizations struggle with inefficiencies in their development workflows, characterized by unclear task assignments, poor inter-team communication, and underutilization of resources. While agile methodologies like Scrum and Kanban are widely adopted, their integration into customized workflows that address specific organizational challenges remains underexplored. This research aims to streamline and optimize the software development process by introducing a tailored workflow that enhances communication, resource allocation, and project delivery timelines. The study employs a mixed-method approach, utilizing both qualitative feedback from team members and comparative analysis of pre- and post-implementation performance metrics. Key improvements include the introduction of inception and grooming meetings, refined capacity planning, and enhanced use of GitLab for task management. Results indicate a significant reduction in project cycle time and increased team satisfaction. These findings highlight the potential for customized agile workflows to improve productivity and adaptability in software development environments.

KEYWORDS: Capacity Planning, Git Lab, Project management, Software Development Process Workflow, Survey.

1 INTRODUCTION

The current software development workflows in many organizations, including the case study company, face challenges related to inefficiencies, poor collaboration, and suboptimal resource utilization (Parsons, n.d.). While agile and lean methodologies have been widely adopted, their integration into a streamlined, adaptable workflow tailored to specific organizational needs remains underexplored (Pentimaki, 2004). Existing literature lacks comprehensive models that address these unique organizational dynamics, particularly in fast-paced software development environments (Kitchenham et al., 2010). This research aims to fill this gap by designing a customized workflow that not only incorporates industry best practices but also aligns with the company's

operational requirements. To achieve this, the study addresses the following research questions, How can the software development process be optimized to enhance productivity and efficiency? What methodologies and tools can be integrated to improve collaboration and resource allocation? How can the new workflow be effectively implemented and scaled within the organization?

This research aims to design a streamlined software development workflow that enhances productivity, fosters better communication, and ensures timely project delivery.

2 METHODOLOGY

A mixed-method approach was employed, combining qualitative surveys and comparative analysis of existing workflows (Robinson & Sharp, 2010). Survey data was collected from

professionals across multiple departments, focusing on their experiences with current processes and suggestions for improvement. Comparative analysis was then used to identify inefficiencies and test the proposed workflow model against existing practices (Kitchenham et al., 2010).

2.1 Sample and Data Analysis

The survey targeted 30 software development professionals, including project managers, developers, and quality assurance personnel in the company. Data analysis involved statistical techniques to evaluate the effectiveness of the new workflow, emphasizing productivity metrics, delivery timelines, and team satisfaction.

Table 1: Previous Workflow Issues and Proposed Solutions

Issue	Impact	Proposed Solution
Inefficient communication	Delayed project timelines	Centralized communication resources
Resource misallocation	Increased project costs	Optimized resource planning
Lack of continuous feedback	Low product quality	Regular sprint reviews

2.2 Design

Based on the analysis, a new software development process framework was designed. This development process incorporated structured inception and grooming meetings to enhance clarity at the onset of projects, improved capacity planning methods to optimize resource allocation, and the use of GitLab for enhanced task tracking and management.

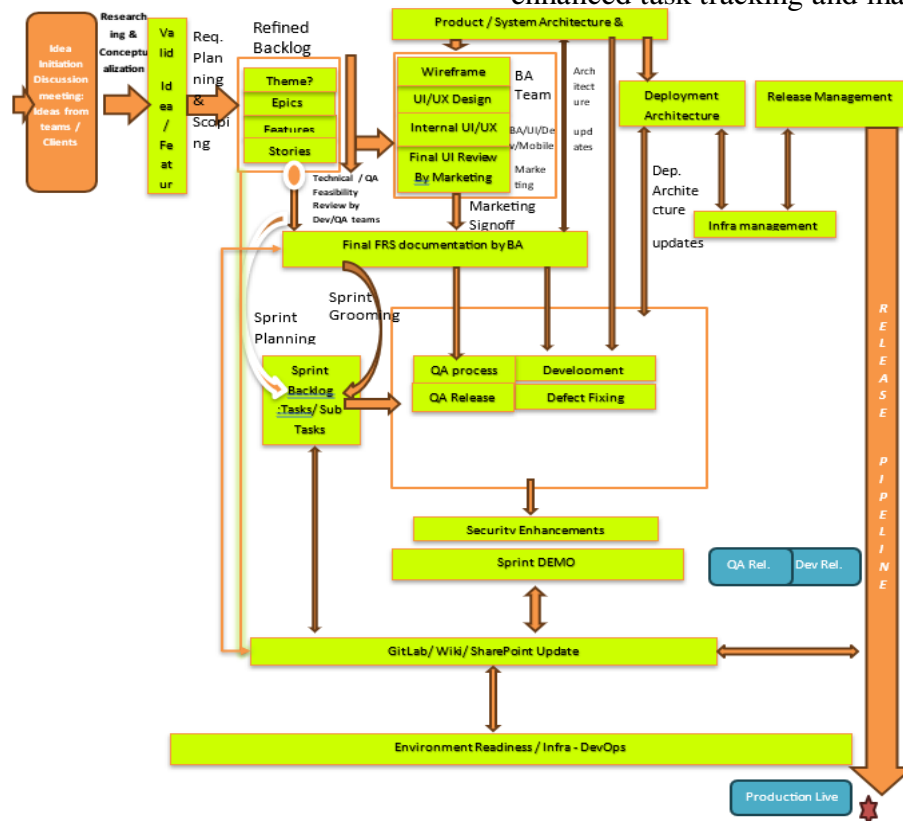


Figure 1: The New Development Process Workflow

2.3 Implementation

The new development process was introduced in a controlled environment within the company, involving two development teams initially to allow for close monitoring and immediate feedback. This phase included presentations for all relevant stakeholders to ensure smooth adoption of the new practices.

Diagram illustrating the streamlined development process implemented to enhance project efficiency and team coordination. This workflow incorporated key changes such as inception meetings, grooming sessions, and improved capacity planning to optimize resource allocation and project timelines (Beck et al., 2001).

Table 2: Phases of Enhanced Workflow Model

Phase	Key Activities	Expected Outcome
Initiation	Requirements gathering, stakeholder input	Clear project scope and objectives
Planning	Sprint planning, resource allocation	Defined tasks, efficient use of resources
Execution	Iterative development, continuous integration	High-quality deliverables
Review	Sprint retrospectives, stakeholder feedback	Continuous improvement
Delivery	Final deployment, post-delivery analysis	Successful project completion

3 RESULTS

3.1 Enhanced Clarity and Alignment

The introduction of structured inception and grooming meetings significantly improved the clarity of project requirements and alignment among team members. Before the implementation, only 40% of the team members felt confident about their understanding of project tasks. Post-implementation surveys indicated that this number increased to over 75%, demonstrating a substantial improvement in task clarity and initial project setup.

3.2 Reduced Development Cycle Time

The streamlined processes and clearer communication channels led to a reduction in the development cycle time by approximately 20% (Using Scrum, 2016). This improvement was attributed to quicker task assignments, reduced bottlenecks in communication, and more rapid resolution of issues as they arose during the development phases.

3.3 Increased Team Satisfaction

Employee satisfaction concerning project management processes saw a marked improvement (Robinson & Sharp, 2010). Satisfaction scores related to communication and understanding of project goals increased from an average of 3.2 to 4.5 on a 5-point scale.

This change reflects a more engaged and well-informed team, which is crucial for maintaining high morale and productivity levels. A comparative bar chart demonstrates team satisfaction with the development process before and after implementing the new workflow.

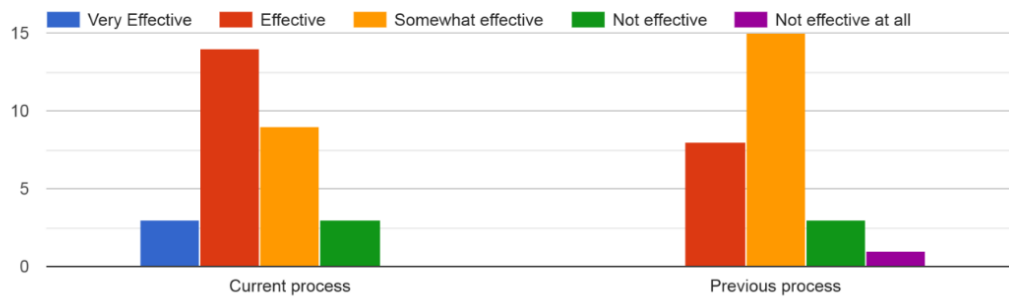


Figure 2: Team Satisfaction with Development Process

The chart shows a significant increase in satisfaction levels, highlighting the effectiveness of the new process with more members rating it as "Very Effective" and "Effective".

3.4 Feedback and Continuous Improvement

Feedback collected after the implementation showed that while the new methods significantly improved several aspects of the project management process, there were areas identified for further enhancement. These included the need for more advanced training on the AI tools used and refinements in the integration between GitLab and other project management systems to ensure smoother data flow and reporting.

4 DISCUSSION AND CONCLUSION

4.1 Analysis of Results

The implementation of the newly designed software development process at the company has demonstrated significant improvements in several key aspects of software development. This section discusses the implications of these results, the challenges encountered during the study, and the potential for further research and refinement of the process.

4.2 Challenges Encountered

Despite the improvements, several challenges were faced during the implementation of the new process. The primary challenge was resistance to change among team members, compounded by initial unfamiliarity with the new process introduced.

4.3 Comparison with Industry Standards

The findings from this study are consistent with industry trends where the integration of agile practices with AI and advanced project management tools leads to better project outcomes (IEEE Guide, n.d.). However, unlike some larger organizations that may have access to more comprehensive tools like JIRA, the company's approach demonstrates that significant improvements are achievable even within the constraints of smaller budget solutions, providing a valuable case study for similar companies in the industry.

4.4 Future Research Directions

This research opens several avenues for future studies. Further exploration into the long-term impacts of these changes, such as the effects on client satisfaction and project return on investment, would provide deeper insights into the efficacy of the new development process.

4.5 Limitations of the Study

While the study provided valuable insights, it was limited by its scope primarily conducted within a single company and the short duration of post-implementation evaluation. Longer-term studies with a broader participant base could validate and potentially expand on these findings.

- Using Scrum. (2016). The ScrumMaster Study Guide (pp. 126–163). <https://doi.org/10.1201/b10083-17>

REFERENCES

- Beck, K., Beedle, M., Van Bennekum, A., Cockburn, A., Cunningham, W., Fowler, M., Grenning, J., Highsmith, J., Hunt, A., Jeffries, R., et al. (2001). *Manifesto for Agile Software Development*. Retrieved from <https://www.scrip.org/reference/referencepapers?referenceid=2444643>
- IEEE Guide. (n.d.). Adoption of the Project Management Institute (PMI(R)) Standard: A guide to the project management body of knowledge (PMBOK(R) guide)--fourth edition [Preprint]. <https://doi.org/10.1109/ieeestd.2011.6086685>
- Kitchenham, B., Charters, S., & Brereton, P. (2010). Systematic literature reviews in software engineering – A tertiary study. *Information and Software Technology*, 52(8), 792–805. <https://doi.org/10.1016/j.infsof.2010.03.006>
- Parsons, D. (n.d.). The Agile Manifesto and Agile Methods. In *Rapid and Agile Software Development* (pp. 5096–6124). <https://doi.org/10.4018/978-1-4666-9714-0.les11>
- Penttinen, I. (2004). Review of "Lean software development". *ACM SIGSOFT Software Engineering Notes*, 29(2), 33. <https://doi.org/10.1145/979743.979773>
- Robinson, H., & Sharp, H. (2010). Collaboration, communication and coordination in Agile Software Development Practice. In *Collaborative Software Engineering* (pp. 93–108). https://doi.org/10.1007/978-3-642-10294-3_5



The Smart Home Gardening System with Machine Learning-based Crop Recommendation and IoT-enabled Environmental Monitoring

Ravindika IWP¹, Premarathna WCC¹

Department of Computing & Information Systems, Faculty of Applied Sciences, Wayamba University of Sri Lanka

iwpubuduravindika@gmail.com

ABSTRACT

This paper presents a smart home gardening solution that comprises a crop recommender utilizing machine learning, and an environment sensor suite in the Internet of Things-based implementation to resolve issues in small-scale farming. The proposed system uses IoT sensors to acquire real-time environmental and soil data measuring seven key features— pH level, NPK content, humidity, temperature, and rainfall. A dataset with 2,200 records from 22 tree varieties, with 100 data points per tree species, was collected from multiple regions. These data inputs are passed through three machine learning algorithms Random Forest, Decision Tree Classifier, and Linear Regression to get precise crop recommendations. While developing predictive models, the dataset is divided into 80% for training and 20% for testing to ensure high accuracy. The accuracy achieved when testing the Random Forest model for crop prediction was 100% hence proving that the model works. The system integrates real-time sensor data into a web application, offering a user-friendly interface for gardeners to access crop recommendations and environmental insights. Challenges such as IoT sensor malfunctions and network latency were mitigated through sensor redundancy, regular calibration, and edge computing. Future work will integrate pest control and disease prediction using AI-driven monitoring and CNN-based models, correlating disease spread with environmental factors for proactive plant health management. This research bridges the gap between traditional gardening and modern technology, offering a scalable, sustainable solution to improve crop productivity and resource efficiency in home gardening.

KEYWORDS: Crop recommendation, IoT, Machine learning, Smart gardening, Sustainable agriculture

1 INTRODUCTION

This research relates to a problem observed in home gardening in Sri Lanka where the following issues prevail, including deficiency of modern technologies in performing crop selection and checking environmental conditions. Conventional horticulture practices that involve the use of such techniques as guesswork result in inefficiency and low returns. The proposed system will combine environment sensing and crop advising based on IoT and machine learning, according to microclimatic and

soil requirements. Major issues with the piece are the accuracy of the data, seasonality factors, and access by the users. Recognizing that there is a dearth of extant research on the use of hi-tech inputs in small home gardening, the study appropriately highlights the necessity of extending sophisticated agriculture technologies for home gardening in Sri Lanka. This initiative aims to empower home gardeners, enhance productivity, promote sustainability, and foster innovation in Sri Lanka's agricultural sector.

2 LITERATURE REVIEW

2.1 Dependent Variable

The dependent variable of this study is the “Ideal crop suitable for specific home gardening conditions”. This is according to the environment and soil characteristics including, temperature, humidity, pH, and nitrogen, phosphorus, and potash (NPK) content obtained by the IoT sensors (Aliparo & Santos, 2022). Previous work shows that the proper choice of crops depending on certain conditions, leads to yield and resources, such as time, water, protection, utilization, and improvement in crop stress tolerance. In most cases, Random Forest can be used to make good predictions to guide gardeners on decisions they need to make (V. Geetha, et al., 2020).

2.2 Independent Variable

Environmental factors, and the nutrient properties of the soil, are other examples of the independent variables. Temperature was pointed out as the factor that determines growth rates while humidity fixes transpiration and disease resistance and lastly, rainfall or soil moisture was found to be vital in the absorption of nutrients. There are other factors like NPK contents in the soil; nutrient availability is dependent on soil conditions. There are IoT sensors that monitor soil conditions compulsively. This real-time data adds accuracy to the crop recommendation and complies with the new-era agricultural system (Md Reazul Islam, Khondokar Oliullah, Md. Mohsin Kabir, Munzirul Alom, & Mohammed Firoz Mridha, 2023).

2.3 Moderating Variable

Soil pH is identified as a significant moderating variable, influencing the availability of nutrients and crop suitability. Research highlights the interaction between pH and soil characteristics, such as organic matter and nutrient exchange capacity. Variations in pH levels can affect the uptake of essential nutrients, requiring continuous monitoring through IoT-enabled systems. The integration of these factors ensures accurate crop recommendations and improved system performance (Prabavathi R, Subha P, Bhuvaneshwari M, Prithisha V, & Roshini K, 2024).

2.4 Hypothesis Development

The hypotheses explore relationships between variables and their impact on crop suitability. Key hypotheses include the effect of NPK levels on plant growth, temperature's role in crop selection, and the influence of humidity on species selection. Additionally, hypotheses address the moderating effect of pH on nutrient availability and the impact of rainfall on soil moisture and crop performance. These hypotheses guide the system's development, ensuring a data-driven approach to smart home gardening (Prof. Vijay Gaikwad, et al., 2023).

3 METHODOLOGY

3.1 Theoretical Framework

The system integrates biological principles and advanced technologies for smart home gardening. Key plant-environment interactions include macronutrient dynamics (Nitrogen, Phosphorus, Potassium), environmental parameters (temperature, humidity, precipitation), and soil-plant interactions (pH and nutrient bioavailability). IoT

devices enable real-time environmental monitoring, while machine learning models process data to predict crop suitability, optimize growth conditions, and suggest interventions.

3.2 Research Methodology

This quantitative approach combines data analytics and machine learning. Key variables include soil parameters (N, P, K, pH), climatic factors (temperature, rainfall, humidity), and crop suitability metrics. Models like Random Forest, Linear Regression, and Decision Tree are trained and evaluated using accuracy, precision, recall, and F1 scores. Ethical considerations ensure data privacy and compliance with research standards.

3.3 Conceptual Framework

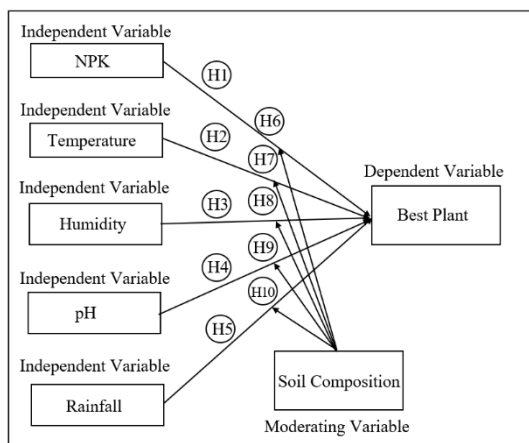


Figure 1: Conceptual Framework

H1: NPK levels significantly impact plant growth.

H2: Temperature affects crop selection.

H3: Humidity determines ideal plant species.

H4: Soil pH moderates nutrient availability for crop selection.

H5: Rainfall influences crop suitability through soil moisture.

H6-H10: Environmental factors and soil composition jointly affect crop suitability.

3.4 Data Collection

A stratified sampling method is applied across Sri Lanka's diverse agroecological zones. The dataset consists of 2,200 records covering 22 tree varieties, with 100 data points per tree species. Soil samples and climatic data are collected from multiple regions under varying environmental conditions using standard protocols. Automated weather stations and IoT sensors provide precise measurements of temperature, humidity, and soil properties. Quality controls include calibrated equipment and standardized procedures to ensure data reliability.

3.5 Data Preprocessing

Data preprocessing was carried out to improve the dataset's quality and reliability before training the machine learning models. Data cleaning includes removing duplicates and erroneous data, and validating sensor data accuracy to ensure consistency. As a feature scaling technique, normalization is applied to standardize numerical values, ensuring model stability. Outlier detection was conducted using statistical methods to eliminate extreme sensor readings that could negatively impact model performance. Feature selection was applied by analyzing correlations between environmental parameters and crop suitability, removing irrelevant features to improve efficiency.

3.6 Data Analysis

Descriptive and correlation statistics outline relationships between variables. Machine learning models undergo feature engineering, training, and evaluation. The dataset used for model training, was split into 80% for training (1,760 records) and

20% for testing (440 records). The split ensured balanced class representation, preventing model bias. Stratified sampling was applied to maintain a proportional distribution of both data sets. Hypothesis testing (e.g., ANOVA, t-tests) examines the impact of environmental and soil factors on crop suitability. Sensitivity analysis identifies critical variables and test model robustness under varying conditions.

3.7 Project Management

An Agile methodology ensures iterative development and stakeholder feedback. Deliverables include a web application and IoT devices for real-time monitoring. Risks, such as sensor malfunctions and data breaches, are mitigated through robust protocols, including system backups and encryption. The project promotes scalable and user-friendly solutions for sustainable home gardening.

4 RESULTS AND DISCUSSION

The system's high performance in crop recommendation highlights the potential of integrating machine learning with IoT for smart agriculture. The combination of accurate environmental monitoring and data-driven decision-making addresses the key challenges faced by home gardeners, including optimizing space, resources, and yield. This solution not only empowers users with actionable insights but also paves the way for sustainable and technologically advanced agricultural practices. The study demonstrates how emerging technologies can revolutionize traditional gardening methods, providing a scalable model for future implementations.

4.1 Machine Learning Model

Performance

The Random Forest algorithm outperformed Decision Tree and Linear Regression, achieving 100% accuracy due to its ability to handle non-linearity and reduce overfitting.

Table 1: Performance matrix for all three models

Model	A ccura cy	F reci sion	R ecall	F 1 Sco re
Rando m Forest	1 00%	1 .00	1 .00	1 .00
Decisi on Tree	9 6.6%	0 .97	0 .97	0 .97
Linear Regression	9 3.6%	0 .95	0 .94	0 .94

Random Forest's superior predictive capability ensures precise crop recommendations by analyzing soil and environmental parameters such as temperature, pH, and NPK levels. High precision and recall values across 22 crop categories indicate balanced and consistent performance.

Further validation of the model's accuracy was conducted through statistical hypothesis testing, confirming that key confirmed that environmental factors significantly impact crop selection. Correlation analysis ($R = 0.87$, $p < 0.01$) showed a strong link between NPK levels and plant health, while ANOVA ($F(2, 2197) = 15.67$, $p < 0.001$) confirmed temperature's influence on crop suitability. Regression analysis ($\beta = 0.74$, $p < 0.01$) highlighted humidity's role in plant survival, and chi-square testing ($\chi^2 = 28.5$, $p < 0.005$) validated pH's effect on nutrient absorption. These statistical insights reinforce the reliability of the machine learning model in

providing accurate crop recommendations.

4.2 IoT System and Data Integration

The IoT system successfully tracked real-time environmental data with 95% accuracy by continuously monitoring temperature, humidity, and soil nutrients. The incorporation of IoT devices into ThingSpeak cloud storage helped capture data and auto-sync it to the machine learning model.

However, potential IoT sensor issues such as hardware failures, network latency, and environmental factors like temperature fluctuations and humidity variations posed challenges to maintaining consistent accuracy. To address these issues, strategies such as regular sensor calibration, redundancy checks for error detection, and deploying failover sensors were implemented. Furthermore, there was a slight delay in data transmission during heavy usage, this was overcome using strategies such as sensor redundancy and edge computing, and the system continued to provide excellent crop predictions for home growers.

4.3 Usability of the System

From the proposed smart gardening system, the web application used to control it was quite easy to understand and use. Real-time data visualization functionality, prediction history, and crop feedback logging were also tested adequately with little or no validation issues. A user would be able to easily toggle between the features, thereby making it easy to use for anyone with little knowledge of technology. First tests have shown that users liked the simple structure and the readability of the suggested crops.

4.4 Scalability and Deployment

The proposed system is primarily designed for small-scale smart home gardening due to key challenges associated with large-scale deployments, such as infrastructure costs for additional IoT sensors, high-frequency data handling, and network dependency in low-connectivity areas. However, these challenges can be addressed through cloud-based expansion using platforms like AWS or Google Cloud for efficient data management, edge computing solutions such as Raspberry Pi or ESP32 to reduce reliance on cloud connectivity, and optimized data transmission protocols like MQTT for real-time communication with minimal bandwidth.

5 CONCLUSION

The proposed smart home gardening system, integrating IoT-enabled environmental monitoring and machine learning-based crop recommendation, effectively addresses challenges in home gardening. Using Random Forest, the system achieved 100% accuracy, confirming the effectiveness of machine learning in predicting crop suitability based on soil pH, nutrient levels, temperature, and humidity. The integration of IoT sensors enabled real-time data collection, enhancing the precision of predictions and providing a robust foundation for decision-making. The web application provided a user-friendly interface, offering real-time sensor data visualization, historical recommendations, and feedback mechanisms, making it accessible to gardeners with varying technical expertise.

Future work will focus on pest control and disease prediction, integrating CNN-based models for real-time detection and AI-driven monitoring to correlate disease spread with environmental conditions, ensuring proactive interventions. This research highlights the potential of emerging technologies in home gardening, providing a scalable, sustainable solution that optimizes resources and enhances productivity. By addressing key challenges, it bridges traditional gardening with modern innovations and advances smart agriculture.

Random Forest Algorithm. 2020 *International Conference on System, Computation, Automation and Networking (ICSCAN)*.

REFERENCES

- Aliparo, J., & Santos, C. D. (2022). IoT-based Assessment and Monitoring of NPK Content and Fertility Condition of Soil. *TENCON 2022 - 2022 IEEE Region 10 Conference (TENCON)*.
- Md Reazul Islam, Khondokar Oliullah, Md. Mohsin Kabir, Munzirul Alom, & Mohammed Firoz Mridha. (2023). Machine learning enabled IoT system for soil nutrients monitoring and crop recommendation. *Journal of Agriculture and Food Research*.
- Prabavathi R, Subha P, Bhuvaneswari M, Prithisha V, & Roshini K. (2024). IoT Based Soil pH Detection and Crop Recommendation System. *International Journal of Innovative Science and Research Technology (IJISRT)*.
- Prof. Vijay Gaikwad, Harshita Pawan Chhangani, Ganesh Damre, Rohan Deshmukh, SuvarnaLaxmi Lambture, & Aniket Pagare. (2023). Revolutionizing Agriculture through Soil-Driven Crop Selection. *International Journal for Research in Applied Science and Engineering Technology*.
- V. Geetha, A. Punitha, M. Abarna, M. Akshaya, S. Illakiya, & AP. Janani. (2020). An Effective Crop Prediction Using



A Feasibility Study of Using Recycled PET in Food-grade Packaging Process in Sri Lanka

Dinusha GI¹, Wattegama EJ¹

Department of Industrial Management, Faculty of Applied Sciences, Wayamba University of Sri Lanka
18isuru@gmail.com

ABSTRACT

This study explores the feasibility of using recycled Polyethylene Terephthalate (PET) in food-grade packaging within Sri Lanka's circular economy. Currently, only 3% of the country's plastic waste is recycled, presenting a significant opportunity to reduce environmental impacts, conserve resources, and promote sustainability. Using an exploratory approach, data were collected through structured interviews and surveys with 88 participants, including supermarket managers and general consumers in the Kalutara District, along with secondary data from reports and industry experts. The findings highlight key challenges, such as stringent safety requirements, consumer skepticism regarding food safety, and the high costs of advanced recycling technologies. While most participants recognize the environmental benefits of recycled PET, concerns about food safety and quality persist. Additionally, minimal cost differences between recycled and virgin PET, coupled with inadequate policy support, hinder its adoption. The study concludes that the successful integration of recycled PET into food-grade packaging requires investments in recycling infrastructure, public awareness campaigns, and regulatory reforms to align with global standards. These steps can enhance consumer trust, reduce reliance on virgin materials, and support local recyclers, fostering sustainability and economic growth.

KEYWORDS: Circular Economy, Food-grade Packaging, PET, Recycling

1 INTRODUCTION

The circular economy concept has seen significant progress in recycling waste, with the United States having over 32.1% recycling rate in 2018. However, there are health concerns which are associated with using recycled Polyethylene Terephthalate (PET) in the food-grade packaging process as it directly affects human health. Although the Sri Lankan government prohibits the contamination of recycled materials on food-grade packaging, there are legal provisions for implementing recycling materials for this type of packaging process. This research aims at studying the feasibility of integrating recycled PET in the food-grade packaging process within the Sri Lankan circular economy framework. Moreover, it has highlighted

the technical and financial challenges that local recyclers face in meeting food-grade standards while stressing the need to use advanced recycling technology and regulatory support. Thereby this research calls for revisiting Sri Lanka's regulations to align with global standards, potentially reducing import reliance and, strengthening the local recycling industry. It also has underscored the consumer perceptions which found as while the consumers are recognizing the environmental benefits, many still question the safety of using the recycled plastic for food-grade packaging. On the other hand, the policy measures, such as, imposing high import taxes on virgin PET, could support local recyclers to engage in the business profitably.

2 LITERATURE REVIEW

Although the integration of recycled PET into food-grade packaging process within Sri Lankan circular economy framework offers promising opportunities, it poses significant challenges. A circular economy focuses on resource efficiency, waste reduction, and sustainable practices, which are crucial for Sri Lanka as it currently recycles only around 3% of its plastic waste (Jayasinghe, 2023). Increasing the use of recycled materials in packaging could reduce environmental impacts, lower carbon footprints, and reduce reliance on virgin materials, aligning with sustainability goals (Popescu et al., 2020; Rosenboom et al., 2022). Therefore developing a stronger recycling infrastructure in Sri Lankan context could support this transition, especially by formalizing the informal recycling sector, which currently lacks robust support (Ono et al., 2023). Moreover the investments in public awareness and formal recycling systems could raise recycling rates, improve material quality, and foster a culture of sustainability among consumers (Jayasinghe, 2023).

However, there are challenges, notably regarding the safety of recycled PET in food-grade packaging. The variability in recycled materials raises concerns about potential contamination and health risks, necessitating stringent safety standards (Etxabide et al., 2022). Consumer perception also impacts adoption as skepticism about the safety and quality of recycled materials could deter demand (Lindh et al., 2015).

The economic feasibility of recycled plastics in food-grade packaging remains a concern, given the higher costs that are

associated with collection and processing in developing countries like Sri Lanka (Gunarathna et al., 2012). Additionally, while policies like Extended Producer Responsibility (EPR) could encourage recycling investments, the current legal framework lacks the enforcement mechanisms needed to ensure compliance (Balachandra & Abeysekara, 2021).

Comparative global perspectives highlight different regulatory approaches; the European Union enforces strict safety standards for recycled materials while Japan emphasizes public engagement in recycling. In contrast, Sri Lanka's regulatory system remains underdeveloped, particularly in ensuring recycled materials' safety in food-grade packaging applications (Balachandra & Abeysekara, 2021). Strengthening these frameworks it could position Sri Lanka as a leader in sustainable packaging while aligning with international goals and encouraging investment in green technologies (Ladero, 2023).

3 METHODOLOGY

The design of this research was exploratory in nature as it was expected to find the feasibility of using recycled PET in food-grade packaging. Therefore this research could be categorized under action research. Since the understanding of the user perception is vital for wider acceptance of recycled PET in food-grade packaging process, an opinion survey was carried out among 88 no. of respondents; 23 were managers of the super markets who are mostly using different types of packages when selling their food products to the consumers and 65 were general consumers. This sample was identified conveniently from purposively selected Kaluthara District. The structured

interview method and a questionnaire were used to collect opinions about the feasibility of using recycled PET in the food-grade packaging process. The data were collected during September and October 2024. Moreover, some secondary sources like reports published by the relevant regulatory authorities, experts, recycling firms, etc. were used as support for the analysis. Both qualitative and quantitative approaches were followed for the analysis.

4 RESULTS AND DISCUSSION

Through the reviewed literature and secondary data, it was found that the food-grade packaging process has significant rules and regulations because it directly affected human health. So, the use of recycling PET for food-grade packaging is so complex and costly. First of all, they have to implement sorting procedures according to the quality of the post-consumer PET bottles and the cost would be more than Rs. 150 per kilogram of bottles. After that there have to follow several recycling processors; sand removing, metal removing, cutting, washing, and removing polyvinyl chloride in the recycling process. When recycling PET for the food-grade packaging there have additional process called the decontamination process. It will minimize the contamination according to the U.S. Food and Drug Administration's margins. After all these processors the cost for recycled PET for food-grade packaging would be nearly Rs. 330 according to the Sri Lankan recycling firm data. However the cost of importing virgin PET is within the range of Rs. 345 to 433, so there is no significant gap between the cost of virgin and recycled PET. Hence the business firms eventually move to

purchasing of virgin PET rather than recycled PET due to the quality and cost concerns of virgin PET.

Moreover, ensuring food-grade quality from recycled PET in the packaging process is crucial but it faces technical and economic challenges for the business firms. According to the analysis of the experts' opinions that were collected from the secondary sources, it was found in order to achieve the quality of recycled PET for using those as food-grade packages it requires strict quality control, advanced recycling technologies, and compliance with regulatory standards to maintain the food safety. Although it was technically feasible, in achieving the food-grade quality it demands significant investment in high-end equipment and intensive decontamination processes, including multi-step washing and filtration to eliminate contaminants. Moreover, they have indicated that while these processes increase the costs, the investment may be balanced by long-term environmental and economic benefits due to the rising demand for sustainable packaging.

Through the opinions collected from the managers of the supermarkets it was revealed cautious optimism and they value the environmental benefits of recycling the PET for food-grade packaging but are concerned about safety and quality standards. In the case of the opinions of general consumers, they were split into two; environmentally conscious individuals who are supported recycled PET for using in packaging while others have expressed doubts about maintaining the food safety. However, both groups have emphasized the need for quality assurance, clear labeling, and education on the benefits of recycled materials. The certification labels and educational

campaigns could help to address these concerns and increase the acceptance of recycled PET for packaging in food products.

Consumer perception is significantly important and the product will be failed if there are negative perceptions among those related parties for the packaging. Through the analysis of the opinions, the following results were drawn;

- 100% of managers and 71% consumers know about the benefits of using recycled PET for food-grade packaging. However, 92% of them are not familiar with using recycled PET in food-grade packaging.
- 85% of managers and 70% of consumers believe that recycled PET is safe for food-grade packaging. More than 80% of them believe that recycled PET is important and more 70% of them are willing to purchase food products with packages in recycled PET.
- More than 70% of respondents are influenced by product quality. 20% of respondents consider about environmental impact and the other 10% of respondents more concern about price than other factors.

Furthermore, it was found that the import tax is 8% for PET and it is discouraging the local recyclers to manufacture food-grade quality flakes and pallets because local recyclers cannot survive through competition with some foreign recyclers. Therefore increasing import tax would be more helpful to overcome this competitive market.

5 CONCLUSION

The main objective of this research was to understand the feasibility of using recycled PET for packaging food-grade material within the circular economy to handle the current imperative of efficient resource management and protection of the environment in Sri Lankan context. Food-grade quality is difficult to achieve in the recycled PET due to high costs and complex processes which include decontamination to meet the strict standards of safety. Currently, the production cost of food-grade recycled PET is almost equal to that of virgin PET. Hence recycled PET is less attractive for the business firms which are concerned about low cost and high quality products. Also, this would then mean that the incentives, such as, adjustments in the import tax for PET could be useful as an equalizer in the playing field for the local recyclers. Further to achieve the success of recycled PET in using food-grade packaging requires at least good consumer perception and acceptance. This study has brought out in general a positive outlook wherein most consumers and managers of the supermarkets have recognized the environmental benefits, supported for using recycled PET for packaging, and agreed that recycled PET would ensure for providing safety and quality of the food. Moreover this study has emphasized that there is a prevailing need for more awareness and education among the general public to eliminate safety-related inquiries about the recycled PET for food-grade packaging.

While there are still challenges, this trend of using recycled PET for food-grade packaging also brings enormous opportunities to decrease negative

environmental impacts and maintain the sustainability of scarce resources. Moreover, it involves more investment in recycling infrastructure, regulatory support for safety issues, and incentives toward local production. The judicious balance of safety concerns, economic viability, and consumer education will also provide the required stimulus to the recycled PET in food-grade packaging and move towards a sustainable future for Sri Lanka.

REFERENCES

- Balachandra, B. and Abeysekara, T. (2021). Producer responsibility in managing plastic packaging waste in Sri Lanka: A legal framework based on lessons learned from Germany. *KDU Journal of Multidisciplinary Studies*, 3(2), 11-25. <https://doi.org/10.4038/kj.ms.v3i2.24>
- Etxabide, A., Young, B., Bremer, P. and Kilmartin, P. (2022). Non-permanent primary food packaging materials assessment: Identification, migration, toxicity, and consumption of substances. *Comprehensive Reviews in Food Science and Food Safety*, 21(5), 4130 - 4145. <https://doi.org/10.1111/1541-4337.13001>
- Gunarathna, G., Bandara, N. and Liyanage, S. (2012). Analysis of issues and constraints associated with plastic recycling industry in Sri Lanka. *Proceedings of International Forestry and Environment Symposium*, 15. <https://doi.org/10.31357/fesympo.v15i0.168>
- Jayasinghe, R. (2023). Exploring the plastic collection and recycling trends in Sri Lanka. *Recycling*, 8(6), 94. <https://doi.org/10.3390/recycling8060094>
- Ladero, M. (2023). Lignocellulose-based materials for food packaging: A bio refinery perspective. 24 - 69. <https://doi.org/10.21741/9781644902639-2>
- Lindh, H., Olsson, A. and Williams, H. (2015). Consumer perceptions of food packaging: Contributing to or counteracting environmentally sustainable development? *Packaging Technology and Science*, 29(1), 3 - 23. <https://doi.org/10.1002/pts.2184>
- National Overview: Facts and figures on materials, wastes and recycling | US EPA. (2024, November 8). US EPA. <https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials>
- Ono, S., Hewage, H. and Visvanathan, C. (2023). Towards plastic circularity: Current practices in plastic waste management in Japan and Sri Lanka. *Sustainability*, 15(9), 7550. <https://doi.org/10.3390/su15097550>
- Popescu, P., Popa, E., Miteluț, A. and Popa, M. (2020). Development of recyclable and biodegradable food packaging materials – Opportunities and risks. *Current Trends in Natural Sciences*, 9(17), 142-146. <https://doi.org/10.47068/ctns.2020.v9i17.016>
- Rosenboom, J., Langer, R. and Traverso, G. (2022). Bio plastics for a circular economy. *Nature Reviews Materials*, 7(2), 117-137. <https://doi.org/10.1038/s41578-021-00407-8>



A Study on Defects Minimization in Apparel Manufacturing: A Case of Sri Lanka

Jayamini MDDC¹, Dilanthi MGS¹

Department of Industrial Management, Faculty of Applied Sciences, Wayamba University of Sri Lanka
dasunicetiva98@gmail.com

ABSTRACT

In the fast-paced world of apparel manufacturing, ensuring high quality and minimizing defects are key to meeting customer expectations. This study explores ways to reduce garment defects at ABC Company using a Total Quality Management approach. By analyzing defect data from four garment styles produced in August, the research identifies key problem areas using tools like Fishbone Analysis, Statistical Process Control (SPC), Pareto charts, and pie charts. The findings highlight those issues related to materials, workers, machines, and methods are the main causes of defects. Addressing these factors can improve First Pass Yield (FPY) and reduce rework. To tackle these challenges, the study recommends better machine maintenance and improved material management, providing practical solutions to enhance garment quality and guide future research in defect control.

KEYWORDS: Apparel Manufacturing, Defect Minimization, Total Quality Management (TQM), Fishbone Analysis, Statistical Process Control (SPC), First Pass Yield (FPY)

1 INTRODUCTION

The global apparel market is highly competitive due to unpredictable consumer behavior and the demand for high-quality goods, making defect control and quality management essential for manufacturers. Many adopt TQM to enhance product quality, reduce defects, and improve production efficiency. ABC company has implemented TQM with a focus on minimizing defects, but challenges remain in analyzing and managing defect causes. This study explores advanced strategies for defect reduction within ABC's TQM framework, aiming to close quality gaps and enhance overall efficiency.

1.1. Research Problem

Despite advancements in quality improvement, defects in garment sewing processes remain a significant challenge for ABC company, leading to inefficiency, increased rework, and customer

dissatisfaction. Identifying defect causes and trends is critical for effective mitigation. This research addresses this gap by analyzing defect classifications, rates, and causes using FPY data and the fishbone diagram for root cause analysis, aiming to enhance both product quality and production processes.

1.2. Objectives

- To identify and categorize defect types in garment production at ABC company.
- To analyze defect frequency across different garment styles.
- To assess quality performance using FPY data and analyze the impact of defects on production quality.
- To conduct a root cause analysis of the most prevalent defect using Fishbone Theory.
- To propose strategies for defect minimization based on the findings

1.3. Significance

This research holds both theoretical and practical significance for the apparel industry. Theoretically, it enriches the literature on quality management and defect reduction by exploring advanced TQM practices and leveraging FPY data and Fishbone Theory to identify defect causes (Abtew et al., 2013; Choudhary et al., 2018). Practically, it offers actionable strategies to enhance product quality, reduce rework costs, and improve customer satisfaction, benefiting ABC company and similar firms in adopting effective quality control techniques (Hoque et al., 2023). Broadly, the study provides a model for implementing quality management and defect prevention strategies, promoting higher standards and efficiency across the apparel industry (Islam et al., 2013).

2 LITERATURE REVIEW

2.1 Defects in Apparel Manufacturing

Defects in apparel production arise from factors such as fabric quality, human error, and equipment issues, with examples including fabric holes, color variations, seam slippage, and skipped stitches, which diminish garment quality and customer satisfaction (Islam et al., 2013). Many sewing defects stem from inadequate machine maintenance and operator inexperience, leading to rework and time wastage (Choudhary et al., 2018). Additionally, poor stitching and fabric handling practices impact garment structure and aesthetics. Untrained operators and uncalibrated machines exacerbate these issues (Abtew et al., 2013). Proper classification and analysis of defects enable targeted corrective actions, improving quality, reducing

rework, and enhancing customer satisfaction.

2.2 Approaches to defect minimization

The garment industry employs quality management frameworks like Six Sigma and TQM to reduce defect rates and improve productivity. Six Sigma uses the Define, Measure, Analyze, Improve, and Control (DMAIC) model to systematically address process variations and defects, enabling long-term quality improvements (Mridha et al., 2018). TQM, by involving all organizational levels in quality enhancement and fostering a proactive attitude, reduces internal defect rates and boosts productivity, as demonstrated in garment manufacturing countries like Bangladesh (Joy et al., n.d.). Both frameworks provide structured approaches to sustaining high-quality production and minimizing defects.

2.3 Total Quality Management (TQM)

Total Quality Management emphasizes quality improvement across all organizational levels, encouraging employee involvement and proactive problem prevention. TQM uses tools like Statistical Process Control (SPC) and Fishbone analysis to refine processes, reduce defects, and enhance customer satisfaction (Rahman, 2014). Beyond meeting quality standards, TQM fosters continuous product and process improvement, aligning operations with organizational objectives. Its implementation in apparel manufacturing eliminates defect causes, optimizes production, and strengthens quality reputation, offering a sustainable strategy for long-term efficiency and customer satisfaction in competitive markets.

2.4 Lean Manufacturing

Lean manufacturing, originally developed by Toyota, minimizes defects

by eliminating waste and improving process efficiency. By removing nonvalue-added activities, lean practices such as value stream mapping and continuous flow production reduce cycle time and enhance quality control in apparel manufacturing (Karuppusami et al., 2006). This approach emphasizes workforce involvement, empowering employees to identify inefficiencies and suggest improvements, fostering continuous process refinement. Lean manufacturing aligns with TQM in prioritizing efficiency and continuous improvement, together providing a strong framework for defect reduction and maintaining cost competitiveness in global markets.

2.5 *Pareto Analysis: Prioritizing Defects*

The 80-20 or Pareto principle is one of the foundations of management which is used in prioritizing the defects to be worked on based on their effect to the overall quality. It actually helps in understanding that a number of factors (or rather causes about 20%) are responsible for most of the problems (approximately 80%) enabling the manufacturers to action on the most pertinent problems first. Pareto graphs, usually found together with Fishbone diagrams, classify the defects in order from the most common to the least common, with the objective of assisting quality managers in corrective measures where resources are required the most.

2.6 *Pie Charts for Data Visualization*

A pie chart accurately illustrates the distribution of defect data by showing how many of each defect type there are, in turn allowing the manufacturer to focus on the issues that are the most recurrent. They are relatively simple to construct and they also help in assessing the complexity of the

issue and allow interventions to be put in place within the required time frame (Tincher et al, 1992).

2.7 *Fishbone Analysis for Root Cause Identifications*

Three production lines were intentionally drawn from the population, each chosen on the grounds of efficient records of defects and First Pass Yield FPY kept up by the Quality Control department. The defect logs had information on problems such as stitching, alignments, fabrics quality, and the FPY data showed the production efficiency in terms of the percentage of goods which passed the inspection without undergoing any rework processes. These sources of data provide a common ground for analysis of the trends and causes of the defects in detail.

2.8 *Technological Interventions and Automation*

Automation enhances garment production by reducing human error and improving precision. Technologies like automated sewing machines, CAD, and CAM systems ensure consistent stitching, streamline production, and minimize defects (Mridha et al., 2018). Real-time monitoring and automated quality control detect defects early, reducing rework and waste while boosting productivity (Abtew et al., 2013). These advancements enable apparel manufacturers to meet global quality demands efficiently.

2.9 *Challenges in the Sri Lankan Apparel Sector in Defect Minimization*

The Sri Lankan apparel sector faces challenges such as a lack of skilled labor, outdated machinery, limited funds, and high worker turnover, hindering quality improvement efforts (Moin et al., 2023). Smaller manufacturers often rely on

manual quality inspections due to resource constraints, leading to inconsistent quality and higher defect rates (Islam et al., 2013). Addressing these issues requires industry-wide mobilization, including government support for training and technological upgrades, to enhance quality and competitiveness.

3 METHODOLOGY

This qualitative study focuses on minimizing defects in apparel manufacturing at ABC Company by analyzing secondary data from the Quality Control department. It examines defect counts and First Pass Yield (FPY) data from end-line checks conducted in August 2024 across four garment styles. Defects, including stitching, fabric, and finishing faults, are categorized and analyzed using Fishbone diagrams, Pareto charts, and pie charts. Fishbone analysis helps identify root causes by classifying defects under machine, method, material, and manpower. Pareto charts apply the 80/20 rule to prioritize critical defects, while pie charts visually represent defect proportions. The study integrates Total Quality Management (TQM) and Lean Manufacturing principles, emphasizing continuous improvement and waste reduction. FPY data is used to measure production efficiency and inspection effectiveness. Statistical tools and Excel facilitate data processing and visualization, providing a structured approach to identifying defect trends and improving garment quality.

4 RESULTS & DISCUSSION

The study aimed to minimize defects in apparel manufacturing at ABC company, focusing on sewing processes. Data analysis included defect categorization, FPY evaluation, and root

cause identification using Fishbone diagrams.

4.1 Key Findings

1. Defect Trends: Common defects included pleated forms, oil stains, and broken/missing stitches, accounting for a significant proportion of quality issues. For instance, pleated form defects alone constituted 14% of defects, while oil stains and stitch-related issues contributed 27% and 45%, respectively.

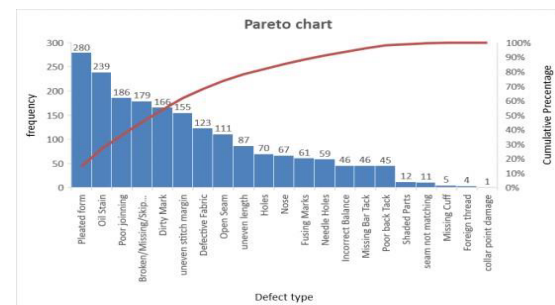


Figure 1: Pareto Chart

2. FPY Analysis: End Line Checking recorded a high FPY of 95.18%, while End Line Audit revealed a lower FPY of 76.26%, highlighting potential gaps in quality assurance during final inspections.

3. Root Cause Analysis: Fishbone diagrams identified key contributors to defects:

Pleated forms were linked to poor fabric handling and machine calibration issues

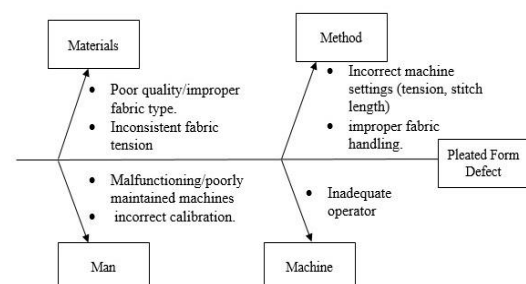


Figure 2: Fishbone analysis for Pleated Form

o Oil stains were attributed to inadequate machine maintenance and contamination

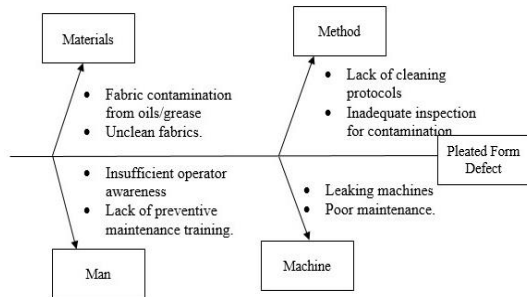


Figure 3: Fishbone analysis for Oil Stain Defects

o Stitch-related defects resulted from worn-out machine parts and operator errors.

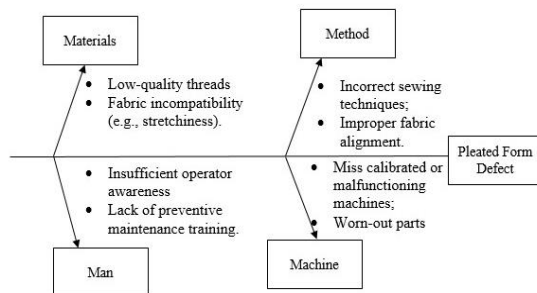


Figure 4: Fishbone analysis for Broken/ Missing/ Skip Stitches

4.2 Discussion

The results align with previous studies, emphasizing the role of proper training, machine maintenance, and fabric quality in defect minimization (Rahman, 2013; Moin et al., 2023). For instance, implementing TQM principles effectively reduced defect rates through systematic quality control and root cause analysis. Furthermore, lean manufacturing practices such as regular equipment calibration and enhanced operator training were identified as pivotal for maintaining high-quality standards.

4.3 Proposed Improvements:

- Enhanced operator training programs targeting defect recognition and machine operation.

- Preventive maintenance schedules to ensure optimal machine performance.
- Strengthened inspection protocols at all production stages.

5 CONCLUSION

5.1 Conclusion

This study focused on identifying, categorizing, and minimizing defects in the sewing section of ABC company's garment production. Key defects such as stitch flaws, pleated forms, and oil stains were analyzed using tools like Pareto charts, Fishbone diagrams, and FPY metrics. Root causes included inadequate operator training, poor machine maintenance, and low-quality raw materials. The findings revealed that adopting structured quality management practices, such as TQM and SPC, effectively reduced defects and improved overall production quality. These insights align with previous studies, demonstrating the importance of proactive quality management in the apparel industry.

5.2 Recommendations

Operator Training – Train workers on defect recognition, machine use, and fabric handling.

Machine Maintenance – Schedule regular maintenance to prevent defects.

Inspection Improvement – Enhance final checks with stricter protocols and automation.

Raw Material Quality – Inspect fabrics pre-production to catch defects early.

Real-Time Monitoring – Track defects instantly to address recurring issues.

Lean Practices – Apply 5S and Kaizen to optimize processes and reduce waste.

These measures can enhance defect minimization efforts, improving product quality, operational efficiency, and customer satisfaction. By addressing root causes and implementing proactive quality strategies, ABC company and similar manufacturers can achieve sustainable quality improvements and remain competitive in the global market.

REFERENCES

- Abtew, M. A., Kropi, S., Hong, Y., & PU, L. (2013). Implementation of statistical process control (SPC) in the sewing section of garment industry for quality improvement. *Research Journal of Textile and Apparel*.
- Choudhary, A. K., Sikka, M. P., & Bansal, P. (2018). The study of sewing damages and defects in garments. *Research Journal of Textile and Apparel*, 22(3), 85-99.
- Islam, M. M., Khan, A. M., & Khan, M. M. R. (2013). Minimization of defects in the sewing section of apparel industry. *Daffodil International University Journal of Textile Engineering*, 5(2), 45-56.
- Hoque, J. M., Hasan, S. M. M., Shahjalal, M., & Ahmed, F. (2023). Implementation of Six Sigma to minimize defects in sewing section of apparel industry in Bangladesh. *Bangladesh Textile Journal*, 28(4), 123-136.
- Rahman, H. (2013). Improving sewing quality in ready-made garment industry of Bangladesh: A case study. *Textile Progress*, 45(3), 160-175.
- Moin, C. J., Hossain, K. R., & Baral, L. M. (2023). Investigating root causes of sewing defects using TQM tools for quality improvement in the knit garment industry. *Textile & Leather Review*, 6(2), 417-433.
- Islam, M. M., Khan, A. M., & Khan, M. M. R. (2013). Minimization of reworks in quality and productivity improvement in the apparel industry. *Research Journal of Textile and Apparel*, 12(1), 22-35.
- Abtew, M. A., Kropi, S., Hong, Y., & PU, L. (2013). Implementation of statistical process control (SPC) in the sewing section of garment industry for quality improvement. *Research Journal of Textile and Apparel*, 10(2), 98-115.
- Tincher, W. C., Daley, W., & Holcomb, W. (1992). Detection and removal of fabric defects in apparel production. *International Journal of Clothing Science and Technology*, 4(2/3), 54-65.



Analysis of the Queuing System of a Popular Bookshop Using Simulation Modelling: A Case Study of Sri Lanka

Paranawithana CD¹, Dilanthi MGS¹, Weeraratne WLMP¹, Podirathna HKCRJ¹, Rashmika HPS¹
Department of Industrial Management, Faculty of Applied Sciences, Wayamba University of Sri Lanka
chamodadeshani5@gmail.com

ABSTRACT

Unnecessary waiting in the queue causes dissatisfaction among the customers. Therefore, optimizing customer service through effective queue management is important. Accordingly, this study focused on a well-known bookshop in Sri Lanka experiencing this issue and aimed to minimize unnecessary customer waiting through simulation. The study investigated the ground-floor operations of two service counters during a weekend day to capture peak traffic scenarios. Counters were observed and 150 customers' data were collected for each counter. The essential timestamps regarding customer queue dynamics were recorded. Key variables included customer arrival time, service beginning time, and service completion time, enabling the calculation of customer inter-arrival times and service durations in seconds. The data were then analyzed using ARENA software. The results showed the average waiting time, and the average number in the system respectively 9.6691 minutes and 46. Also, the study revealed the challenges faced by the bookshop during peak periods and proposed three queue management systems to minimize waiting times and enhance customer satisfaction. The optimal solution was identified through feasibility analysis to mitigate queue congestion effectively. This research contributes to understanding and addressing queue management challenges in retail environments, providing actionable insights for enhancing customer experiences and operational efficiency.

KEYWORDS: Arena, Queuing, Simulation, Waiting Time

1 INTRODUCTION

Waiting in queues is a significant issue in businesses, and their duration significantly impacts customer satisfaction. In today's competitive business landscape, cost savings are a key objective. Optimization, focusing on strategic resource alignment, has become a central concept. Computer simulation has revolutionized optimization techniques by simulating complex systems in a controlled virtual environment. This paper explored the intersection of cost savings, optimization, and computer simulation in contemporary business operations, focusing on the queue management challenges faced by a

popular bookshop in Sri Lanka. The study aimed to provide actionable insights and practical recommendations for mitigating queue congestion and driving cost savings in retail environments. The research contributes to practical implications for businesses in the stationary retail sector. The findings fill a critical gap in the literature and provide valuable guidance for optimizing queue management processes in bookshops and similar retail environments

2 LITERATURE REVIEW

Hillier and Lieberma (2010) defined queuing as the occurrence when demand exceeds the capacity to deliver a service, leading to customer

dissatisfaction or discontinuing service usage. Conversely, an excessive number of servers can result in high maintenance costs, necessitating a balance between service provision and cost management. Queuing theory utilizes mathematical models to predict service delivery system behavior and aims to optimize service organization while balancing costs and user delays (Arenales et al., 2007). Guedes and Araújo (2013) emphasized that queuing theory seeks to measure queues through mathematical analysis, organizing waiting to enhance customer satisfaction and company profitability. This body of knowledge found diverse applications across sectors, including call centers, supermarkets, port terminals, banks, hospitals, and the metallurgical industry, as demonstrated by various authors (Doile, 2010).

A queuing system typically consists of a source where customers arrive, a queue for waiting, and a service mechanism where customers are served before leaving the system (Fogliatti & Mattos, 2007). Queuing models may follow different principles, such as First In - First Out (FIFO) or Last In - First Out (LIFO), determining the order of service provision and prioritization of customers (Andrade, 2009).

Entringer and Cremonini, (2020) studied queues in a Rio de Janeiro banking agency that aims to improve service efficiency, reduce waiting times, and enhance operational performance. Using qualitative and quantitative approaches, the research examines queue behavior in a real-world banking environment, contributing to a deeper understanding of factors influencing service delivery and customer experience.

This study applies queuing theory and simulation to optimize queue management, enhance customer satisfaction, and drive cost savings in retail.

3 METHODOLOGY

The study was designed as a case study and focused on the billing service counter process at the selected bookshop, quantitatively analyzing workflow steps and customer waiting times. A simulation model was developed using Arena simulation software to replicate the billing process, generating data on queue lengths, waiting times, and overall process efficiency. The simulation results were analyzed to identify congestion and inefficiency. Three proposed queue management systems were compared to determine their effectiveness in reducing customer waiting times and improving operational efficiency. The system with the least waiting time in the queue was identified, facilitating the identification of the optimal queue management solution for the bookshop implementation. The study aimed to provide a comprehensive understanding of the billing process and identify areas for improvement.

Overall, this methodology employed a combination of empirical observation, simulation modeling, and data analysis to inform decision-making and optimize queue management processes within the bookshop setting.

ANALYSIS OF THE QUEUING SYSTEM OF A POPULAR BOOKSHOP USING SIMULATION MODELLING: A CASE STUDY OF SRI LANKA

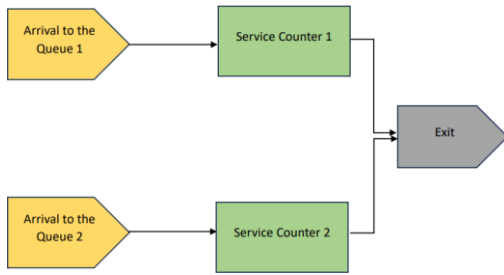


Figure 1: Billing Process at Service Counters

Based on the observational data, parameters like customer arrival rates, service times, and queue lengths were calibrated. Then the identified distributions were considered for designing the ARENA model.

4 DATA COLLECTION &

ANALYSIS

This study collected data through simulations and observational studies at the Bookshop. Observations focused on customer arrival times, service beginning times, and completion times. A comprehensive dataset of 150 observations was done, providing a detailed view of customer wait times and queue dynamics.

Table 1: Distribution of Arrival and Service counters of Existing system

Activity	Distribution	Expression
Arrival to Counter 01	Beta	$0.999 + 3.59e+003$ * BETA (0.172, 4.27)
Arrival to Counter 2	Exponential	$2 + EXPO (124)$
Service process in Counter 1	Erlang	$8 + ERLA (44.5, 2)$
Service process in Counter 2	Gamma	$11 + GAMM (44.9, 1.39)$

The ARENA model for the counter-billing process was developed using the identified statistical probability distributions. The developed ARENA model for the counter-billing process is shown in Figure 2.

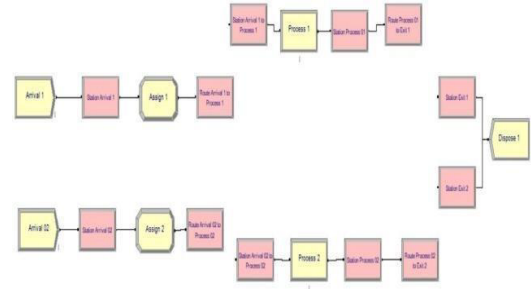


Figure 2: Arena Simulation model for the current system

Table 2: Overview of the Existing system

System		
Number In	Entry to Counter 1 - 5055	
	Entry to Counter 2 - 5748	
Number Out	Entry to Counter 1 - 5055	
	Entry to Counter 1 - 5748	
Queue Detail Summary		
Counter	Average waiting time (minutes)	Number Waiting (Maximum)
Counter 1	8.4434	37
Counter 2	1.2257	9
Total	9.6691	46

Table 3: Overview of the Proposed Systems

System			Queue Details Summary						
			Average Waiting Time (Minutes)			Number Waiting (Maximum)			
	Number In	Number Out	Counter 01	Counter 02	Total	Counter 01	Counter 02	Counter 03	Total
Proposed System 01	Entity 1 - 4923	Entity 1 - 4923	0.9344	1.1154	2.0498	14	9		23
	Entity 2 - 5615	Entity 2 - 5615							
Proposed System 02	Entity 1 - 4992	Entity 1 - 4992	0.9716	0.0776	1.0492	15	4		19
	Entity 2 - 5585	Entity 2 - 5584							
Proposed system 03	Entity 1 - 5218	Entity 1 - 5218	1.6255	1.1816	2.8141	9	8	0	17
	Entity 2 - 5683	Entity 2 - 5681							

5 RESULTS & DISCUSSIONS

The investigation into the three proposed systems, as outlined in Table 3, provided valuable insights into their impacts on queue dynamics within the bookshop. Proposed System 01 added a resource person to Counter 1, reducing the average waiting time from 8.44 to 2.05 minutes per entity, and reducing the maximum number of entities waiting from 37 to 23. Proposed System 02 added two resource persons to counters, reducing average waiting times and increasing maximum entity waiting, resulting in a more balanced workload distribution and improved system performance. Proposed System 03 aimed to add a counter staffed by one person, reducing waiting times, but faces challenges like increased average waiting times for Counter 1 and idle counters,

raising concerns about resource allocation and efficiency.

The study demonstrated the effectiveness of Proposed System 02 in the bookshop, reducing waiting times and maintaining workload balance. However, the feasibility and practicality of Proposed System 03 need further consideration.

6 CONCLUSIONS

After a thorough analysis and comparison of the three proposed systems, it was evident that Proposed System 02 emerged as the optimal solution for enhancing the queuing system at the selected bookshop. With the lowest total average waiting time (1.0492 minutes) and a relatively low total maximum waiting number (19), System 02 offered a practical and efficient

approach to address queue imbalances and improve customer service.

The decision to implement Proposed System 02, which involves recruiting an additional resource person per counter, can be supported by several factors. Firstly, it offers cost efficiency by minimizing initial investment and ongoing operational costs compared to installing another counter. Additionally, distributing the workload more evenly among resource persons reduces the risk of burnout, fatigue, and human errors, thereby enhancing service quality. Moreover, by reducing waiting times, System 02 enhances customer satisfaction and loyalty, ultimately improving the overall customer experience.

Overall, the adoption of Proposed System 02 aligns with the company's goals of optimizing operational efficiency, minimizing costs, and maximizing customer satisfaction. By leveraging internal resources effectively, The Book Shop can streamline its queuing system and ensure a seamless and satisfactory experience for its customers, challenges like increased average waiting times for Counter 1 and idle counters, raising concerns about resource allocation and efficiency.

REFERENCES

- Abdulaziz Alnowibet, Khalid. (2022). Airport terminal building capacity evaluation using queuing system. Alexandria Engineering Journal, 61(12), 10109-10118. Retrieved from <https://doi.org/10.1016/j.aej.2022.03.055>
- Andrade, E. L. (2009) Queue Congestion Problems. Introduction to Operations Research: Methods and Models for
- Decision Analysis, 4 ed. Rio de Janeiro: LTC.
- Arenales, M. et al. (2007) Operational Research, 1 ed. Rio de Janeiro:Elsevier.,https://www.researchgate.net/publication/341811126_Simulation_and_analysis_of_queues_in_banks_a_case_study_of_an_agency_in_the_southern_State_of_Rio_de_Janeiro
- Doile, L. F. P. (2010) Queue Theory: Analyzing Service Flow and Service Numbers in a Supermarket. Monograph. Porto Alegre: UFRGS.Available: <https://lume.ufrgs.br/handle/10183/2974>
- Access: 15/02/2018
- Ďutková, Silvia. (2019). Simulation of queuing system of post office. Transportation Research Procedia, 1037-1044. doi:10.1016/j.trpro.2019.07.145
- Entringer, Tulio Cremonini. (2020). Simulation and analysis of queues in banks: a case study of an agency in the southern State of Rio de Janeiro. Independent Journal of Management & Production, 892. doi:10.14807/ijmp.v11i3.1074
- Fogliatti, M. C.; Mattos, N. M. C. (2007) Queue Theory. Rio de Janeiro: Interciência.
- Guedes, D. B.; ARAÚJO, A. C. (2013) Queue Management: A Case Study on the Quality of Services in a Bank Branch in the Metropolitan Region of Recife – PE, 2013.
- Hillier, F. S.; Lieberman, G. J. (2013) Introduction to Operations Research, 9th Edition. Porto Alegre: AMGH,https://www.academia.edu/29281242/HILLIER_Frederick_S_LIEBERMAN_Gerald_J_Introdu%C3%A7%C3%A3o_%C3%A0_Pesquisa_Operacional



Factors Affecting the Loss of Standard Allocated Hours in Production Lines: A Study of An Apparel Manufacturing Company in Sri Lanka

Dias DLHS¹, Dharmawansa AD¹

Department of Industrial Management, Faculty of Applied Sciences, Wayamba University of Sri Lanka
diashasari@gmail.com

ABSTRACT

This study investigates the factors influencing losses in Standard Allocated Hours (SAH) on production lines within a Sri Lankan apparel manufacturing company, where production efficiency is essential to meet deadlines and maintain profitability. The primary objective is to identify key factors contributing to these losses and analyze their impact on production efficiency. The research categorizes these factors into four main groups: human resources, supply chain, machinery, and operational. Data for the study were collected from Lost SAH reports spanning two years, focusing on the relationship between various factors and SAH losses. Using R software, regression analysis was used to explore the impact and significance of each factor. Findings suggest that improvements in workforce training, supply chain coordination, and regular machinery maintenance could minimize SAH losses and improve productivity. Future research should consider a broader range of factors. Recommendations include the implementation of targeted interventions to address key loss factors, aiming to streamline production and reduce inefficiencies in the apparel manufacturing sector.

KEYWORDS: Apparel, Efficiency, Production, SAH

1 INTRODUCTION

The apparel manufacturing sector in Sri Lanka mainly contributes to the national economy, accounting for a significant portion of the country's exports. In the first quarter of 2024, Sri Lanka's garment exports were valued at \$321.7 million which was \$6.4 million lower than in 2023 (Industry Capability Report Sri Lankan Apparel Sector, 2024). Each production line in a factory is assigned monthly targets for standard hours and there are some variations between the planned standard hours which highlights a significant issue in achieving production goals (Senavirathna et al., 2020). However, understanding the causes of these variations is essential for optimizing production processes. This research seeks to identify and analyze these factors in the context of the Sri Lankan apparel manufacturing industry. The objectives of this research are to

identify the key factors contributing to standard hour variations in garment production lines, to assess the relationship between the factors with standard hour variations, and to provide recommendations for minimizing standard hour loss to improve production line efficiency.

2 LITERATURE REVIEW

2.1. Apparel Manufacturing Industry

The apparel industry is not only one of the oldest, largest, and most labor-intensive industries globally but also a key "starter" industry for countries pursuing export-oriented industrialization (Abteu et al., 2020). The USA and UK are the top markets for Sri Lankan apparel and Sri Lanka has around 300 apparel manufacturers (Industry Capability Report Sri Lankan Apparel Sector, 2024).

2.2. Standard Allocated Hours

Some authors have explained the term standard allocated time (hours) which is the total time a job should be completed at the standard performance (De Silva et al., 2021). Hui et al. (1999) defined standard time as a common measure in the clothing industry to predict production efficiency. To establish a correlation between standard allowed hours, variables such as production rate, number of workstations, and operation breakdown have a distinct impact (Senavirathna et al., 2020).

2.3. Factors affecting the loss of SAH

In the past, the apparel industry relied heavily on human labor, but it has since shifted towards automation, with industrial machinery increasingly replacing human operators (Michelini, 2013). According to (Rahman et al., 2016) machine problems are the common issue in apparel manufacturing industries and occur regularly. Some researchers have shown that specific human resource practices are closely linked to employee performance, particularly in the apparel export industry (Mittar et al., 2014). Additionally, sewing-related issues contribute to production delays and loss in standard hours. This often occurs when a new style is introduced without adequate instructions from the quality control department, or when operators are rushed, leading to an increase in reject rates (Rahman et al., 2016).

3 METHODOLOGY

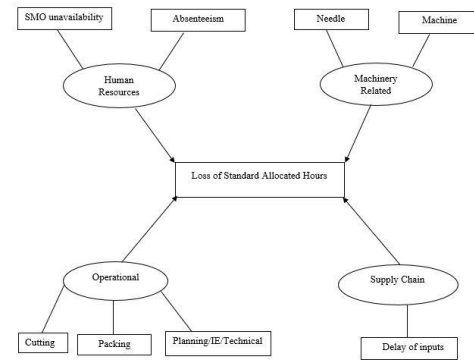


Figure 1: Conceptual Framework

This research indicates the several factors affecting the loss of SAH such as; machinery-related factors, human-resource-related factors, operational factors, and supply-chain-related factors. This research model shows the relationship between variables and loss of SAH. According to the conceptual model, the following hypotheses can be proposed:

H₁: Machinery-related factors significantly impact the loss of allocated hours in production lines.

H₂: Human resource-related factors significantly impact the loss of standard

H₃: Operational factors significantly impact the loss of standard allocated hours in production lines.

H₄: Supply chain-related factors significantly impact the loss of standard allocated hours in production lines.

Secondary data from September 2022 to September 2024 was collected from the SAH reports which were extracted from ABC company's internal database, which includes a total of 456 data points. The R software was used to do regression analysis for the collected data to examine the relationship between the independent and dependent variables.

4 DATA ANALYSIS

4.1 Descriptive Analysis

According to the following table, the data shows variability across all variables with the loss of standard allocated hours.

Table 1: Model Summary

	LSA H	HR	SC	OP	MC
Min	0	0	0	0	0
Max	1160	498	776	932	382
Mean	203.9	9.1	99.4	53.5	40.7
		9	3	8	4

Note: LSAH= Loss of Standard Allocated Hours, HR=Human Resources, SC=Supply chain, OP=Operational, MC=Machinery

4.2 Correlation Analysis

Table 1: Correlation Between Variables

Variable	SAH	HR	SC	OP	MC
LSAH	1.00	0.24	0.62	0.52	0.52
	0	7	2	0	2
HR	0.24	1.00	-0.03	0.05	0.10
	7	0		2	0
SC	0.62	-0.03	1.00	0.04	0.10
	2		0	5	3
OP	0.52	0.05	0.04	1.00	0.38
	0	2	5	0	9
MC	0.52	0.10	0.10	0.38	1.00
	2	0	3	9	0

The above table demonstrates that loss of standard allocated hours has a moderate positive correlation with supply chain-related factors, operational factors, and machinery-related factors indicating that these variables are significant predictors of SAH loss. Also, human resource-related factors show a lower correlation with loss SAH which shows a weaker association with Loss SAH.

4.3 Regression Analysis

The result of the multiple regression model shows a strong overall fit since the R-squared is 0.7624. It indicates that approximately 76.24% of the variation in SAH loss can be explained by the independent variables.

Table 2: Summary of Fitted Model

Predictor	Estimate	Std. Error	t-value	p-value
Intercept	25.57	6.60	3.88	<0.001
HR	1.10	0.12	9.46	<0.001
SC	0.87	0.03	25.20	<0.001
OP	0.74	0.05	14.69	<0.001
MC	1.02	0.09	11.83	<0.001

H₁: Machinery-related factors significantly impact the loss of standard allocated hours in production lines.

The coefficient for machinery-related factors is 1.02 and the p-value is less than 0.05 and the hypothesis is accepted demonstrating that the impact is highly statistically significant.

H₂: Human resource-related factors significantly impact the loss of standard allocated hours in production lines.

The coefficient for human resource-related factors is 1.10 and the p-value is less than 0.05 and the hypothesis is accepted. It demonstrates that the impact is highly statistically significant, increasing SAH losses.

H₃: Operational factors significantly impact the loss of standard allocated hours in production lines.

The coefficient for operational factors is 0.74 and p-value is less than 0.05 and the hypothesis is accepted. It demonstrates that the impact is highly statistically significant.

H₄: Supply chain-related factors significantly impact the loss of standard allocated hours in production lines.

The coefficient for supply chain-related factors is 0.87 and p-value is less than 0.05 and the hypothesis is accepted. It demonstrates that the impact is highly statistically significant.

4.4 Autocorrelation Assessment

To assess for autocorrelation in residuals, the Durbin-Watson test was performed for the fitted model and the results are shown in Table 4.

Table 4: Durbin Watson Test of the Fitted Model

D-W Statistic	0.744
Autocorrelation	0.611
P-value	0.00

These results show that the D-W statistic is significantly lower than 2 and coupled with a p-value of 0, indicates positive autocorrelation in the residuals. This suggests that the residuals are not independent, which may impact model validity. Therefore, ARIMA modeling can further refine predictions in this analysis.

Table 5: Training Set Error Measure

Metri c	ME	RMS E	MAE	MAS E	ACF 1
Value	0.02 7	67.97 0	26.63 9	0.252	- 0.001

Note: ME=Mean Error, RMSE= Root Mean Squared Error, MAE=Mean Absolute Error, MASE=Mean Absolute Scaled Error, ACF1=Autocorrelation Function at Lag 1

The ARIMA(2,0,2) model with variables appears to be a good fit for the data and a near-zero ACF1(auto-correlation function at lag 1) indicates minimal autocorrelation in the residuals, implying the model has adequately addressed autocorrelation, validating the model assumptions and enhancing its reliability. This analysis suggests that the selected model provides a strong foundation for understanding the influence of the selected factors on the daily loss of standard allocated hours.

4.5 Multicollinearity Assessment

According to the VIF values, they are below the threshold of 5, which indicates

that multicollinearity is not a concern in this fitted model.

Table 6: Collinearity Statistics of the Fitted Model

Variable	HR	SC	OP	MC
VIF	1.012	1.013	1.179	1.199

5 DISCUSSION

However, the findings align with previous research indicating that machinery and supply chain factors significantly impact production efficiency. For example, studies have shown that frequent machinery breakdowns can lead to substantial losses in production time (Rahman et al., 2016). Additionally, delays in supply chain logistics negatively affect the overall productivity of apparel manufacturing (Kader et al., 2014). In contrast, the weaker relationship between human resource-related factors with loss of standard allocated hours made conflicts, given in the literature on how the importance of human capital in enhancing productivity (Kader et al., 2014). The results suggest that improving machinery efficiency and optimizing supply chain processes could lead to significant reductions in the loss of standard allocated hours.

6 CONCLUSION

The findings indicate that supply chain-related factors had the strongest positive correlation with SAH loss followed by operational factors and machinery-related factors. In contrast, human resource-related factors have a weaker correlation.

The organization should focus on rewarding the best attendance using motivational incentives such as bonuses or recognition for the best attendance rates

to encourage the employees. However, supply chain-related factor has a strong impact on SAH loss, especially strengthening relationships with suppliers and improving logistics can help ensure the timely delivery of materials develop alternative sourcing strategies and maintain stocks to face unexpected supply chain disruptions can reduce the issues related to the supply chain. Also in case to reduce the issues related to machines, ensuring backup machines are available for critical operations will avoid loss during breakdowns. Regularly following lean manufacturing principles such as 5S, in the company and collaboration between departments can also reduce the loss and ensure alignment in operations.

Future research could investigate SAH loss across multiple apparel manufacturing firms could provide a more comprehensive understanding of the factors influencing production efficiency. Also, further research could focus on sub-factors that affect key factors to identify the real cause of SAH Loss.

REFERENCES

- Abtew, M. A., Kumari, A., Babu, A., & Hong, Y. (2020). Statistical analysis of standard allowed minute on sewing efficiency in apparel industry. *Autex Research Journal*, 20(4), 359–365. <https://doi.org/10.2478/aut-2019-0045>
- Ahmed Abir, S. (2020). Study on Factors Delaying Lead Time in the Apparel Supply Chain Management: A Case Study on the Order of Execution Strategies of a Garment Factory in Bangladesh. *European Scientific Journal ESJ*, 16(3). <https://doi.org/10.19044/esj.2020.v16n3p244>
- De Silva, A., Gunathilake, S., Munaweera, H., Perera, D., & Gunathilake, L. (2021). *Competitive Edge Through Automation: A Study on the Sri Lankan Apparel Industry*.
- Hui, C. L. P., & Ng, S. F. F. (1999). A study of the effect of time variations for assembly line balancing in the clothing industry. *International Journal of Clothing Science and Technology*, 11(4), 181–188. <https://doi.org/10.1108/09556229910281894>
- *Industry capability report Sri Lankan apparel sector*. (n.d.).
- Kader, M. S., & Khairul Akter, M. M. (2014). Analysis of the factors affecting the lead time for export of readymade apparels from Bangladesh; proposals for strategic reduction of lead time. *Article in European Scientific Journal*. <https://doi.org/10.19044/esj.2014.v10n33p%25p>
- Michelini, R. C. (2013). Robotics in Clothes Manufacture. *International Journal of Mechanical Engineering and Applications*, 1(1), 17. <https://doi.org/10.11648/j.ijmea.20130101.13>
- Mittar, S., & Mathew, S. K. (2014). Human Resource Factors Influencing Employee Performance in Garment Manufacturing Firms (GMF) in Delhi/NCR. *Journal of Business and Economics*, 5(7), 990–1002. [https://doi.org/10.15341/jbe\(2155-7950\)/07.05.2014/006](https://doi.org/10.15341/jbe(2155-7950)/07.05.2014/006)
- Rahman, H., & Al Amin, M. (2016). An Empirical Analysis of the Effective Factors of the Production Efficiency in the Garments Sector of Bangladesh. In *European Journal of Advances in Engineering and Technology* (Vol. 3, Issue 3).
- Senavirathna, S., Rathnamali, P., (2020). Factors Associated with Standard Hour Variations of Production Lines: A Case of a Sri Lankan Manufacturing Company Factors Associated with Standard Hour Variations of Production Lines: A Case of a Sri Lankan Manufacturing Company. <https://www.researchgate.net/publication/377063929>



Factors Affecting the Perception on Privacy Disclosure to Accept the Mobile App

Rashmika HPS¹, Dharmawansa AD¹

Department of Industrial Management, Faculty of Applied Sciences, Wayamba University of Sri Lanka
sadinirashmika@gmail.com

ABSTRACT

This study investigates the factors affecting the perception of privacy disclosure among state university students in Sri Lanka when accepting mobile apps. With the development of technology, mobile app usage has increased and it has become an important part of day-to-day life. This research focuses on the factors that students consider when downloading mobile apps. The research model investigated five factors: perceived benefits, user reviews, app reputation, trustworthiness, and type of app. A Likert scale questionnaire was used to collect data. Multiple Regression Analysis was conducted by using SPSS software, to analyze the relationship between these five and the perception of privacy disclosure to accept the mobile app. The findings include that perceived benefits, user reviews, trustworthiness, and type of app significantly influence students' privacy disclosure decisions, while app reputation does not significantly affect. This research provides valuable insights for app developers to develop mobile apps to satisfy and be accepted by the users.

KEYWORDS: Privacy Disclosure, Perceived Benefits, Trustworthiness, User Reviews, App Type, App Reputation

1 INTRODUCTION

With the development of technology, mobile app usage has increased while it has become an important part of day-to-day life. It is estimated that 75% of the world's population uses more than 5 billion mobile devices (Besmer, 2020). Mobile apps often require permissions like access to camera, location, contacts, etc. from users to provide functionality properly (Zhang & Garcia, 2020). There are different types of mobile apps that are developed for various purposes. Thus, users are more concerned about privacy with the growth of privacy breach incidents.

The privacy calculus concept suggested that users consider perceived benefits rather than perceived risks when disclosing personal details (Wang et al., 2016). In Sri Lanka, mobile users care

more about privacy, especially the students who often use mobile apps for educational and social connectivity purposes (Maduragoda et al., 2023). Though some apps provide the same features or tasks, user perception may differ towards the apps. Therefore, this study investigates factors influencing the perception on disclosing personal information through mobile apps. Moreover, this study provides insights to app developers to consider more about app features and privacy policies to align with user expectations because it can increase trustworthiness which is essential in dealing with data.

2 LITERATURE REVIEW

a. Perceived Benefits

Perceived benefits mean positive outcomes that individuals expect to receive from using social media

(Maduragoda et al., 2023). When perceived benefits of social media increased, students were more likely to reveal personal information and if students were more concerned about privacy, they posted less about themselves. Therefore, there was a positive relationship between perceived benefits and privacy disclosure (Maduragoda et al., 2023). When users manage their image on online platforms and activities related to social networks, it is called self-presentation.

b. User Reviews

User reviews provide information about the quality of the app, its performance, and potential risks or benefits to users. High app quality ratings increase perceptions related to the trustworthiness of the app (Keith, 2016). Then they prefer to download and disclose their personal information because they trust the app rather than considering privacy risks. Further user reviews help to understand users' perceptions about privacy whether it was positive, negative, or neutral. Also, the apps which do not give privacy policies have less probability to download.

c. Trustworthiness

Trust refers to the users' confidence in the safety and reliability of the app. When consumers feel the app handles their information responsibly, they were willing to share personal information. The trustworthiness of the app is affected by user interface design, clear privacy policies, etc. (Morosan, 2015). Based on age, younger adults were more likely to share personal information based on app trust while older adults were more likely to share personal information based on perceived benefits (Anaraky et al., 2021).

d. App Type

In 2023, Brits and Jonker conducted research about the privacy paradox in financial app usage, which found that if users were more concerned about their privacy, the usage of financial apps would be low. Also, it revealed that certain types of apps depend significantly on users' trust in the app providers (Brits, 2023). They explored trust in financial information apps, mobile payments apps, and activity apps (Brits, 2023). The type of data required for these apps is different. Then users' perception of trust differs from the type of app (Brits, 2023).

e. App Reputation

Perceived app popularity negatively influenced privacy concerns and that means if the app is popular, users have fewer privacy concerns about it (Gu, 2016). Further, users always think heuristically which means if many people download and have positive user reviews, that app can be trusted and safe, hence it reduces privacy concerns.

Most studies explored particular app types (financial, social, etc) with various populations. However, this study explores diverse apps with a focus on university students in Sri Lanka. Further, studies like Keith, 2016 used experimental or market-level data, while this study uses self-reported Likert-scale survey specific to state university students. Thus, this study presents the gap in the methodology by targeting a specific educational group rather than a general audience.

3 METHODOLOGY

3.1 Conceptual Framework

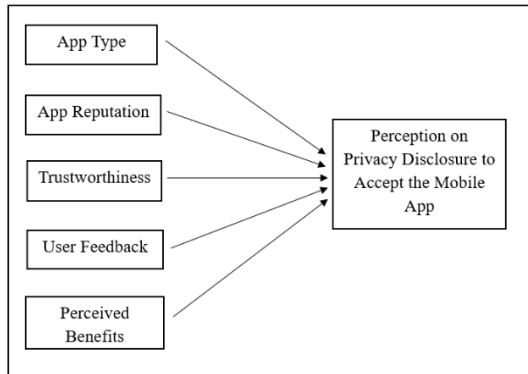


Figure 01: Conceptual Framework

3.2 Hypothesis Development

H₁: Perceived benefits positively influence the perception on privacy disclosure to accept the mobile app.

H₂: User reviews positively influence the perception on privacy disclosure to accept the mobile app.

H₃: App reputation positively influences the perception on privacy disclosure to accept the mobile app.

H₄: Trustworthiness positively influences the perception on privacy disclosure to accept the mobile app.

H₅: App type positively influences the perception on privacy disclosure to accept the mobile app.

3.3 Data Collection

The data were collected using a structured questionnaire to a sample of state university students in Sri Lanka. Data collection was conducted through an online survey and the survey was distributed using social media (Facebook, WhatsApp) and LinkedIn.

3.4 Data Analysis

The reliability of the given data set and the validation of the data set were checked using appropriate statistical tests

with the use of SPSS software. Multiple linear regression was used to analyze the collected data. Before implementing multiple linear regression, assumptions have been checked such as normality, linearity, homoscedasticity, multicollinearity, and independence of residuals. The multiple linear regression results are mentioned below;

Table 1: Multiple Linear Regressions

R-value	R Square	Adjusted R Square	Standard Error
0.834 ^a	0.695	0.691	0.35526

Table 2: Coefficient Table

Variable	Beta Value	T Value	P Value	Results
Perceived Benefits	0.253	5.335	0.000	Supported
User Reviews	0.152	3.358	0.000	Supported
App Reputation	-0.038	-0.697	0.486	Not Supported
Trustworthiness	0.293	5.465	0.000	Supported
App Type	0.296	4.940	0.000	Supported

4 RESULTS AND DISCUSSION

Multiple linear regression analysis indicates that 69.5% variability of the perception on privacy disclosure to accept the mobile app can be explained by the predictor measurements (perceived benefits, user reviews, app reputation, trustworthiness and app type). Perceived benefits has positive beta value (0.253), which means there is a positive relationship with the dependent variable. Also, the t value is 5.335 that means the relationship is statistically significant. It

matches with the privacy calculus concept, which describes users considering perceived benefits rather than perceived risk when disclosing personal information. Also, this supports Maduragoda et al., 2023, who concluded that the perceived benefits of social media increase, users are more likely to share their personal information.

User reviews have a positive beta value (0.152) and the t value is 3.358, which describes that there is a significant influence to disclose personal information through mobile apps. Students consider the feedback from other people when downloading a mobile app. As mentioned by Kelley et al., 2013, user reviews provide information about benefits as well as potential risks. Apps with positive user reviews seem to be good or safer, while apps with negative user reviews get rejected by the users (Keith, 2016).

The study found that trustworthiness has a positive beta value (0.293) and t value (5.465), which means trustworthiness significantly affects privacy disclosure decisions. If the app mentions privacy policies, security measures, and what they are going to do with user's data, students tend to trust and are willing to disclose their personal information. As mentioned in the previous findings by Zhang & Garcia, 2020, students rely on trust rather than considering the perceived risk, when disclosing their information.

The findings of this study show that the app type has a positive beta value (0.296) and t value (4.940), which means the type of the app strongly affects privacy disclosure decisions. The previous finding Mamonov & Benbunan-Fich, 2015 emphasize that users disclosing levels depend on the type of the app. That study

considered paid apps and non-paid apps. This study focused on different types such as educational apps, fitness related apps, financial apps, social media apps etc. Moreover, as the Brits, 2023 explained, users' perception of disclosing personal information differed according to the type of the app. Also, this research emphasizes that students tend to share personal details more with the app whose functionality connects to social interaction and communication.

5 CONCLUSION

The findings of this study suggest that perceived benefits, user reviews, trustworthiness, and app type are important factors that influence students' willingness to disclose their personal information when accepting mobile apps. In contrast, the app's reputation did not influence significantly to disclosure of personal information.

App developers should highlight the benefits of using apps such as personalized services (Wang et al., 2016), time-saving features, social connectivity, etc. because users are more likely to share personal details when they receive good benefits. Developers should clearly mention privacy policies, what type of data they will collect, and how they will use them and store. Some apps need more information that is not related to their functionality (Zhang & Garcia, 2020). Apps should collect only the details that are needed for the app's functionality. If apps request unnecessary app permissions, this could make users uncomfortable.

Because app reputation did not significantly influence disclosing information in this study, developers require to focus more on developing

strong security features, transparent privacy policies and creating good user experiences rather than building brand image.

On the other hand, mobile app users should ensure their privacy is protected when interacting with mobile apps. Users should read privacy policies, what data collected from the app and whether they share your information with third parties. When accepting mobile apps, users should consider what kind of permission requests include in the app and grant only permissions which are essential for functionality of the app. For example, a book reading might need to access user's camera, location, record video (Zhang & Garcia, 2020), but it doesn't need to access camera and location. Along with that, users should deny permission requests which do not need to its functionality. As well, apps should allow users to change permission requests in settings when they need.

REFERENCES

- Anaraky, R. G., Byrne, K. A., Wisniewski, P. J., Page, X., & Knijnenburg, B. P. (2021). To disclose or not to disclose: Examining the privacy decision-making processes of older vs. younger adults. *Conference on Human Factors in Computing Systems - Proceedings*. <https://doi.org/10.1145/3411764.3445204>
- Atchariyachanvanich, K., Mitinunwong, N., & Tamthong, B. (2017). Factors affecting disclosure of personal health information via mobile application. *Proceedings - 16th IEEE/ACIS International Conference on Computer and Information Science, ICIS 2017*, 203–208. <https://doi.org/10.1109/ICIS.2017.7959994>
- Brits, H., & Jonker, N. (2023). The Use of Financial Apps: Privacy Paradox or Privacy Calculus? *SSRN Electronic Journal*, November. <https://doi.org/10.2139/ssrn.4624569>
- Keith, M. J., Babb, J., Furner, C., Abdullat, A., & Lowry, P. B. (2016). Limited Information and Quick Decisions: Consumer Privacy Calculus for Mobile Applications. *AIS Transactions on Human-Computer Interaction*, 8(3), 88–130. <https://aisel.aisnet.org/thci>
- Kelley, P. G., Cranor, L. F., & Sadeh, N. (2013). Privacy as part of the app decision-making process. *Conference on Human Factors in Computing Systems - Proceedings*, 3393–3402. <https://doi.org/10.1145/2470654.2466466>
- Maduragoda, C. S. K., Senarath, T. U. S., & Manorathne, L. I. (2023). Factors Associated with the Privacy Disclosure on Social Media by State University Students in Sri Lanka. *Journal of Management Matters*, 10(1), 83–92. <https://doi.org/10.4038/jmm.v10i1.49>
- Wang, T., Duong, T. D., & Chen, C. C. (2016). Intention to disclose personal information via mobile applications: A privacy calculus perspective. *International Journal of Information Management*, 36(4), 531–542. <https://doi.org/10.1016/j.ijinfomgt.2016.03.003>



Impact of Cultural Values on Brand Engagement through Electronic Word of Mouth

Dinusha GI¹, Wattegama EJ¹

Department of Industrial Management, Faculty of Applied Sciences, Wayamba University of Sri Lanka
18isuru@gmail.com

ABSTRACT

Understanding how cultural values shape consumer brand engagement (CBE) through digital communication platforms is crucial, particularly in diverse societies like Sri Lanka. This study investigates the impact of cultural values on CBE, emphasizing the mediating role of electronic word of mouth (eWOM). The key cultural dimensions examined include collectivism, masculinity, uncertainty avoidance, power distance, and long-term orientation. Data was collected from 168 respondents and analyzed using correlation and regression analysis alongside a mediation analysis using the PROCESS tool. Findings indicate that long-term orientation and power distance have significant positive effects on CBE, while uncertainty avoidance negatively influences engagement. However, collectivism and masculinity do not show significant impacts. Although cultural values directly influence CBE, eWOM is not found to be a significant mediator. The findings of this study have contributed to fill the existing literature gap by examining how cultural values interact with eWOM in a Sri Lankan context and offered insights for marketers to design culturally sensitive engagement strategies.

KEYWORDS; Brand Engagement, Cultural Values, Electronic Word of Mouth

1 INTRODUCTION

At present social media, blogs, and forums play a significant role in the consumer buying decision-making process. In the Sri Lankan context, its unique cultural factors; collectivism, high power distance, and high uncertainty avoidance strongly influence how the Sri Lankan consumers buy things. Despite this growing impact of electronic word of mouth (eWOM) on consumer brand interactions, limited researches have examined the interplay with cultural dynamics in the Sri Lankan context. Hence the objective of the present study has been established to uncover how the cultural factors impact the consumers to engage with the brands by comparing the mediating effect which is generated from the culturally relevant versus generic

eWOM messages. Accordingly, it is expected that the findings of this study would contribute to fill the existing literature by advancing the understanding of cultural impacts on eWOM-driven CBE. Also, those findings would provide actionable insights for the marketers to craft culturally sensitive strategies and for the policymakers to frame guidelines for ethical and culturally resonant marketing by navigating Sri Lanka's complex digital consumer landscape.

2 LITERATURE REVIEW

The eWOM is a critical marketing tool that is influenced by cultural factors that shape CBE. It thrives on consumer-generated content, such as, ratings, reviews, and recommendations (Wattegama & Qing, 2014). Cultural dimensions like collectivism which often

drive communal reliance on the eWOM while individualism emphasizes the personal experiences (Kusawat & Teerakapibal, 2022; Dang & Raška, 2021). Aligning brand personality with cultural factors it enhances the emotional connections and advocacy through the eWOM (Mahlke et al., 2020). The social media platforms amplify the eWOM's reach by necessitating culturally sensitive strategies (Severi et al., 2014). The eWOM influencers also play a key role by embodying cultural factors, strengthening engagement, and loyalty (Azim & Nair, 2021). According to Seifert and Kwon (2020) and Cheung et al. (2020), the positive eWOM boosts trust and purchase intentions with cultural factors by moderating its effects.

The cultural sensitivity plays a key role as individualistic cultures focus on self-expression while collectivist cultures emphasize shared experiences (Park & Jeon, 2018). According to Iqbal et al. (2020) and Qu and Yang (2015), the eWOM induced consumers who are also aligning with cultural factors amplify the CBE while psychological factors like satisfaction also drive the eWOM intentions. Moreover, collectivism emphasizes group goals over individual objectives which shapes the behavior, coping strategies, and societal outcomes. Variants like horizontal and vertical collectivism affect equality and hierarchy in groups (Brewer & Chen, 2007; Huang et al., 2015), and those foster cooperation, stress coping, adherence to public health rules, and organizational loyalty (Kim & Han, 2022; Galanaki et al., 2019). Power distance reflects societal acceptance of inequality, influencing relationships, organizational behavior, and ethics. High power distance fosters hierarchy, limits

innovation, and reduces whistleblowing, while low power distance promotes egalitarianism, open communication, and accountability (Khatri, 2009; Puni & Anlesinya, 2017).

The long-term orientation which emphasizes persistence and future benefits influences the CBE and positive eWOM. Long-term-oriented consumers value loyalty while contributing to personalized experiences, brand communities, and co-creation activities that strengthen brand allegiance. This dynamic fosters the eWOM which in turn is enhancing brand equity and visibility in digital marketplaces (Almeida et al., 2018; Bowden et al., 2017). Masculinity which emphasizes traits like assertiveness and competitiveness significantly influences the eWOM and CBE. Male consumers favor brands that reflect masculine traits aligning with values like durability and performance, fostering loyalty and advocacy. Social media amplifies this effect through authentic exchanges, enhancing brand equity and visibility (Haxhialushi & Panajoti, 2018; Mahar, 2022).

3 METHODOLOGY

The present study employed a deductive research design to explore the relationships between variables through a cross-sectional approach. The target population was comprised of Sri Lankan workforce consumers with purchasing power. A sample of 385 participants which was determined via Krejcie and Morgan's table was selected using the convenience sampling technique. Data collection tools included a questionnaire and interviews with the measurements for cultural orientation, eWOM, and CBE in 5-point Likert scales. The variables like long-term orientation, collectivism,

IMPACT OF CULTURAL VALUES ON BRAND ENGAGEMENT THROUGH ELECTRONIC WORD OF MOUTH

uncertainty avoidance, power distance, and masculinity were operationalized following Yoo et al. (2011) while eWOM and CBE indicators were derived from Akyüz (2013) and Vivek (2009) respectively. The research model examined how cultural values influence CBE through the mediation of eWOM. Accordingly, it proposed that collectivism, masculinity, uncertainty avoidance, power distance, and long-term orientation significantly impact on CBE. The SPSS software was employed for the data analysis. The reliability of the measurements was confirmed via a pilot test yielding Cronbach's alpha values above 0.7 for all variables.

4 RESULTS

Although it was expected to collect data from 385 respondents, only 168 valid responses were used for the analysis after excluding illogical responses. Through the Measure of Sampling Adequacy test, it was found the values exceeding 0.5 for all variables which confirmed the adequacy of the sample size for the analysis. The variables, such as, long-term orientation, collectivism, uncertainty avoidance, power distance, masculinity, eWOM, and CBE were analysed with Kaiser-Meyer-Olkin (KMO) test and the values were ranged from 0.783 to 0.874. This ensured the reliability and adequacy of the data for testing the study hypotheses.

Table 1: Results of the ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	12.069	5	2.414	8.064	.000 ^b
Residual	48.526	162	.300		
Total	60.595	167			

Table 2: Results of the Regression Analysis

	Unstandardized B	Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	2.571	.424		6.068	.000
LongTerm Orientation	.308	.098	.275	3.139	.002
Collectivism	.030	.067	.037	.457	.649
Uncertainty Avoidance	-.262	.095	-.245	-2.745	.007
PowerDistance	.245	.057	.401	4.326	.000
Masculinity	-.005	.060	-.008	-.082	.935

Table 3: Results of the PROCESS Tool

Total effect of cultural values on consumer brand engagement						
Effect	se	t	p	LLCI	ULCI	c_cs
.078	.020	3.852	.000	.038	.117	.304
Direct effect of cultural values on consumer brand engagement						
Effect	se	t	p	LLCI	ULCI	c_cs
.059	.021	2.787	.006	.017	.101	.232

Indirect effect(s) of cultural values on consumer brand engagement:				
	Effect	BootSE	BootLLCI	BootULCI
eWOM	.018	.014	-.004	.050
Completely standardized indirect effect(s) of cultural values on consumer brand engagement:				
	Effect	BootSE	BootLLCI	BootULCI
eWOM	.072	.050	-.016	.181

As shown in Tables 1 and 2, the findings of ANOVA and regression analyses have emphasized the significance of cultural dimensions in shaping consumer brand engagement. The overall model is statistically significant ($F = 8.064$, $p < 0.001$), with long-term orientation ($\beta = 0.275$, $p = 0.002$) and power distance ($\beta = 0.401$, $p < 0.001$) having the strongest positive effects. Uncertainty avoidance negatively impacts engagement ($\beta = -0.245$, $p = 0.007$), while collectivism ($\beta = 0.037$, $p = 0.649$) and masculinity ($\beta = -0.008$, $p = 0.935$) show no significant influence. The findings that were shown in Table 3, reveal that eWOM did not significantly mediate the relationship between cultural values and consumer brand engagement, as its indirect effect is negligible (effect = 0.018, $p > 0.05$). Despite this, cultural dimensions like long-term orientation and power distance directly shape consumer behavior, highlighting their importance for

marketers. These results have suggested that strategies that are tailored to cultural contexts, such as, emphasizing hierarchy or long-term value propositions, can effectively enhance brand engagement. At the same time, eWOM's limited mediating role indicates that alternative engagement methods may be more effective in culturally specific markets.

5 CONCLUSION AND RECOMMENDATIONS

The present study has highlighted some key recommendations for enhancing brand engagement, particularly by addressing cultural factors like power distance and long-term orientation. The firms should emphasize prestige and reliability in their brand messaging to better connect with consumers. The findings also have suggested that eWOM did not significantly mediate brand engagement which is prompting marketers to focus on alternative strategies that are aligned with cultural factors, such as, building trust in high uncertainty avoidance regions. However, the study has limitations that restrict its generalizability. The sample size of 168 responses, though sufficient, may not represent diverse cultural settings, and the findings may reflect demographic-specific biases. The cross-sectional design captures only a snapshot of consumer attitudes, limiting causal conclusions. Additionally, the broad measure of eWOM might have overlooked the nuanced impacts of positive or negative reviews on engagement. Therefore future research should adopt longitudinal approaches to explore how cultural factors and CBE evolve. Expanding cultural dimensions and testing alternative mediators, like brand trust or emotional

connection, could yield deeper insights. Comparative studies across countries and regions, along with investigations into digital engagement's cultural influences, would further illuminate the interplay between technology, culture, and brand relationships.

REFERENCES

- Akyüz, A. (2013). Determinant Factors Influencing WOM. Retried from <https://www.richtmann.org/journal/index.php/mjss/article/view/1283>
- Almeida, S., Scaraboto, D., Fleck, J. and Dalmoro, M. (2018). Seriously engaged consumers: navigating between work and play in online brand communities. *Journal of Interactive Marketing*, 44(1), 29 - 42. <https://doi.org/10.1016/j.intmar.2018.05.006>
- Azim, R. and Nair, P. (2021). Social media influencers and electronic word of mouth: the communication impact on restaurant patronizing. *Journal of Content Community and Communication*, 14(8), 46 - 56. <https://doi.org/10.31620/jccc.12.21/05>
- Bowden, J., Conduit, J., Hollebeek, L., Luoma-aho, V. and Solem, B. (2017). Engagement valence duality and spillover effects in online brand communities. *Journal of Service Theory and Practice*, 27(4), 877 - 897. <https://doi.org/10.1108/jstp-04-2016-0072>
- Brewer, M., & Chen, Y. (2007). Where (who) are collectives in collectivism? Toward conceptual clarification of individualism and collectivism. *Psychological Review*, 114(1), 133 - 151. <https://doi.org/10.1037/0033-295x.114.1.133>
- Cheung, M., Pires, G. and Rosenberger, P. (2020). The influence of perceived social media marketing elements on consumer-brand engagement and brand knowledge. *Asia Pacific Journal of Marketing and Logistics*, 32(3), 695 - 720. <https://doi.org/10.1108/apjml-04-2019-0262>
- Dang, A. & Raška, D. (2021). National cultures and their impact on electronic word of mouth: a systematic review. *International Marketing Review*, 39(5), 1182 - 1225. <https://doi.org/10.1108/imr-12-2020-0316>

- Galanaki, E., Papagiannakis, G., & Rapti, A. (2019). Good is not good, when better is expected: Discrepancies between ideal and actual collectivism and their effect on organizational commitment. *European Management Review*, 17(1), 171 - 184. <https://doi.org/10.1111/emre.12347>
- Haxhialushi, R. and Panajoti, V. (2018). How word of mouth in social media affects attitudes toward brands. *China-USA Business Review*, 17(5). <https://doi.org/10.17265/1537-1514/2018.05.003>
- Huang, Z., Li, L., Zheng, W., Tan, X. and Zhao, X. (2015). Walking the straight and narrow: The moderating effect of evaluation apprehension on the relationship between collectivism and corruption. *PLOS ONE*, 10(3), e0123859. <https://doi.org/10.1371/journal.pone.0123859>
- Iqbal, J., Malik, M., Yousaf, S. and Yaqub, R. (2020). Brand reputation, brand experience, and electronic word of mouth toward smartphones: investigating the mediating role of brand love. *Journal of Public Affairs*, 21(3). <https://doi.org/10.1002/pa.2455>
- Jam, F., Singh, S., Ng, B. and Aziz, N. (2018). The interactive effect of uncertainty avoidance cultural values and leadership styles on open service innovation: A look at Malaysian healthcare sector. *International Journal of Business and Administrative Studies*, 4(5). <https://doi.org/10.20469/ijbas.4.10003-5>
- Khatri, N. (2009). Consequences of power distance orientation in organisations. *The Journal of Business Perspective*, 13(1), 1 - 9. <https://doi.org/10.1177/097226290901300101>
- Kim, M. and Han, K. (2022). Social motivation to comply with COVID-19 guidelines in daily life in South Korea and the United States. *Behavioral Sciences*, 12(7), 213. <https://doi.org/10.3390/bs12070213>
- Kusawat, P. and Teerakapibal, S. (2022). Cross-cultural electronic word-of-mouth: a systematic literature review. *Spanish Journal of Marketing - Esic*, 28(2), 126 - 143. <https://doi.org/10.1108/sjme-06-2021-0116>
- Mahlke, C., Lahmeyer, S. and Roemer, E. (2020). What is love? Exploring the meaning of brand love and its role in determining brand loyalty. *Multi-disciplinary Business Review*, 13(2), 54 - 65. <https://doi.org/10.35692/07183992.13.2.6>
- Mahar, F. (2022). The effect of electronic word of mouth on brand equity in the context of social media. *Jobams*, 4(1), 19 - 30. <https://doi.org/10.58921/jobams.4.1.74>
- Park, H. and Jeon, J. (2018). The impact of mixed eWOM sequence on brand attitude change: cross-cultural differences. *International Marketing Review*, 35(3), 390 - 411. <https://doi.org/10.1108/imr-06-2016-0118>
- Puni, A. and Anlesinya, A. (2017). Whistleblowing propensity in power distance societies. *Journal of Global Responsibility*, 8(2), 212 - 224. <https://doi.org/10.1108/jgr-02-2017-0005>
- Qu, W. and Yang, Z. (2015). The effect of uncertainty avoidance and social trust on supply chain collaboration. *Journal of Business Research*, 68(5), 911 - 918. <https://doi.org/10.1016/j.jbusres.2014.09.017>
- Seifert, C. and Kwon, W. (2019). SNS eWOM sentiment: impacts on brand value co-creation and trust. *Marketing Intelligence & Planning*, 38(1), 89 - 102. <https://doi.org/10.1108/mip-11-2018-0533>
- Severi, E., Ling, K. and Nasermoadeli, A. (2014). The impacts of electronic word of mouth on brand equity in the context of social media. *International Journal of Business and Management*, 9(8). <https://doi.org/10.5539/ijbm.v9n8p84>
- Vivek, S.D. (2009). A Scale of Consumer Engagement. Retrieved from <https://ir.ua.edu/handle/123456789/603>
- Wattagama, E.J. and Qing, P. (2014). Impact of electronic word of mouth on brand evaluation in times of negative publicity: A conceptual framework. *European Journal of Business and Management*, 6(36), 203 - 210.
- Yoo, B., Donthu, N. and Lenartowicz, T. (2011). Measuring Hofstede's Five Dimensions of Cultural Values at the Individual Level: Development and Validation of CVSCALE. *Journal of International Consumer Marketing*, 23, 193 - 210.



Impact of Deploying a New Production System on Enhancing the Productivity of Glove Manufacturing

Malinga HVR¹, Wattegama EJ¹

Department of Industrial Management, Faculty of Applied Sciences, Wayamba University of Sri Lanka
raveenhewavithanage@gmail.com

ABSTRACT

Lean Six Sigma and Procter & Gamble Integrated Working System based new production system had been implemented two and a half years ago for optimizing processes and enhancing productivity in a glove manufacturing company in Sri Lanka. Despite these efforts, the actual effects of this new system on enhancing productivity remained unclear. This research aimed to fill the gap by conducting a comparative analysis of productivity metrics before and after this system's deployment, focusing on key performance indicators such as machine breakdowns, process failures, production stops, and overall output. Utilizing a cross-sectional design, the study used secondary data, which comprised 30 months each from the pre-deployment and post-deployment phases. The quantitative analysis of the Wilcoxon signed-rank test was employed to evaluate the impact of operational efficiency metrics on enhancing productivity. The findings revealed that while machine breakdowns did not show a significant impact on productivity, both process failures and production stops showed significant impacts on productivity. Notably, the reductions in process failures and production stops are associated with improved output following the new system's implementation. The results provided valuable insights into the effectiveness of the new production system, identifying areas for further improvement and offering recommendations to optimize production processes.

KEYWORDS: Glove Manufacturing, Operational Efficiency, Production System, Productivity

1 INTRODUCTION

In the fast-changing manufacturing industry, improving productivity and operational efficiency is essential to stay competitive in the industry. To address these needs, the selected glove manufacturing company of this study introduced a new production system two and a half years ago. This new system combined Lean Six Sigma with P&G's Integrated Working System (IWS) to optimize processes, reduce downtime, and enhance overall productivity. Although this new production system was implemented, its impact on enhancing productivity remains uncertain as it may have either positively or negatively affected productivity compared to the

previous system (Salentijn et al., 2021). This study was undertaken to address this issue by assessing whether the new system has delivered measurable productivity improvements or if further adjustments are necessary to achieve the desired outcomes. Accordingly, the main objective of this study was to evaluate whether there is any difference in the impacts of deploying the new production system by comparing before and after conditions on enhancing the productivity of the selected company.

2 LITERATURE REVIEW

The glove manufacturing industry is required for other complementary sectors, such as healthcare, industrial safety, and

food processing. The glove industry has progressed from creating basic hand coverings to designing specialized gloves for various needs. Initially, gloves were made from natural materials like leather and cotton. As industrial demand grew, better protection was needed, leading to the use of rubber and synthetic polymers (Yip & Cacioli, 2002). However, latex allergies led to the development of alternatives like nitrile, neoprene, and vinyl. These materials offer similar protection without the risk of allergic reactions, making them suitable for a broader range of users (Lovato et al., 2023).

The glove manufacturing industry is significantly influenced by global economic trends, regulatory standards, and public health crises. For instance, the COVID-19 pandemic caused an unprecedented surge in demand for disposable gloves, which put immense pressure on production capacities around the world. These issues highlighted the industry's challenges in meeting sudden spikes in demand and managing global supply networks (Meneguetti et al., 2021). The glove product market is highly segmented, and standards are enforced to protect both patients and healthcare providers, which reflects the critical nature of these products (Perbandingan et al., n.d.).

Recent studies have highlighted various ways to enhance productivity in glove manufacturing, including adopting new technologies, implementing methods, and investing in workforce training (Utama & Abirfatin, 2023). The technologies include robotic systems, the Internet of Things (IoT) (Tan, 2022; Ali et al., 2024), and methods include lean manufacturing, Kaizen, sustainability

practices, etc. (Kumareswaran, 2019; Shettar et al., 2015; Chou, n.d.).

A recent study has highlighted the significant impact of deploying new production systems like TPS and IWS on manufacturing performance. The implementation of TPS and IWS often results in notable improvements in efficiency. Lee and Jo (2007) observed an increase in productivity and a reduction in production costs following the adoption of TPS in a manufacturing plant.

Based on the facts above, the study's conceptual framework is shown in Figure 1.

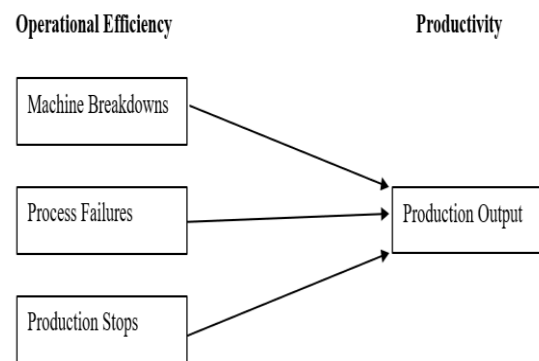


Figure 1: Conceptual Framework

3 METHODOLOGY

Secondary data, which were collected from the company's internal databases, including the ERP system, SPC system, and machine logs over five years from 2019 to 2024 from one plant of the selected glove manufacturing company, was used to measure the variables. Machine breakdowns, Process failures, Production stops, and Output. The time horizon of this study was cross-sectional and allowed for a comprehensive comparison of the company's productivity performance before and after the implementation of the new system.

The statistical analyses were carried out using R software.

4 DATA ANALYSIS

A sequence of steps was followed to achieve the objectives. First, a Shapiro test was conducted to check for normality. Since normality was not met through that test, the Wilcoxon test was performed to examine the differences between the conditions before and after system deployment. The following hypothesis was established to achieve the objective of the study.

Hypothesis:

Null Hypothesis (H_0): There is no significant difference before and after the deployment of the new production system.

Alternative Hypothesis (H_1): There is a significant impact after the deployment of the new production system.

Table 1: Results of the Test

Variable	V value	p-value
Production Stops	349	0.01546
Process Failures	375	0.003492
Machine Breakdowns	208	0.6263
Output	80	0.001131

According to the results as shown in Table 01,

Machine Breakdowns:

The test statistic ($V = 208$) yielded a p-value of 0.6263, which was greater than the significance level of 0.05. Therefore, the null hypothesis could not be rejected, indicating any significant difference in machine breakdowns before and after the implementation of the new production system.

Process Failures:

The test statistic ($V = 375$) yielded a p-value of 0.003492, which was less than the significance level of 0.05. Consequently, the null hypothesis was rejected, and the alternative hypothesis was accepted. This result indicated a significant reduction in process failures following the deployment of the new production system.

Production Stops:

The test statistic ($V = 349$) yielded a p-value of 0.01546, which was less than the significance level of 0.05. Accordingly, the null hypothesis was rejected, and the alternative hypothesis was accepted. This result suggested a significant decrease in production stops after the implementation of the system.

Output:

The test statistic ($V = 80$) yielded a p-value of 0.001131, which was less than the significance level of 0.05. Thus, the null hypothesis was rejected, and the alternative hypothesis was accepted. This result demonstrated a significant improvement in output following the deployment of the new production system.

5 DISCUSSION

The analysis of the study provided valuable insights into the impact of the new production system on operational efficiency and productivity. In line with objectives, the Wilcoxon test results for before-and-after comparisons highlight substantial reductions in process failures and production stops following the new system's implementation. The significant decrease in these operational disruptions translated directly into increased output, validating the system's intended goals. However, the lack of significant

improvement in machine breakdowns could imply that certain machine issues remain unsolved, which may require targeted interventions.

The comprehensive findings underscored that the integration of Lean Six Sigma principles with IWS has positively influenced productivity, especially by reducing operational inefficiencies. The significant improvement in output, paired with a reduction in process failures and production stops, confirmed that the system's deployment has largely met its objectives.

Moreover, the following Figures 2,3,4, and 5 show the differences between the operational efficiency matrices and the output before and after the implementation of the new production system.

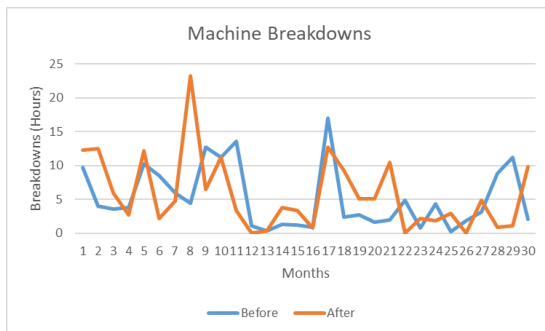


Figure 2: Changes in Machine Breakdowns

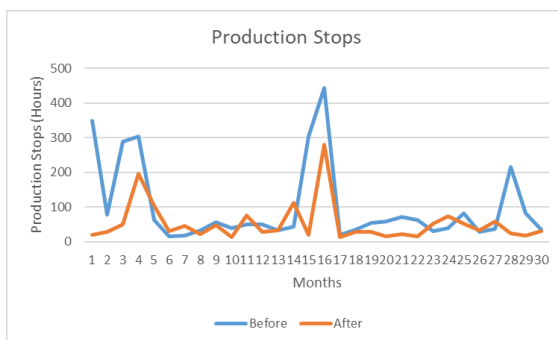


Figure 3: Changes in Production Stops

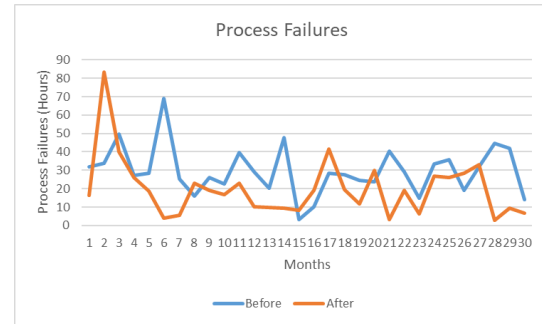


Figure 4: Changes in Process Failures

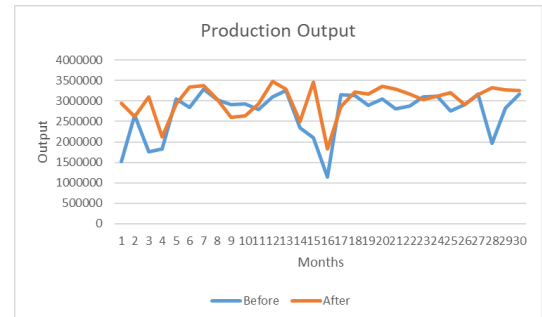


Figure 5: Changes in Production Output

6 CONCLUSION

This study evaluated the impact of a newly implemented production system on productivity in a glove manufacturing company by integrating Lean Six Sigma with IWS principles. The system aimed to reduce inefficiencies and enhance operational output. The findings confirmed a positive impact on productivity, primarily through significant reductions in process failures and production stops. However, the persistent machine breakdowns indicated that further adjustments are necessary to fully achieve the system's goals. The study's limitations included the exclusive focus on quantitative operational metrics, which may overlook qualitative aspects, such as employee satisfaction or changes in workplace dynamics that also impact productivity. Future researchers could expand on this study by examining additional factors like labor efficiency or employee morale. A long-term study

could provide insights into the sustained impact of the new production system and its influence on overall organizational performance.

REFERENCES

- Ali, M.N., Senthil, T.S., Ilakkiya, T., Hasan, D.S., Ganapathy, N.B.S., & Boopathi, S. (2024). *IoT's Role in Smart Manufacturing Transformation for Enhanced Household Product Quality*. Retrieved from <https://doi.org/10.4018/979-8-3693-1694-8.ch014>
- Chou, W. (n.d.). *How Sustainable Practices Affect the Financial Performance of Glove Manufacturers*. Retrieved from <https://doi.org/10.13140/RG.2.2.17011.75040>
- Kumareswaran, S. (2019). *Factors Affect Effective Implementation of Lean System in the Glove Manufacturing Industry in Sri Lanka*. Retrieved from <https://doi.org/10.13140/RG.2.2.13843.22562>
- Lee, B. H., & Jo, H. J. (2007). The mutation of the Toyota Production System: Adapting the TPS at Hyundai Motor Company. *International Journal of Production Research*, 45(16), 3665–3679. <https://doi.org/10.1080/00207540701223493>
- Lovato, M.J., Valle, L.J. del, Puiggalí, J., & Franco, L. (2023). *Smart Materials in Medical Gloves*. Retrieved from <https://doi.org/10.20944/preprints202306.0485.v1>
- Meneguetti, M.G., Bellissimo-Rodrigues, F., Ciol, M.A., Auxiliadora-Martins, M., Basile-Filho, A., da Silva Canini, S.R.M., Gir, E., & Laus, A.M. (2021). Impact of replacing powdered gloves with powder-free gloves on hand-hygiene compliance among healthcare workers of an intensive care unit: a quasi-experimental study. *Antimicrobial Resistance and Infection Control*, 10(1). <https://doi.org/10.1186/s13756-020-00877-5>
- Perbandingan, K., Sarung, S., Karet, T., Rumah, U., Yani, T., Pertiwi, K., Martianto, T., & Priatni, A. (n.d.). *Comparative Study of Rubber Household Gloves Standard*.
- Salentijn, W., Beijer, S., & Antony, J. (2021). Exploring the dark side of Lean: a systematic review of the lean factors that influence social outcomes. *International TQM Journal*, 33(6), 1469 – 1483. <https://doi.org/10.1108/TQM-09-2020-0218>
- Shettar, M., Hiremath, P., Rao Chauhan, V., & Professor, A. (2015). KAIZEN-A case study. *International Journal of Engineering Research and Applications*, 5
- Tan, A.H. (2022). Glove Manufacturing: Opportunities and Challenges in Control Engineering. *IFAC-PapersOnLine*, 55(1), 872 – 877. <https://doi.org/10.1016/j.ifacol.2022.04.143>
- Utama, D.M., & Abirfatin, M. (2023). Sustainable Lean Six Sigma: A new framework for improving sustainable manufacturing performance. *Cleaner Engineering and Technology*, 17, <https://doi.org/10.1016/j.clet.2023.100700>
- Yip, E., & Cacioli, P. (2002). The manufacture of gloves from natural rubber latex. *Journal of Allergy and Clinical Immunology*, 110(2), S3 – S14. <https://doi.org/10.1067/mai.2002.124499>



Impact of Digital Marketing on Purchasing Behavior of the Users of Mobile Data Packages

Jayarathna GGDV¹, Wattegama EJ¹

Department of Industrial Management, Faculty of Applied Sciences, Wayamba University of Sri Lanka
dinethvimukthi98@gmail.com

ABSTRACT

With the rapid expansion of digital platforms, it is critical to understand how online advertising, social media marketing, email marketing, and Internet purchasing experiences impact the purchasing behavior of the consumers. This study investigates the effect of digital marketing strategies on the purchasing behavior of the users of mobile data packages in the Sri Lankan context. A structured online questionnaire has been provided to a stratified random sample of 384 mobile data users to collect data for testing the study hypotheses. The results show a substantial positive correlation between online advertising, social media marketing, and purchasing behavior. However, email marketing has a negative correlation. Furthermore, Internet buying experiences have a significant favorable impact, which has underscored the relevance of those in customer decision-making. According to regression analysis, the independent factors explain 24.2% of the variance in consumer purchasing behavior. These findings highlight the requirement of engaging telecommunication marketers to improve online advertising and social media campaigns while revisiting email marketing techniques to meet customer expectations effectively. The present study enhances the knowledge of digital marketing through telecommunication media and provides practical insights for professionals. Future researchers should explore the other factors that are affecting consumer purchasing behavior in the digital space for a deeper understanding of this evolving field.

KEYWORDS: Consumer Behavior, Digital Marketing, Mobile Data Packages

1 INTRODUCTION

Rapid digital growth is driving a transformational shift in Sri Lankan telecommunication sector. Data usage is now a major part of consumer lifestyles due to the widespread adoption of cutting-edge technology and the increased affordability of smartmobile phones. Digital channels are widely used by mobile users to research, evaluate, and choose data plans that meet their Internet accessing requirements. To draw in and keep their target audience, telecom businesses have been forced to use a variety of digital marketing techniques, such as social media campaigns, Internet advertising, and email marketing. Additionally, now customers can easily

purchase data packages due to the convenience of online shopping platforms. Telecom firms must understand the effectiveness of their digital marketing strategies to influence consumer behavior, increase customer loyalty, and stay in the competition. The present study examines how digital marketing affects mobile data users' purchase decisions, providing insightful information for improving marketing strategies and encouraging consumer interaction in Sri Lankan energetic telecommunication industry.

2 LITERATURE REVIEW

Digital marketing has a significant impact on what people buy, and different tactics have different functions. Email

marketing establishes a personal and direct relationship with customers, which frequently influences their purchase decisions. According to Khan and Iftikhar (2017), well-written and educational emails encourage product searches and form repeat behaviour but lose the impact if they are perceived as irrelevant or untrustworthy. Customer preference for mobile marketing or retargeting presents difficulties by underscoring the necessity of interesting and customized email content.

Online advertising has grown to be a vital tool for business firms that are looking to attract customers and thereby encourage sales. Effective product promotion is crucial, and according to Ndaghu et al. (2017), there is a substantial relationship between better purchasing behavior and well-conceived advertisements. According to Kamins (1990), effective endorsements and congruence between advertising messaging and customer perceptions are essential.

Social media marketing leverages large audiences and real-time interactions to influence buying decisions. As noted by Autio (2020), the social media platforms, such as Facebook and Instagram, facilitate pre-purchase research, product comparisons, and reviews. Social media is essential for modern business firms because it promotes customer engagement, brand reputation, and loyalty.

Then, the shopper's perceptions of future purchases are influenced by their online purchasing experiences. Positive prior experiences lower uncertainty and increase buy intentions (Shim & Drake, 1990). Ling et al. (2010) have noted that aspects like payment security and product

details affect how satisfied customers are with their online purchases. Providing outstanding online experiences fosters long-term loyalty and trust, as both are essential for e-retail success. The telecom industry has revealed a gap in understanding the impact of digital marketing strategies on the purchasing behavior of mobile data package users. This study aims to address this gap by analyzing the effects of these strategies on purchasing decisions and providing actionable insights for telecom companies to optimize their digital marketing efforts and improve customer engagement.

3 METHODOLOGY

Using the deductive approach, this study looked at mobile consumer behavior in a non-contrived environment. Primary data was collected using a structured questionnaire, which was directed at mobile data consumers in the Sri Lankan context as part of a quantitative research approach. The questionnaire was divided into two parts; the first part was used to ask about personal information, such as age, gender, district, and type of employment. The second part contained questions to measure how the digital marketing tools have impacted the purchasing behavior of the users of data packages.

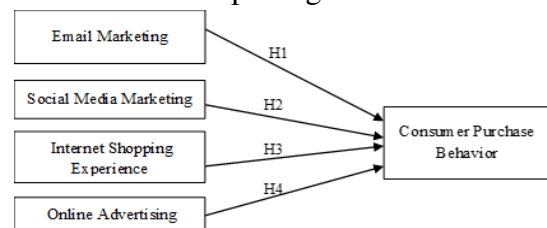


Figure 1: Research Model

Based on the research model, as shown in Figure 1, the following hypotheses have been established.

- H1: Email marketing has an impact on consumer purchase behavior.
H2: Social media marketing has an impact on consumer purchase behavior.
H3: Internet shopping experience has an impact on consumer purchase behavior.
H4: Online advertising has an impact on consumer purchase behavior.

According to the Morgan's table, the sample size was determined as 384 no. of users of the data packages. SPSS software was used for the data analysis. The pilot test showed that all variables have high reliability, as Cronbach's alpha values for those variables were more than 0.7.

4 DATA ANALYSIS

Out of 384 questionnaires that were distributed, 330 were completed accurately (The response rate was 85.94%). Moreover, the dataset displayed a balanced gender mix, and accordingly, the study was more comprehensive. The fact that 20 districts were represented among the respondents, including the major districts, such as 123 (37.3%) from Gampaha, 45 (13.6%) from Colombo, and 36 (10.9%) from Kandy.

To investigate how digital marketing tactics affect the consumer's purchasing behavior, the data was subjected to regression and correlation analysis. Regression linearity, collinearity, independence, and normality assumptions were verified using residual checks, skewness, kurtosis, and scatterplots. Descriptive statistics confirmed the reliability of the data set for the analysis.

Regression analysis was used to examine how four independent variables, email marketing, online advertising, social media marketing, and online

shopping experience, affect the dependent variable of consumer purchasing behavior.

Table 1: Results of the Regression Analysis

Variable	Beta value	T statistics	P value	Results
Email Marketing	-0.055	-2.823	0.005	Significant (p < 0.05)
Online Advertising	0.110	6.370	0.000	Significant (p < 0.05)
Social Media Marketing	0.146	3.937	0.000	Significant (p < 0.05)
Internet Shopping Experience	0.014	1.639	0.102	Not Significant (p > 0.05)

As shown in Table 01, the techniques that are used under email marketing may not be in line with the customer desires, as seen by the considerable negative effect it showed on consumer behavior (p = 0.005). The efficiency of online advertising in promoting customer purchases was highlighted by the large positive influence (p = 0.000). Similarly, social media marketing showed a significant positive impact (p = 0.000), emphasizing its role in boosting customer engagement. On the other hand, the impact of online shopping on customer behavior was minimal and statistically insignificant (p = 0.102). These results implied that although social media marketing and online advertising are good indicators of consumer behavior, email marketing needs to be strategically updated, and online shopping experiences need to be improved to have a greater impact. The findings emphasize how crucial digital marketing initiatives are to

influencing customer choices in the telecom industry.

5 DISCUSSION

Regression analysis was conducted to examine the impact of digital marketing strategies, email marketing, online advertising, social media marketing, and Internet shopping on consumer behavior related to mobile data packages. The regression assumptions were thoroughly checked for linearity, collinearity, independence of observations, and normality, ensuring the validity and reliability of the analysis. The results revealed key insights into the effectiveness of these strategies. Email marketing demonstrated a significant negative effect on consumer behavior ($\beta = -0.055$, $t = -2.823$, $p = 0.005$), indicating that its current implementation does not align with consumer preferences in this context. This suggests a need to revise email marketing strategies to better resonate with mobile data package users. Online advertising showed the strongest positive influence on consumer behavior ($\beta = 0.110$, $t = 6.370$, $p = 0.000$), highlighting its critical role in driving purchase decisions. The results confirm that well-targeted and persuasive online advertisements significantly improve consumer engagement and purchase behavior. Social media marketing also had a significant positive impact ($\beta = 0.146$, $t = 3.937$, $p = 0.000$), emphasizing the importance of leveraging social media platforms to foster customer engagement and influence buying decisions. In contrast, Internet shopping exhibited a weak and statistically insignificant relationship with consumer behavior ($\beta = 0.014$, $t = 1.639$, $p = 0.102$). Although a slight positive trend exists, its influence

on purchasing behavior was negligible in this study's context. The variance in consumer behavior is accounted for by the regression model to the extent of 24.2% ($R^2 = 0.242$), highlighting the complexity of purchasing decisions and the impact of other unexplored factors. Overall, the findings suggest that telecom companies should focus on optimizing online advertising and social media marketing while revising email marketing strategies to align better with consumer needs.

These findings provide actionable insights into the effectiveness of digital marketing strategies and guide telecom companies in enhancing their marketing approaches to positively influence consumer purchasing behavior.

6 CONCLUSION

The present study looked at how digital marketing strategies impact consumer purchasing behavior among the users of Sri Lankan mobile data packages. The findings revealed the varying effectiveness of various strategies and offered insights into how digital marketing techniques affect consumer purchasing behavior. While social media marketing and online advertising demonstrated strong positive links with customer behavior, email marketing demonstrated a negative influence, showing a misalignment with consumer preferences. Furthermore, despite a positive association, the study concluded that the influence of online purchasing experiences was not statistically significant. These findings highlight how crucial it is to match consumer expectations with digital marketing strategy. It has been demonstrated that effective social media content and

efficient Internet advertising greatly influence consumers' choices. The negative impacts of email marketing indicate that tactics, including audience-specific content creation, should be improved to better connect with customers. Improving customer service, return policies, and navigation could have a favorable effect on consumer purchasing behavior even while online shopping experiences lacked statistical significance.

Despite its valuable insights, the study's limitations limit the ability to apply its findings beyond the mobile data package segment. Self-reported data may introduce bias and limitations in the current research, particularly in the Sri Lankan context, complicating thorough analysis.

Future research should expand to include more Sri Lankan consumer segments, examine the moderating impact of demographic variables on digital marketing strategies, and examine related fields like reverse logistics and its effects on brand reputation. Understanding these characteristics will help businesses create more successful digital marketing strategies that will increase client engagement and impact purchasing behavior in a rapidly evolving digitalized economy.

REFERENCES

- Autio, S. (2020). The impact of social media on consumer purchasing. Retrieved from https://www.theseus.fi/bitstream/handle/10024/352736/Thesis%20Impact%20of%20social%20media%20on%20consumer%20purchasing%20behavior_Susanne%20Autio.pdf?sequence=2
- Hair, J., Black, W., Babin, B. and Anderson, R. (2019). *Multivariate Data Analysis*, 7th Edition, Pearson Prentice Hall
- Kamins, M.A. (1990). An Investigation into the 'Match-Up' Hypothesis in Celebrity Advertising: When Beauty May be Only Skin Deep. *Journal of Advertising*, 4 - 13.
- Khan, I., & Iftikhar, F. (2017). The Impact of Email Marketing, Mobile Marketing and Retargeting on Online. Retrieved from <https://urn.fi/URN:NBN:fi:amk-2017112818600>
- Ling, K.C., Chai, L.T., & Piew, T.H. (2010). The Effects of Shopping Orientations, Online Trust and Prior Online Purchase Experience on Customers' Online Purchase Intention. *International Business Research*, 3(3), 63 – 76.
- Ndaghu, J.T., Augustine, M.V., Habibu, S.A., & Magaji, B.Y. (2017). Assessment of the Impact of advertisement on consumer buying behaviour in the food and beverages industry. *Nigerian Journal of Management Research*, 11(2), 12 – 24.
- Shim, S., & Drake, M. (1990). Consumer Intention to Purchase Apparel by Mail Order: Beliefs, Attitude, and Decision Process Variables. *Clothing and Textiles Research Journal*, 9(1), 18 - 26.



Impact of Poverty on Household Consumption Expenditures: An Empirical Evidence Using Sri Lankan Microdata

Perera GDN¹, Pallegedara A¹

Department of Industrial Management, Faculty of Applied Sciences, Wayamba University of Sri Lanka
dilshaperera99@gmail.com

ABSTRACT

This study investigates the impact of poverty on household consumption expenditures in Sri Lanka. Focusing on food, non-food, healthcare, and education expenditures, the research examines how poverty influences these categories using secondary data from the Household Income and Expenditure Survey (HIES). Employing descriptive and regression analyses, this study provides insights into the dynamics between poverty and consumption. The findings emphasize the need for targeted policy interventions to alleviate poverty and improve consumption outcomes, ensuring sustainable development and better living standards.

KEYWORDS: Poverty, Household Consumption, Sri Lanka, Food expenditure, Non-Food Expenditure, Healthcare, Education, Household Income and Expenditure Survey

1 INTRODUCTION

Poverty, a multidimensional challenge, affects education, healthcare, and employment opportunities, shaping household consumption patterns. In Sri Lanka, poverty exhibits regional and socio-economic disparities, influencing expenditures on essential categories such as food, healthcare, and education. Analyzing these patterns offers valuable insights for policymaking aimed at sustainable development. The study addresses the lack of comprehensive understanding of how poverty influences consumption choices among Sri Lankan households, particularly in areas like food, healthcare, and education. By bridging this gap, the research aims to inform effective policy interventions. The objectives of this research study are;

- To examine the relationship between poverty and food expenditures.

- To assess the impact of poverty on non-food expenditures.
- To analyze how poverty affects healthcare spending.
- To investigate the effect of poverty on education-related expenditures.
- To explore mediating factors such as resource access and geographic disparities.

2 LITERATURE REVIEW

Keynesian consumption theory highlights the relationship between household income and consumption, emphasizing that poorer households allocate a larger proportion of their income to basic needs such as food, healthcare, and shelter (Keynes, 1936). The Permanent Income Hypothesis extends this by suggesting that households base their consumption on expected long

term income, although poorer households struggle with income shocks due to limited access to credit (Friedman, 1957). Sen's Capability Approach underscores the multidimensionality of poverty, linking it to a lack of opportunities and freedoms essential for a dignified life, such as adequate healthcare and education (Sen, 1999). The Life-Cycle Hypothesis suggests that households plan consumption and savings over their lifetime, but impoverished households often lack the means to save, leading to limited consumption during income instability (Modigliani & Brumberg, 1954). Lastly, the elasticity of demand demonstrates how price changes disproportionately affect low-income households, forcing them to adjust consumption significantly when basic goods become more expensive (Deaton, 1997). Poverty substantially influences household consumption patterns, with impoverished families prioritizing essential needs over long-term investments. Engel's Law states that the proportion of income spent on food decreases as income rises, highlighting that poorer households dedicate most of their income to food (Engel, 1857). In Sri Lanka, studies reveal that low-income families allocate a large share of their budget to food, with minimal spending on education and healthcare, perpetuating cycles of poverty (Department of Census and Statistics, 2019).

Microdata from the Household Income and Expenditure Survey (HIES) offers granular insights into income and expenditure patterns, allowing for a detailed analysis of poverty's impact on various consumption categories. HIES data captures regional and demographic disparities, enabling researchers to

explore the differential effects of poverty on urban versus rural households and across income quintiles. Such data supports empirical investigations into the allocation of household resources and helps identify vulnerabilities (Deaton & Muellbauer, 1980; World Bank, 2020).

Analyzing poverty's effect on consumption has significant policy implications. Effective poverty alleviation strategies should target specific consumption needs while addressing structural barriers to economic mobility. Social safety nets, targeted subsidies, and improved access to education and healthcare are essential to reduce disparities and improve living standards (Gunatilaka & Chotikapanich, 2006). This study's novelty lies in its category-specific analysis of poverty's impact on household expenditures—food, non-food, healthcare, and education—using recent HIES microdata. By integrating multidimensional economic frameworks and examining regional and socio-economic disparities, it provides actionable insights for targeted policy interventions, addressing critical gaps in existing research on poverty in Sri Lanka.

3 METHODOLOGY

The study employs a quantitative design using secondary data from the HIES, focusing on descriptive and regression analyses to examine poverty's impact on consumption. The research model is the multiple linear regression model:

- **Dependent Variable (Y):** Household consumption (food, non-food, healthcare, education).

- **Independent Variables:** Poverty, geographical location, resource access.

- **Equation:**

$$Y = \beta_0 + \beta_1(\text{Poverty}) + \beta_2(\text{Geographical Location}) + \beta_3(\text{Access to Resources}) + \epsilon$$

A stratified two-stage sampling method selects 2,500 households across Sri Lanka. The **stratified two-stage sampling method** was selected to ensure representativeness and precision in capturing the diverse socio-economic and geographic characteristics of Sri Lankan households. Stratified sampling allows for adequate representation of key subgroups, such as income levels and geographic regions, reducing variability within each group and improving the reliability of results. The two-stage approach enhances efficiency by first selecting larger units (e.g., districts) and then sampling households within those units, minimizing logistical challenges. This method aligns with the sampling framework used in the Household Income and Expenditure Survey (HIES), ensuring compatibility and facilitating targeted analysis of poverty's impact on household consumption. The 2019 HIES dataset ensures representative coverage of diverse socio-economic and geographic groups. Statistical analyses include:

- **Descriptive Statistics:** Illustrating expenditure distributions.
- **Inferential Statistics:** Employing regression models to identify relationships between poverty and expenditure categories.

4 RESULTS & DISCUSSION

The analysis highlights the multifaceted relationship between poverty and household consumption expenditures. Households below the poverty line allocate a significant share of their limited income to food, with mean food expenditure recorded at LKR 27,632.06. Non-food expenditures, which represent spending on non-essential goods and services, remain minimal at a mean of LKR 17,694.37. Healthcare and education expenditures, critical for long-term human capital development, are significantly constrained among poorer households. The average healthcare expenditure is LKR 1,991.78, while education expenditure stands at LKR 21,904.34, reflecting substantial barriers to accessing these essential services.

Regression analysis further substantiates these observations. The education expenditure model shows an R-value of 0.563, indicating a moderate negative relationship with poverty, and an R-squared value of 0.317, suggesting that 31.7% of the variability in education expenditure is explained by poverty levels. The coefficient demonstrates a significant reduction in spending as poverty increases ($p < 0.001$). Healthcare expenditures exhibit a weaker yet significant negative relationship, with an R-value of 0.342 and an R-squared value of 0.117, indicating that 11.7% of healthcare expenditure variability is attributed to poverty. The coefficient confirms the reduction in spending under increasing poverty levels ($p < 0.001$).

Food expenditure, a critical survival category, shows a moderate correlation with poverty, with an R-value of 0.476 and an R-squared value of 0.227. This

indicates that 22.7% of the variation in food expenditure is explained by poverty levels. The coefficient of ($p < 0.001$) underscores the substantial impact of poverty on food security. Non-food expenditures follow a similar trend, with an R-value of 0.340 and an R-squared value of 0.115, showing that 11.5% of the variability is linked to poverty. The coefficient of ($p < 0.001$) reflects the constrained spending on non-essential goods among poorer households.

These findings emphasize the critical need for targeted poverty alleviation measures. Education and healthcare expenditures are disproportionately affected, limiting opportunities for upward mobility and human capital development. Food security, being a fundamental need, requires immediate attention through policy interventions. Addressing regional disparities and improving resource accessibility are essential steps toward equitable development.

5 CONCLUSION & RECOMMENDATIONS

The findings of this study underscore the significant influence of poverty on household consumption patterns in Sri Lanka. Households below the poverty line allocate disproportionately more to food, while expenditures on non-food, healthcare, and education remain severely constrained. These limitations hinder human capital development and perpetuate cycles of poverty, emphasizing the need for policy interventions that directly address these disparities.

To mitigate the adverse effects of poverty, targeted subsidies for essential categories like food, healthcare, and education must be implemented.

Strengthening social safety nets and improving access to affordable services are vital steps toward reducing inequities. Additionally, addressing regional disparities through investments in infrastructure and resource distribution can promote inclusive development.

Future research should investigate the role of informal economies, environmental influences on consumption, and intra-household dynamics. By addressing these gaps, policymakers can design more effective poverty alleviation strategies that support sustainable development and improve household well-being.

REFERENCES

- Deaton, A. (1997). The analysis of household surveys: A microeconomic approach to development policy. World Bank Publications.
- Deaton, A., & Muellbauer, J. (1980). Economics and consumer behavior. Cambridge University Press.
- Department of Census and Statistics. (2019). Household Income and Expenditure Survey 2019. Colombo, Sri Lanka: Department of Census and Statistics.
- Engel, E. (1857). Die productions- und consumtionsverhältnisse des königreichs Sachsen. Zeitschrift des Statistischen Bureaus des Königlich Sächsischen Ministeriums des Inneren, 8, 1-54.
- Friedman, M. (1957). A theory of the consumption function. Princeton University Press.
- Gunatilaka, R., & Chotikapanich, D. (2006). Inequality trends and determinants in Sri Lanka 1980–2002: A Shapley approach to decomposition. Journal of Asian Economics, 17(5), 799-815.
- Keynes, J. M. (1936). The general theory of employment, interest, and money. Palgrave Macmillan.
- Modigliani, F., & Brumberg, R. (1954). Utility analysis and the consumption

IMPACT OF POVERTY ON HOUSEHOLD CONSUMPTION EXPENDITURES: AN EMPIRICAL
EVIDENCE USING SRI LANKAN MICRODATA

function: An interpretation of cross-section data. In K. K. Kurihara (Ed.), *Post-Keynesian economics* (pp. 388–436). Rutgers University Press.

- Sen, A. (1999). *Development as freedom*. Oxford University Press.
- World Bank. (2020). *Poverty and shared prosperity 2020: Reversals of Fortune*. World Bank Publication.



Investigating Learning Preferences for AI-Driven Tools: A Case Study of ChatGPT Integration among Undergraduates of Wayamba University of Sri Lanka

Sewwandika AWS¹, Pallegedara A¹

Department of Industrial Management, Faculty of Applied Sciences, Wayamba University of Sri Lanka
ssewwandika92@gmail.com

ABSTRACT

The research seeks to examine how university students would like to integrate ChatGPT in their day-to-day academic tasks through the lens of the Technology Acceptance Model (TAM), a widely used framework for understanding user acceptance of technology due to its robust ability to explain behavioral intentions. The main purpose of the research was to determine the construct, which includes perceived ease of use, perceived usefulness, attitude and trust, privacy concerns, and information quality, that is likely to influence the students' behavioral intention to use ChatGPT. Based on data from 361 Undergraduates collected through an online survey and analyzed using PLS-SEM, the findings indicate that ease of use ($R^2 = 54.3\%$) and usefulness ($R^2 = 68.9\%$) significantly impact attitudes and behavioral intentions, with trust playing a vital role in shaping perceptions. Privacy concerns enhance trust and perceived usefulness, while information quality has a relatively minor impact. These insights emphasize the importance of usability, privacy, and trust to encourage the widespread adoption of ChatGPT in education.

KEYWORDS: ChatGPT, TAM, University students, PLS-SEM

1 INTRODUCTION

ChatGPT is an artificial intelligence chatbot developed by OpenAI and has seen significant advancements, including the release of GPT-4 with improved contextual understanding. Its impact on organizational management has been extensively studied, considering its development, practical uses, ethical implications, governance mechanisms, regulations, and policies (Resti et al., 2023).

Research on ChatGPT has explored its applications and implications in fields such as education, research, healthcare, and finance (Ayinde et al., 2023). Intelligent agents, characterized as programs capable of autonomous action and decision-making based on environmental observations, human input,

and internal knowledge, exemplify this integration. The purpose of this study is to explore how undergraduate students at Wayamba University of Sri Lanka prefer to integrate ChatGPT into their academic tasks, addressing the limited research on its adoption in higher education. By using the Technology Acceptance Model (TAM), the research aims to identify key factors such as perceived ease of use, perceived usefulness, trust, privacy concerns, and information quality that influence students' attitudes and behavioral intentions. This understanding is intended to guide the effective adoption and optimization of AI-driven tools like ChatGPT in educational environments.

2 LITERATURE REVIEW

a. ChatGPT Definition and Importance

ChatGPT, a popular AI tool, offers ease of communication and idea exchange, making it accessible to non-experts. Its widespread use since November 2022 demonstrates its role in improving knowledge acquisition and educational support. (Iorliam & Ingio, 2024). It is a natural language model trained on a text database, able to generate human-like responses for user inputs. In a similar vein, Albayati (2024) investigated undergraduate students' perceptions and awareness of using ChatGPT as a regular assistance tool.

b. Technology Acceptance Model

In 1989, the Technology Acceptance Model (TAM) was developed by Davis. TAM is an accepted framework for understanding how users come to accept and use a technology. The Model has been widely use in numerous of researches offering insights into various aspects of technology adoption among users (Folkinshteyn & Lennon, 2016) Initially developed by Fred Davis in the 1980s and subsequently refined by Venkatesh and Davis in the 1990s (Davis et al., 1989), TAM has consistently proven reliable with studies reporting Cronbach's alpha values for core constructsnd valid across diverse technologies, including websites, mobile apps, social media, and e-commerce platforms (Gracin & Marangoni, 2019; Salloum et al., 2019).

c. Attributes for ChatGPT Integration Experimentation

The attributes are important for understanding and evaluating preferences in different contexts. The study by Indan et al. (2016) highlights the importance of

ease of use, trust, and usefulness in internet banking. Ease of use refers to the simplicity and efficiency of navigating online banking platforms.

For instance, studies show that perceived usefulness directly impacts users' behavioral intentions towards adopting mobile wallets like Gopay (Ramadhan & Saputro, 2024).and also the perceived benefits of using digital currencies, such as the digital RMB, also play a critical role in user acceptance (Yu & Zhan, 2024).

According to the findings of the previous research, perceived usefulness can have a positive impact on perceived ease of use, which in turn influences how users feel about the technology (Kim, 2023). But according to some research, like the Gopay study by Ramadhan & Saputro (2024), even though usability is important, it might not always have a direct effect on behavioral intention; in some situations, other factors might be more important.

3 METHODOLOGY

a. Research Design

This quantitative study employed a stratified random sampling method combined with a survey-based approach, targeting 361 undergraduates across diverse faculties at Wayamba University. The survey instrument, structured around TAM constructs, utilized a 5-point Likert scale to capture perceptions of PEOU, PU, trust, privacy, and information quality.

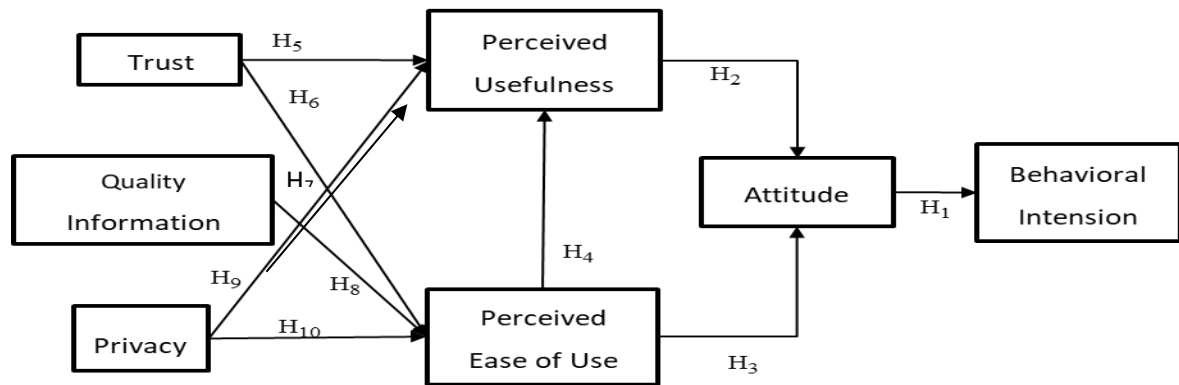


Figure 1: Conceptual Framework

b. Analytical Framework

Partial Least Squares Structural Equation Modeling (PLS-SEM) was employed to evaluate the structural relationships between constructs due to its ability to handle complex models with multiple latent variables and its suitability for exploratory research. This method is particularly suited for complex models involving latent variables and small-to-medium sample sizes. Reliability and validity checks, including Cronbach's alpha and composite reliability, ensured the robustness of the measurement model.

c. Data Collection

The surveys will include hypothetical scenarios presenting different attributes of ChatGPT integration, allowing participants to express their preferences. A convenience sampling approach will be used and the questionnaire was made in such way which could assist in collecting information regarding the factors impacting acceptance of ChatGPT by the undergraduate students of WUSL.

Hypothesis

H₁: Attitude significantly impacts on the

undergraduate's Behavioral Intention toward use of ChatGPT as a daily reference.

H₂: Perceived Usefulness significantly impacts the undergraduate's attitude toward ChatGPT as a daily reference.

H₃: Perceived Ease of Use significantly impacts undergraduates' attitudes toward using ChatGPT as a daily reference.

H₄: Perceived Ease of Use significantly impacts the undergraduates' perceived usefulness of ChatGPT as a daily reference.

H₅: Trust significantly impacts Perceived Usefulness toward the use of ChatGPT as a daily reference.

H₆: Trust significantly impacts Perceived Ease of Use toward the use of ChatGPT as a daily reference.

H₇: Information quality impacts toward the use of ChatGPT as a daily reference.

H₈: Information quality impacts Perceived Ease of Use toward the use of ChatGPT as a daily reference.

H₉: Privacy significantly impacts the Perceived Usefulness of the use of ChatGPT as a daily reference.

H₁₀: Privacy significantly impacts Perceived Ease of Use toward the use of ChatGPT as a daily reference.

4 RESULT AND DISCUSSION

The sample for research study comprised 372 undergraduate students in the Wayamba University of Sri Lanka. After removing missing responses and outliers, the finalized dataset included 361 responses. The demographic breakdown shows a female majority, with 68.14% of respondents identifying as female and 31.86% as male. The most recent age demographics showed that the major age group was 20-25 years old with 73.41% respondents, next out of the age groups was 26-30 years with 26.59%

a. Measurement Model

The study assesses internal consistency reliability using Cronbach's Alpha and Composite Reliability, with values exceeding 0.7 indicating sufficient reliability (Ahmad et al., 2023; Haji-Othman & Yusuff, 2022). Convergent validity is evaluated through Average

Variance Extracted (AVE), where values above 0.5 suggest that constructs explain a significant portion of variance in their indicators. This study uses cross-loadings and the Fornell-Larcker criterion to evaluate discriminant validity. According to table 1, These results validate the robustness of constructs such as Perceived Ease of Use, Perceived usefulness, Trust, Quality Information, Privacy, Attitude, and Behavioral Intention, ensuring the model's adequacy for further analysis.

b. Structural Model

The R² values indicate strong predictive power for Behavioral Intention (63.9%), Perceived Usefulness (68.9%), and Attitude (62.9%) showing large effects, while Perceived Ease of Use (54.3%) shows an acceptable large influence, reflecting a well-fitting and robust model

Table 1: Measurement Model Results

Item	Outer Loading	Cronbach's Alpha	Composite Reliability	AVE
A1 <- Perceived Ease of Use	0.919	0.899	0.937	0.833
A2 <- Perceived Ease of Use	0.882			
A3 <- Perceived Ease of Use	0.935			
B1 <- Perceived Usefulness	0.882	0.883	0.928	0.810
B2 <- Perceived Usefulness	0.929			
B3 <- Perceived Usefulness	0.889			
C1 <- Trust	0.940	0.920	0.950	0.863
C2 <- Trust	0.931			
C3 <- Trust	0.915			
D1 <- Quality Information	0.957	0.901	0.953	0.910
D2 <- Quality Information	0.951			
E1 <- Privacy	0.884			
E2 <- Privacy	0.877	0.903	0.932	0.774
E3 <- Privacy	0.889			
E4 <- Privacy	0.867			
F1 <- Attitude	0.926	0.891	0.932	0.820
F2 <- Attitude	0.884			
F3 <- Attitude	0.906			
G1 <- Behavioral Intention	0.941	0.933	0.957	
G2 <- Behavioral Intention	0.933			
G3 <- Behavioral Intention	0.943			

INVESTIGATING LEARNING PREFERENCES FOR AI-DRIVEN TOOLS: A CASE STUDY OF CHATGPT INTEGRATION AMONG UNDERGRADUATES OF WAYAMBA UNIVERSITY OF SRI LANKA

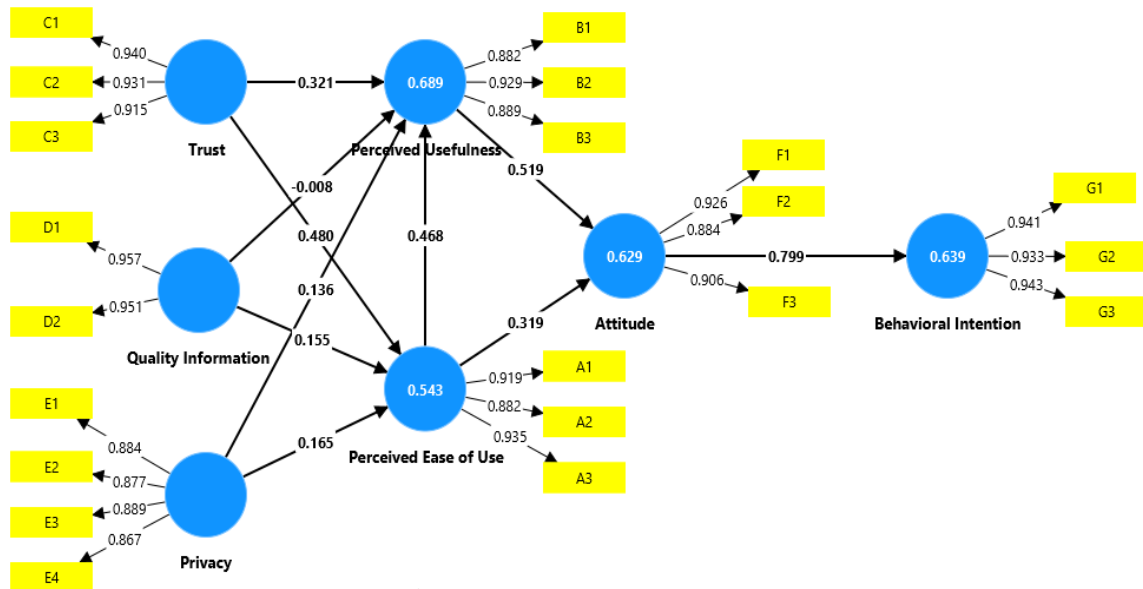


Figure 2: Path Analysis Results

The results show that most relationships in the model are statistically significant ($p < 0.05$), highlighting the strong influence of factors such as Attitude, Perceived Ease of Use, Privacy, and Trust on shaping key constructs. For instance, Perceived Ease of Use significantly influenced Behavioral Intention ($p = 0.003$), while Trust strongly impacted Perceived Usefulness ($p = 0.002$), emphasizing the roles of Attitude, Ease of Use, Privacy, and Trust in shaping key constructs. However, the pathway from Quality Information to Perceived Usefulness ($p = 0.424$) is not significant, indicating that quality information does not have a notable direct impact on perceived usefulness in this context.

5 CONCLUSION

The study explores the factors influencing undergraduate students' acceptance of ChatGPT as a learning tool, focusing on information quality, ease of use. It found that perceived usefulness and ease of use positively impact students' attitudes towards using ChatGPT, while trust and privacy are key factors. The

study recommends simplifying the interface and enhancing security to gain user trust and ensure accurate information. However, there are some limitations to the research including the fact that the sample was drawn from one university and the research was cross-sectional.

REFERENCES

- Albayati, H. (2024). Investigating undergraduate students' perceptions and awareness of using ChatGPT as a regular assistance tool: A user acceptance perspective study. *Computers and Education: Artificial Intelligence*, 6, 100203
- Ayinde, L., Wibowo, M. P., Ravuri, B., & Emdad, F. B. (2023, July 18). ChatGPT as an important tool in organizational management: A review of the literature. *Business Information Review*, 40(3), 137–149.
- Jones, R., & Johnson, M. (2019). The impact of artificial intelligence on student engagement: A meta-analysis. *Educational Psychology Review*, 36(2), 245-263
- Resti Tito H, V., & Maureen Lorence F, V. (2023, December 31). ChatGPT (Generated Pre-Trained Transformer) As an Adjunct to Mental Health

Interventions: A Commentary.
International Journal of Psychology and
Psychoanalysis, 9(1).

- Folkinshteyn, D., & Lennon, M. (2017).
Braving Bitcoin: A Technology
Acceptance Model (TAM)
analysis. Journal of Information
Technology Case and Application
Research, (2016), 220-249



Propensity to Adopt Pet Insurance: A Case Study Insurance Industry in Sri Lanka

Gunathilake AHMSB¹, Jayasena DM¹

Department of Industrial Management, Faculty of Applied Sciences Wayamba University of Sri Lanka

sandunigunathilake99@gmail.com

ABSTRACT

The Sri Lankan pet insurance market remains underdeveloped despite growing demand driven by increasing pet ownership and rising veterinary expenses. This study focuses on understanding the factors shaping pet owners' decisions to adopt pet insurance, emphasizing familiarity with pet insurance and financial vulnerability perception as key variables based on a survey of 322 pet owners. The analysis shows that familiarity with pet insurance has a limited influence on purchase intentions, while financial vulnerability perception demonstrates a moderate negative impact. These findings suggest that low awareness and concerns about affordability significantly hinder the adoption of pet insurance. To overcome these barriers, the study recommends targeted consumer education to improve understanding of pet insurance benefits and flexible pricing strategies to address affordability concerns. These insights provide actionable strategies for expanding the pet insurance market in Sri Lanka and similar developing economies.

KEYWORDS: Pet Insurance, Veterinary, Sri Lanka

1 INTRODUCTION

Sri Lanka's insurance sector, which traditionally focuses on life, health, and motor insurance, is now exploring opportunities in emerging areas like pet insurance. While established markets in North America and Europe have thrived due to increasing pet ownership and high veterinary costs, Sri Lanka remains underserved, presenting a clear market gap and potential for growth. Pet owners in the country often face significant financial strain from unexpected veterinary expenses, which can deter them from seeking timely care without appropriate insurance solutions. This study concentrates on two core objectives: (1) assessing the demand for pet insurance by analyzing familiarity with pet insurance and financial vulnerability perception and (2) providing actionable recommendations for designing a suitable

insurance product tailored to local pet owners. Through a survey of Sri Lankan pet owners, the research aims to uncover critical insights to inform the development of a pet insurance market segment. Globally, pet insurance has demonstrated its value by offering financial protection and improving animal welfare through better access to veterinary care. For Sri Lanka, introducing a well-designed and affordable pet insurance solution could address the financial challenges faced by pet owners while fostering customer trust and loyalty. This would not only benefit pets and their owners but also enable insurers to diversify their offerings and tap into a promising new revenue stream. By bridging the existing gap in the market and understanding consumer readiness, this study contributes to the strategic development of pet insurance as a viable

and impactful addition to Sri Lanka's insurance industry.

2 LITERATURE REVIEW

The global pet insurance industry has grown significantly, especially in North America and Europe, driven by rising veterinary expenses and increasing pet ownership (Mintel, 2023). Studies highlight that consumer familiarity with pet insurance is critical to adoption rates. Weiss and McGinty (2016) found that educational initiatives and awareness campaigns can improve understanding of pet insurance benefits, thereby increasing enrollment. However, in developing countries like Sri Lanka, pet insurance adoption remains low due to limited awareness and affordability concerns (Animal Medicines Australia, 2022). Research by Smith and Jones (2018) emphasized that financial constraints often deter potential adopters, as insurance is perceived as an additional expense rather than a cost-saving solution. Financial vulnerability has also been identified as a significant barrier to insurance adoption. According to Bain & Company (2019), individuals with greater financial vulnerability are more likely to avoid insurance due to cost-related fears. Flexible pricing strategies, such as tiered premiums, have proven successful in addressing affordability concerns in other markets. This study addresses gaps in existing research by exploring the relationship between consumer familiarity, financial vulnerability perception, and the adoption of pet insurance in Sri Lanka.

3 METHODOLOGY

This study employed a mixed-method approach to investigate factors

influencing the adoption of pet insurance in Sri Lanka, focusing on familiarity with pet insurance and financial vulnerability perception. Quantitative data were gathered through a survey of 322 pet owners to measure their awareness, financial concerns, and likelihood of purchasing pet insurance. Qualitative insights were obtained from interviews with 30 veterinarians to explore expert perspectives on consumer behavior and market challenges. The data were analyzed using descriptive statistics to identify key trends and regression models to evaluate the relationships between the variables. Regression results revealed that familiarity with pet insurance has a limited positive effect on adoption, while financial vulnerability perception shows a significant negative impact. This methodology allowed for a detailed understanding of informational and financial barriers, providing a foundation for strategies to improve awareness and affordability in the Sri Lankan pet insurance market.

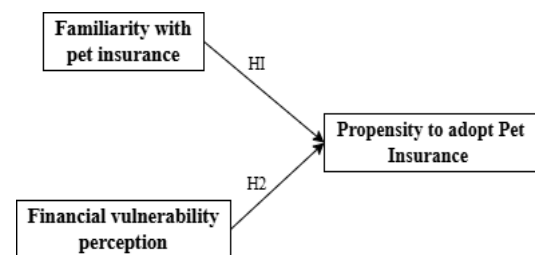


Figure 1: Hypothesis

H1: Familiarity with pet insurance is positively associated with the propensity to adopt Pet Insurance among pet owners.

H2: Financial vulnerability is positively associated with the propensity to adopt Pet Insurance among pet owners.

4 DATA ANALYSIS

The regression analysis conducted examined the impact of Familiarity with Pet Insurance and Financial Vulnerability Perception on the Propensity to Adopt Pet Insurance. The results revealed that familiarity with pet insurance had a weak positive relationship with the propensity to adopt it, as indicated by a correlation coefficient of 0.082 and a p-value of 0.132, which was not statistically significant. This suggests that familiarity alone does not significantly drive adoption intentions, indicating that other factors may play a more substantial role. In contrast, Financial Vulnerability Perception exhibited a significant negative relationship with the propensity to adopt pet insurance, with a correlation coefficient of -0.198 and a p-value of <0.001. This finding indicates that higher financial vulnerability perception strongly reduces the likelihood of adopting pet insurance, as pet owners who perceive themselves as financially vulnerable may be deterred by concerns about additional costs.

Overall, the analysis highlights that financial vulnerability perception is a critical determinant of adoption intention, whereas familiarity has a limited influence. To improve the adoption of pet insurance, strategies should focus on

alleviating financial concerns by offering affordable and flexible insurance plans while educating pet owners about the financial security that insurance can provide.

5 DISCUSSION AND CONCLUSION

This study investigated the factors influencing the **Propensity to Adopt Pet Insurance** among pet owners, focusing on two key variables: **Familiarity with Pet Insurance** and **Financial Vulnerability Perception**. The findings revealed that familiarity had a weak positive relationship with the propensity to adopt pet insurance, but the relationship was not statistically significant. This indicates that while awareness campaigns may be helpful, they alone are insufficient to drive adoption.

Conversely, financial vulnerability perception showed a significant negative relationship with adoption intention, suggesting that pet owners who perceive themselves as financially vulnerable are less likely to adopt pet insurance. This highlights affordability and cost concerns as major barriers to adoption.

The findings highlight that financial considerations significantly shape consumer behavior, with perceived financial risks acting as a major deterrent.

Table 1: Summary of the Analysis

Variable	Correlation	Significance (p-value)	Conclusion
Familiarity with Pet Insurance	0.082	0.132 – Not significant	Has a weak influence but does not significantly drive purchase intention
Financial Vulnerability Perception	-0.198	0.000 – Strongly significant	Has a Strong relationship, indicating that price sensitivity and risk aversion are crucial factors in decision-making.

This aligns with prior studies, such as Weiss and McGinty (2016), which emphasized affordability as a critical barrier to insurance adoption. Similarly, Bain & Company (2019) found that flexible pricing models effectively address cost sensitivity and increase adoption rates. Although familiarity with pet insurance has a limited influence on adoption, it is not a decisive factor, supporting insights by Smith and Jones (2018), who noted that awareness alone cannot drive consumer interest. To enhance adoption rates, insurers should implement flexible premium structures and educational campaigns that showcase the long-term financial benefits of pet insurance (Mintel, 2023; Animal Medicines Australia, 2022). Veterinarians play a crucial role in shaping consumer decisions (Weiss & McGinty, 2016). Beyond recommendations, efforts should focus on building trust and addressing consumer doubts about insurance offerings.

6 LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

This study was limited by its reliance on self-reported data, which may be subject to biases such as social desirability and recall inaccuracies. Additionally, the sample focused on a specific demographic of pet owners, potentially restricting the generalizability of findings. Rural or low-income pet owners, who may have unique financial concerns or attitudes toward pet insurance, were underrepresented.

The study did not account for variables such as household income, cultural attitudes, or pet types, which could influence adoption decisions. Despite these limitations, the research provides valuable insights into the role of

familiarity with pet insurance and financial vulnerability perception in shaping adoption intentions. By highlighting these key barriers, the study lays a foundation for future work to explore strategies to enhance awareness and affordability in the Sri Lankan pet insurance market.

REFERENCES

- American Pet Products Association (APPA). (2023). Strategic insights for the pet industry: Pet owners 2023 and beyond. National Pet Owners Survey (NPOS), Ukraine.
- Animal Medicines Australia. (2022). Pets in Australia: A national survey of pets and people. Animal Medicines Australia.
- Bain & Company. (2019). Measuring customer loyalty in insurance.
- Brakke, C. (2019). Animal health news & notes for October 25, 2019. Lynn Fondon DVM MBA, Greensboro.
- IBISWorld. (2020). Pet insurance in the US. Progressive Casualty Insurance Company.
- Kirk, C., & Rifkin, L. (2019). Dogs have masters; cats have staff: Consumers' psychological ownership and their economic valuation of pets. *Journal of Business Research*, 117, 399–404. <https://doi.org/10.1016/j.jbusres.2019.06.013>
- Lustgarten, J. L., Zehnder, A., Shipman, W., Ganchar, E., & Webb, T. L. (2020). [Details missing – Please provide complete information for this citation.]
- Mintel, S. (2023). UK Pet Insurance Market Report. UK: store.mintel.com.
- Packaged Facts. (2020). Pet insurance in the US.
- Smith, L., & Jones, R. (2018). Building veterinary partnerships: Strategies for pet insurance companies. *Journal of Veterinary Economics*, 45(2), 87–92. [Add DOI if available]

- Spender, A., Bullen, C., & A.-R., L. (2019). Wearables and the Internet of things: Considerations for the life and health insurance industry. *British Actuarial Journal*, 23, 1–15. <https://doi.org/10.1017/ba.2019.12>
- Weiss, E., & McGinty, M. (2016). The impact of pet insurance on veterinary spending. *Journal of Veterinary Economics*, 12(3), 45–60.



The Effect of Localization Success, Knowledge-sharing Tendency, and Cultural Intelligence on Multinational Company in Indonesia

Bayu Kurniawan¹, Qristin Violinda¹, Chadyan Fathurachman¹, Hawik Ervina Indiworo¹
Faculty of Business and Economics, Universitas PGRI Semarang
qviolinda@upgris.ac.id

ABSTRACT

This study aims to investigate the influence of knowledge-sharing tendencies on cultural intelligence and vice versa and how these two variables can support each other in creating an inclusive and productive work environment. We used SEM AMOS to assess the hypothesized Localization Success with Cultural Intelligence and knowledge-sharing tendency. We use a non-probability sampling technique with purposive random sampling for data collection. The data used is 107 samples. The results of the study indicate that knowledge-sharing tendency and cultural intelligence have a significant positive influence on cultural intelligence. Managerial implication from this research Employee can be given cross-cultural training to understand the cultural difference among nations. This research also helps to understand the importance of cultural intelligence for employees. Recruiting an employee with cultural intelligence will help the managers decrease the different levels of cross-culture among co-workers.

KEYWORDS: Localization success, Cultural intelligence, Knowledge-sharing tendency

1 INTRODUCTION

In the continuous growth of digitalization and globalization, one of the key successes is the ability of the organization to utilize the knowledge possessed by the individuals within it. The process of knowledge-sharing is an important element in creating an innovative and adaptive knowledge-based organization to change. The knowledge-sharing tendency (KST) is an individual's attitude and intention to voluntarily share knowledge, experiences, and skills with coworkers or other members of the organization. In a multicultural work environment, where cultural diversity is an inseparable part, successful knowledge-sharing requires additional capabilities, namely cultural intelligence (CQ). It has an important role as the bridge of cultural differences, where communication and collaboration become

the barriers. Localization Success (LS) refers to an organization's ability to integrate local talent effectively, a process often hampered by ethnocentric behaviors and inadequate knowledge-sharing mechanisms.

Localization success (LS), knowledge-sharing tendency (KST), and cultural intelligence (CQ) are interlinked factors that significantly influence organizational effectiveness in multicultural environments. This triadic relationship underscores the importance of integrating CQ training and fostering a knowledge-sharing culture to maximize localization outcomes and sustain competitive advantages.

The objective of this study is to investigate the influence of KST on CQ and vice versa, how these two variables can support each other in creating an inclusive and productive work

environment, and also to support the development of organizational policies that can encourage knowledge-sharing in multicultural environments.

2 LITERATURE REVIEW

2.1 *Localization Success and Cultural Intelligence*

Localization Success (LS) refers to the success of an organization in implementing a localization strategy, namely utilizing local labor, adapting products or services to local cultural preferences, and conducting business operations that are sensitive to the local cultural context. Cultural Intelligence (CQ), as defined by Earley and Ang (2003), is the ability of an individual to understand, adapt, and work effectively in cross-cultural situations. LS has a significant impact on the development of CQ because the localization process requires direct engagement with the local culture, continuous learning, and adaptation in various aspects of operations.

2.2 *Localization Success and Knowledge-sharing Tendency*

Knowledge-sharing tendency (KST) is the tendency of individuals or organizations to share information, ideas, or experiences in the work environment. LS can affect KST because this success creates trust, openness, and cross-cultural connections that strengthen collaboration. Social relationships in organizations are built on the principle of reciprocity. LS creates a sense of involvement and recognition for the local workforce. This increases their confidence in sharing knowledge and experiences that are relevant to the local context (Blau, 1964).

2.3 *Knowledge-sharing Tendency and Cultural Intelligence*

Knowledge shared between individuals or groups in a cross-cultural context becomes an asset that supports adaptation and cooperation so that KST increases the ability of individuals to understand the dynamics of different cultures, supporting the behavioural dimension of CQ (Teece, 1997). Knowledge-sharing supports better cross-cultural cooperation, allowing individuals to adapt quickly in multicultural contexts.

2.4 *Localization Success is Mediated by Knowledge-sharing Tendency towards Cultural Intelligence*

LS strengthens the social networks between the local workforce and the organization, creating conditions that support knowledge-sharing that will help individuals understand local cultural norms and values, thereby strengthening the cognitive and metacognitive dimensions of CQ (Nahapiet & Ghoshal, 1998). Successful localization increases the sense of involvement and appreciation of the local workforce, encouraging them to share their unique knowledge. The process of knowledge-sharing becomes a bridge between localization and the development of CQ (Deci & Ryan, 1985).

3 METHODOLOGY

This study conducted the pilot survey in Indonesia in September 2024, involving employees from a multinational company, and pre-tested it on a small group of respondents. The questionnaire was designed in Indonesian and English. Using a non-probability sampling technique with purposive random sampling technique.

Slovin test is conducted for sample adequacy and found that 107 should be an adequate sample size. The demographics of the sample were gender, type of employee, education, tenure, age, and work experience.

Instrument development

This study used a Likert scale to collect data from respondents. It adopted a questionnaire that was created, validated, and used by other researchers.

Localization success (LS)

A seven-item Likert-type scale developed by Law et al. (2009) was used to measure localization success. The internal consistency for this scale in this study was $\alpha = 0.910$.

Knowledge-sharing tendency (KST)

The Likert-type scale we used to measure KST was based on Bock et al.'s (2005) five-item scale used to measure Coworker knowledge-sharing tendency. The internal consistency for this scale in this study was $\alpha = 0.903$.

Cultural intelligence (CQ)

Thomas et al. (2015) was used to measure CQ consisting of a five-item Likert type used to evaluate the cultural intelligence of employees CQ. The internal consistency for this scale in this study was $\alpha = 0.932$. Demographic variables, age, gender, years of work experience, and type of employee were controlled in this study.

Statistical analysis

This study used PLS SEM V18.0 for descriptive analysis and correlation of variables. In SEM AMOS developed by Hayes was used to evaluate the mediation model, and the Model was used to

evaluate the moderated mediation model (Hayes, 2017). First, the independent variable (Ethnocentrism), the dependent variable (LS), and the mediator (KST) were used in the mediation study. The bootstrapping method to measure the indirect effect was used to determine the best mediation effect test, and the 95% confidence interval (CI) was determined. There were 5000 bootstrap samples.

Second, a test was conducted on the moderated mediation effect using the moderator (CQ). The moderated mediation effect can be found in the substantial interaction coefficient between CQ and KST. The moderating effect of CQ is indicated by looking at the conditional effect at one standard deviation (SD) above and below the mean. This investigation looks at whether there is a significant difference between the slope of the regression equation for high and low CQe values. At the 5% significance level, there is no significant mediation (indirect) effect if the confidence interval contains zero. After applying mean centering to the moderating and independent variables, multi-collinearity was reduced, and the same analysis was performed.

4 DATA COLLECTION AND ANALYSIS

In investigating the structural equations, the data is analyzed using partial least squares (PLS-SEM), applying SmartPLS 3.0 software for the analysis. It is implementing the second-order confirmatory factor analysis techniques. Therefore, the data is examined twice.

The validity test can be shown by referring to outer loading and AVE value; it shows that the assessment instrument

stated it had passed the validity test. Furthermore, the instrument reliability test is carried out by observing an Alpha Cronbach value above 0.70 and a reliability composite value above 0.70. all of the variables are considered can be trusted as they are having Alpha Cronbach value and composite reliability higher than the required threshold. The result of the chi-square test $283.337 < 300$ SRMR proven to have a value $0.075 < 0.484$, so the model is fit. Each value of d_{Uls} and d_G is 1.361 and 1.266, with significant values above 0.05. It shows the result is a little fit. The NFI value is 0.27, so the result is fit and fine. Finally, the value of RMS Theta is $0.162 > 0.102$, so the result shows a marginal fit.

The theory is assessed using the suggested model. Statistic-t > 1.96 is the result of the parameter in the PLS-SEM hypothesis test in supporting those hypotheses.

The result of analysis related to the direct effect test shows that Hypothesis 1, KST, has a positive effect on CQ with a value ($p = 0.045$). Hypothesis 2, the LS proven has an impact on CQ with value ($p = 0.032$), and Hypothesis 3 result LS has an impact towards KST with value ($p = 0.007$).

Table 1: Model Summary

Path coefficients – Mean, STDEV, T values, p values					
	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T statistics (O/STDEV)	P values
KST → CQ	0.192	0.205	0.096	2.004	0.045
LS → CQ	0.226	0.226	0.105	2.151	0.032
LS → KST	0.264	0.270	0.098	2.685	0.007

The indirect effect test for Hypothesis 4 shows that there is no impact among LS

towards CQ when it is mediated by KST with value ($p = 0.167$).

Table 2: Model Summary

Specific indirect effects – Mean, STDEV, T values, p values					
	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T statistics (O/STDEV)	P values
LS → CQ	0.051	0.057	0.037	1.382	0.167

5 RESULTS AND DISCUSSION

The study provides valuable insights into the interplay of KST, LS, and CQ, emphasizing the complexity of these organizational dynamics. Hypothesis 1, which posits that KST positively influences CQ, is supported with a statistically significant value ($p = 0.045$). This result highlights that employees who are inclined to share knowledge often enhance their CQ by actively engaging in cross-cultural interactions, learning from diverse perspectives, and fostering mutual understanding in multicultural teams (Van Greunen, 2022). Hypothesis 2 establishes that LS significantly impacts CQ ($p = 0.032$). This finding reflects that effectively integrating local talents not only strengthens organizational adaptability but also contributes to building cultural competence among employees. Successful localization fosters cultural sensitivity and equips employees to operate more effectively in diverse environments, as highlighted in the work of Lee (2024). For Hypothesis 3, the results reveal that LS significantly impacts KST ($p = 0.007$). This suggests that localization strategies that emphasize inclusion and collaboration enhance employees' willingness to share

knowledge. A supportive localization environment facilitates open communication, trust, and teamwork, which are critical for effective knowledge-sharing (Hernawati & Tajib, 2024). Interestingly, Hypothesis 4 finds that KST does not significantly mediate the relationship between LS and CQ ($p = 0.167$). This suggests that while LS and KST individually contribute to CQ, the mediating role of knowledge-sharing may be insufficient to explain their combined effect. Other factors, such as organizational culture or leadership style, might play a stronger role in this relationship, as suggested by Brătianu et al. (2024). These findings collectively underline the importance of fostering both LS and a knowledge-sharing culture to optimize CQ development while encouraging further exploration into indirect mechanisms influencing these dynamics.

6 CONCLUSION

The research findings have theoretical consequences that are significant for future research in human resource management related to the efficacy of human resource localization in multicultural workplaces. First, the findings provide new insights because ethnocentrism and LS through KST as the intervention have never been observed before. As a result, future research that examines the ethnocentrism behaviour and localization effectivity in the subsidiary company can find benefits in our findings. Second, based on literature analysis and publicized findings, the model presented in the study can be expanded in further investigations. Third, this study adds to the knowledge of employee ethnocentric behavior by

offering a more comprehensive understanding of the effectiveness of human resource localization. The specific findings of this study serve as a valuable reference point for anyone interested in the multicultural workplace. This research has contributed to increasing employee ethnocentrism management in multicultural workplaces. Employees can be given cross-cultural training to understand the cultural differences among nations. This research also helps to understand the importance of cultural intelligence for employees. Recruiting an employee with cultural intelligence will help the managers decrease the different levels of cross-culture among co-workers. Cultural intelligence will also help to decrease employee ethnocentric behaviour; thus, recruiting and maintaining an employee with cultural intelligence in the workplace is important for a multinational company. The dissemination of knowledge in a business is very important to drive innovation, increasing productivity, and maintaining competitive advantage. It needs knowledge, skill, and special knowledge-sharing among staff to grow cultural learning and continuous improvement. The multinational company has to take the initiative to reduce cultural resistance in the workplace, which, in turn, will drive the interaction and knowledge-sharing among employees that will contribute to the human resource localization process. Different from other studies, this research shows some limitations. The potential saturation increase in results can be realized by attaching data from various countries. This research uses a quantitative approach that tends to reduce complicated phenomena by turning them into measurable variables, which

sometimes resulting oversimplification and loss of subtle nuances. The representation may not fully capture the depth and complexity of human experience or the condition in which the attitude and behaviour manifested.

REFERENCES

- Ang, S., & Van Dyne, L. (2008). Conceptualization of cultural intelligence: Definition, distinctiveness, and nomological network. In S. Ang, & L. Van Dyne (Eds.), *Handbook of cultural intelligence: Theory, measurement, and applications* (pp. 3–15). Routledge.
- Ang, S., Van Dyne, L., Koh, C., Ng, K., Templer, K., Tay, C., & Chandrasekar, N. (2007). Cultural intelligence: its measurement and effects on cultural judgment and decision-making, cultural adaptation, and task performance. *Management and Organization Review*, 3(3), 335–371. <https://doi.org/10.1111/j.1740-8784.2007.00082.x>
- Bock, G. W., Zmud, R. W., Kim, Y. G., & Lee, J. N. (2005). Behavioral Intention formation in knowledge-sharing: Examining the roles of extrinsic motivators, social-psychological forces, and organizational climate. *MIS Quarterly*, 29(1), 87–111. <https://doi.org/10.2307/25148669>
- Blau, P. M. (1964). *Exchange and Power in Social Life*. John Wiley & Sons.
- Deci, E. L., & Ryan, R. M. (1985). *Intrinsic Motivation and Self-Determination in Human Behavior*. Springer.
- Earley, P. C., & Ang, S. (2003). *Cultural intelligence: Individual interactions across cultures*. Stanford, California: Stanford University Press. Stanford Business Books. Earley, P. C. (2002). Redefining interactions across cultures and organizations: Moving forward with cultural intelligence. *Research in Organisational Behavior*, 24, 271–299. [https://doi.org/10.1016/S0191-3085\(02\)24008-3](https://doi.org/10.1016/S0191-3085(02)24008-3)
- Earley, P. C., & Ang, S. (2003). *Cultural Intelligence: Individual Interactions Across Cultures*. Stanford University Press.
- Harman, H. H. (1960). *Modern factor analysis*. Chicago, IL: University of Chicago Press. Hayes, A. F. (2017). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. New York: Guilford Press.
- Keith, K. (2019). Ethnocentrism: Seeing the world from where we stand. In K. Keith (Ed.), *Cross-cultural psychology: Contemporary themes and perspectives*. Wiley. <https://doi.org/10.1002/9781119519348.ch2>.
- Kessler, T., & Fritsche, I. (2011). Ethnocentrism. *The Encyclopedia of Peace Psychology*. <https://doi.org/10.1002/9780470672532.wbepp107>
- Law, K., Song, L., Wong, C. S., & Chen, D. (2009). The antecedents and consequences of a successful localization. *Journal of International Business Studies*, 40(8), 1359–1373. <https://doi.org/10.1057/jibs.2009.31>
- Lee, L. Y., & Nguyen, P. T. (2019). A synthesis of expatriate competence, intelligence, adaptability, work-role demand, and organizational support on expatriation effectiveness. *International Journal of Services Standards*, 13(1–2), 83–103. <https://doi.org/10.1504/IJSS.2019.104305>
- Lee, J. J., & Hwang, J. (2024). Antecedents of American hospitality students' intercultural communication apprehension: Effect of ethnocentrism, cultural intelligence, and core self-evaluations. *Journal of Hospitality, Leisure, Sport & Tourism Education*, 34, Article 100464. <https://doi.org/10.1016/j.jhlste.2023.100464>
- Lee, A. P. (2023). Cultural intelligence as a predictor of organizational outcome. *International Journal of Cross-Cultural Management*, 23(2), 299–316.

[https://doi.org/
10.1177/14705958231187473](https://doi.org/10.1177/14705958231187473)

- Nahapiet, J., & Ghoshal, S. (1998). Social Capital, Intellectual Capital, and the Organizational Advantage. *Academy of Management Review*, 23(2), 242-266.
- Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic Capabilities and Strategic Management. *Strategic Management Journal*, 18(7), 509-533.



A Mathematical Model for Leukemia Cancer Treatment with Chemotherapy

Sathsarani AKN¹, Vithanage GVRK¹

Department of Mathematical sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka

[nadeerasathsarani99@gmail.com¹](mailto:nadeerasathsarani99@gmail.com)

ABSTRACT

This research develops a mathematical model to analyze the behavior of leukemia cancer cells under chemotherapy treatment. The model incorporates key biological variables, such as susceptible blood cells, infected blood cells, leukemia cells, and chemotherapy drugs. Two scenarios are studied: one without chemotherapy treatment and another one under chemotherapy. Differential equations are used to describe the interactions among these variables, illustrating how leukemia cells respond to chemotherapy. Through numerical simulations, the impact of various parameters, including the killing rate of infected cells and chemotherapy effectiveness, is explored. Results show that higher chemotherapy effectiveness leads to a quicker reduction in leukemia cell populations, whereas the absence of treatment allows cancer to proliferate. Stability analysis using Lyapunov's theorem reveals that both models reach equilibrium, with the treated system achieving significantly better outcomes. Sensitivity analysis identifies critical parameters, such as the natural death rate of cancer cells and chemotherapy concentration, that influence the treatment's success. These findings highlight the importance of tailoring chemotherapy strategies to optimize effectiveness. The model provides a quantitative framework for predicting chemotherapy outcomes, offering insights into treatment strategies for leukemia. Future research could improve this model by incorporating additional therapies, such as immunotherapy, and personalizing it with patient-specific data for more accurate predictions. This could further enhance the ability to design optimal treatment plans for leukemia patients, contributing to more effective and individualized care.

KEYWORDS: Cancer, Chemotherapy, Leukemia, Stability, Tumor

1 INTRODUCTION

Leukemia, a cancer of blood-forming tissues, disrupts normal blood cell production, leading to severe health complications. Unlike solid tumors, leukemia involves abnormal proliferation of immature blood cells, predominantly in the bone marrow, spilling into the bloodstream and affecting various organs. Symptoms range from anemia to frequent infections and excessive bleeding. Known risk factors include genetic predispositions, radiation exposure, and previous chemotherapy treatments.

Chemotherapy remains a cornerstone of leukemia treatment, aiming to reduce abnormal cell populations and restore normal hematopoiesis. However, optimizing chemotherapy regimens requires a detailed understanding of leukemia dynamics. Mathematical modeling offers a quantitative approach to predict outcomes and design effective treatment protocols. This study develops and analyzes a differential equation-based model to evaluate leukemia cell dynamics under chemotherapy, contributing to evidence-based treatment strategies.

2 LITERATURE SURVEY

Mathematical models have been widely used to study cancer dynamics and treatment efficacy. Nave explored combined chemotherapy and immunotherapy for brain cancer, identifying critical treatment points (Nave, 2022). Rodrigues examined chronic lymphocytic leukemia treatment (Rodrigues et al., 2019), finding superior outcomes with combined therapies. (Lestari et al., 2019) analyzed chemotherapy's impact on cancer growth, revealing the role of growth rates in determining treatment success. Yang highlighted (Yang, 2019) how high chemotherapy doses can induce drug resistance, emphasizing the need for optimal dosing strategies. Panetta introduced cycle-specific chemotherapy models, providing insights into individualized treatment (Panetta, 1995). Building on these studies, our model incorporates chemotherapy to address leukemia-specific dynamics, aiming to optimize treatment efficacy.

3 METHODOLOGY

a. Research design and rational

In our research, we try to get a solution among two types of models, and we see how they behave. These types are with the chemotherapy treatment and the model without the chemotherapy treatment. Therefore, we see how to change our model in these types.

- x =Susceptible blood cells,
- y =Infected blood cells,
- c_s =Leukemia cells,
- m =Chemotherapy drugs,

b. Model Without Chemotherapy Treatment

The equations are:

$$\begin{aligned}x' &= A - a_0x - \beta xc_s \\y' &= \beta xc_s - \beta_0y\end{aligned}\quad (1)$$

$$c_s' = k - k_0c_s$$

$$0 < x(0), 0 \leq y(0), 0 \leq c_s(0)$$

c. Model With Chemotherapy Treatment

The equations simplify to:

$$\begin{aligned}x' &= A - a_0x - \beta xc_s \\y' &= \beta xc_s - \beta_0y - k_tm \\c_s' &= k - k_0c_s - k_tc_sm \\m' &= -\gamma m + v_m \\0 &< x(0), 0 \leq y(0), 0 \leq c_s(0), \\&0 \leq m(0)\end{aligned}\quad (2)$$

Table 1: Baseline parameter values and description

Parameters	Base line Parametric value	Description
A	1.5	Recruitment rate of susceptible blood cells entering into the circulating blood from bone marrow.
a_0	0.01	Natural death rate of susceptible blood cells
β	0.00001	Decay rate of susceptible blood cells
β_0	0.3	Killing rate of infected blood cells
k_t	0.0001	Loss of cancer cells due to chemotherapy
k	10	Constant recruitment rate of cancer cells in to blood stream.
k_0	5	Natural death rate of cancer cells
γ	0.01	Rate of decrease in concentration of chemotherapy
v_m	0.9	Supply rate of chemotherapy

At the beginning we are considering the initial values as $x = 5 \times 10^4$, $y = 10 \times 10^4$, $c_s = 10^6$ and the other parameter values are taken as in table 1(Lestari et al ,2019). By considering for 5000 days, we represented 3D graphs to study how equilibrium occurs in without the chemotherapy treatment.

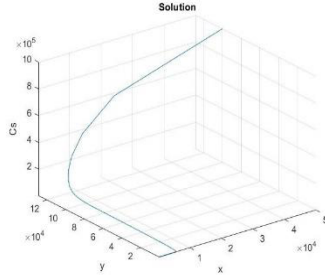


Figure 1: Continuous solution curve of the system for 5000 days.

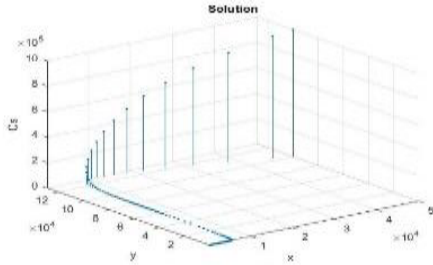


Figure 2: Stem plot diagram of the solution of the system for 5000 days.

d. Numerical simulations of base model

This section analyzes the model numerically, observing the impact of β_0 , k_t , k_0 on infected blood and leukemia cells.

e. Stability and Sensitivity Analysis

Equilibrium points are derived, and stability is assessed using the Jacobian matrix and Lyapunov's theorem. Sensitivity analysis evaluates the impact of parameter variations on model outputs, focusing on critical parameters like natural death rates and chemotherapy concentration.

4 RESULTS AND DISCUSSION

a. Change the killing rate of infected blood cells

Changing β_0 affects tumor population dynamics, with higher values leading to rapid decline, indicating more effective cancer control. (a) $\beta_0 = 0.003$, (b) $\beta_0 = 0.03$, (c) $\beta_0 = 0.3$.

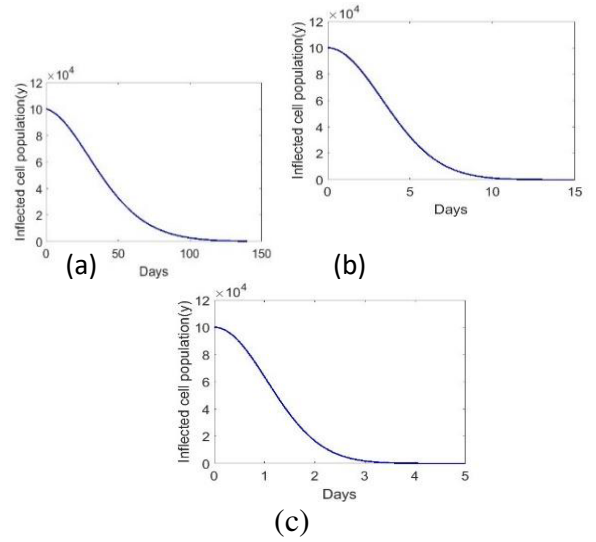


Figure 3: Behavior of infected cell population according to the killing rate of infected blood cells (β_0).

b. Change in loss of cancer cells due to chemotherapy

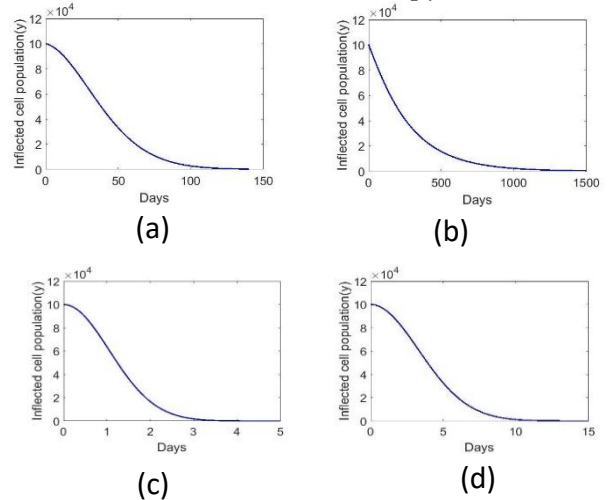


Figure 4: Behavior of infected cell population with the rate of loss of cancer cells due to chemotherapy (k_t), (a) $k_t = 0.0001$, (b) $k_t = 0.001$, (c) $k_t = 0.01$, (d) $k_t = 1$. Varying the interaction rate

constant k_t impacts tumor cell control, with higher values leading to faster reductions in cancer populations.

c. Change natural death rate of cancer cells and analyzing the population of leukemia cells

Higher k_o leads to quicker stabilization with lower c_s , while lower k_o prolongs dynamics and stabilization with higher c_s . (a) $k_o = 0.005$, (b) $k_o = 0.05$, (c) $k_o = 0.5$

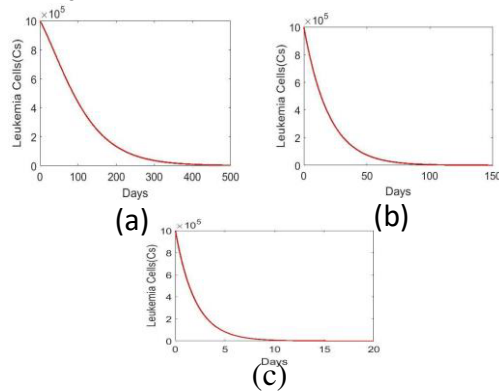


Figure 5: Behavior of increasing natural death rate of cancer cells and analyzing the behavior of leukemia cells (k_o)

d. Sensitivity analysis

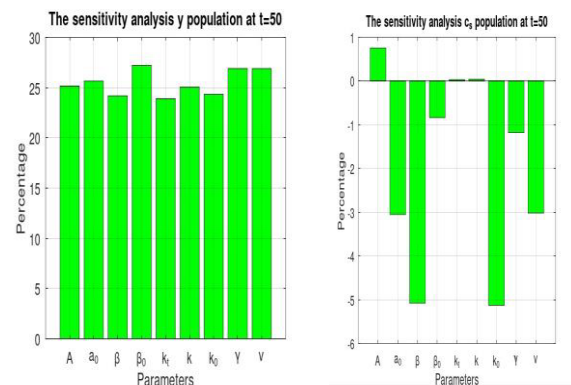


Figure 6: Local sensitivity analysis y and population at $t = 50$.

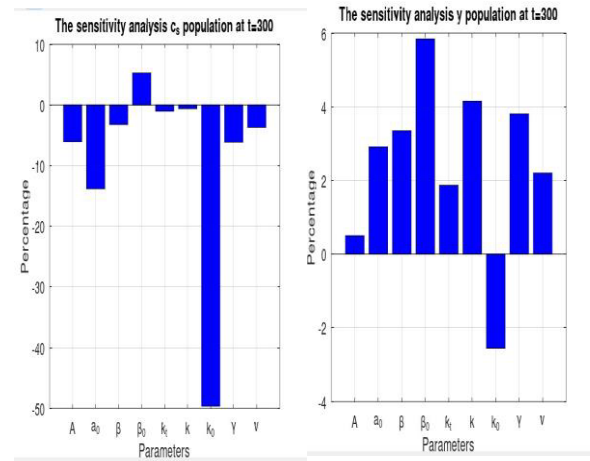


Figure 7: Local sensitivity analysis c_s and y population at $t = 300$.

In Fig. 6, study shows that the decay rate of susceptible blood cells, death rate of cancer cells, and chemotherapy supply rate significantly impact leukemia cell reduction in short-term treatments. Fig. 7 study in long-term chemotherapy treatment, the natural death rates of cancer and susceptible blood cells significantly reduce leukemia cell population.

5 CONCLUSION

This research develops a mathematical model to analyze leukemia treatment, highlighting the impact of chemotherapy on cancer cell reduction. It emphasizes key parameters such as chemotherapy concentration, natural death rates, and the supply rate. The model aids in predicting treatment outcomes, offering insights for personalized therapies and future improvements with additional treatments.

REFERENCES

- Lestari, D., Sari, E. R., and Arifah, H., (2019) have examined Dynamics of a mathematical model of cancer cells with chemotherapy. In *Journal of Physics: Conference Series* (Vol. 1320, No. 1, p. 012026). IOP Publishing.

- Nave,O., (2022) have examined a mathematical model for treatment using chemoimmunotherapy. *Heliyon*, 8(4).
- Panetta, J. C., and Adam, J., (1995) have examined a mathematical model of cyclespecific chemotherapy. *Mathematical and computer modelling*, 22(2), 67-82.
- Rodrigues, D. S., Mancera, P. F., Carvalho, T. D., and Gonçalves, L. F., (2019) have examined a mathematical model for chemoimmunotherapy of chronic lymphocytic leukemia. *Applied Mathematics and Computation*, 349, 118-133.
- Yang, H., and Lei, J., (2019) have examined a mathematical model of chromosome recombination-induced drug resistance in cancer therapy. *Mathematical Biosciences and Engineering*, 16(6), 7098-7111.



Application of a Fifth-Order Runge-Kutta Variant to Riccati Equation

Jayasinghe BHO¹, Gunarathna WA¹, Mohamed MA¹

Department of Physical Sciences, Faculty of Applied Sciences, Rajarata University of Sri Lanka
jhimanthi@gmail.com

ABSTRACT

The quadratic Riccati Differential Equation (RDE), a non-linear ordinary differential equation, has found numerous applications in many fields including biology, finance, stochastic processes, and engineering. Solving the RDE analytically is challenging due to several reasons such as the lack of closed-form solutions, complex solution forms, and singularity issues. As a result, numerical methods are widely applied for obtaining approximate solutions for the quadratic Riccati equation. The initial-value problem for RDE, denoted by IVP RDE, with the initial condition $y(t_0) = \alpha \in \mathbb{R}$, is given by $y'(t) = p(t) + q(t)y + r(t)y^2 = f(t, y)$, where $p(t), q(t)$, and $r(t) (\neq 0)$ are continuous functions defined on the interval $[t_0, T]$. Recently, the classical fourth-order Runge-Kutta (RK4) method has been applied to obtain numerical solutions for IVP RDE. In this paper, a fifth-order Runge-Kutta method is applied to the quadratic Riccati differential equation. The convergence and stability of the proposed method are analyzed by linearizing the Riccati differential equation. Several numerical test examples are solved in this paper to demonstrate its numerical effectiveness. Maximum absolute errors at internal grid points are computed for various grid sizes. These maximum absolute errors are then compared with those obtained using the fourth-order Runge-Kutta method... Numerical test examples confirm that the proposed method is more accurate than the fourth-order Runge-Kutta method.

KEYWORDS: Higher Order Derivatives, Initial-Value Problem, Riccati Differential Equation, Runge-Kutta Method

1 INTRODUCTION

The Riccati Equation, introduced by the Italian mathematician Jacopo Francesco Riccati (Kravchenko, 2009), is a first-order, non-linear ordinary differential equation that finds numerous applications in various applied fields, including biology, engineering, control theory, stochastic processes, quantum mechanics, and finance (Kengne et al, 2013; Boyle et al, 2002). For example, Sergei Kozyrev has used a matrix form of the Riccati equation to present a generalized form of the Eigen's model in population genetics, explaining known patterns of genomic evolution. (Kozyrev, 2023).

The Riccati differential equation (RDE) is given by

$$\frac{dy}{dt} = p(t) + q(t)y + r(t)y^2,$$

where $p(t), q(t)$, and $r(t) (\neq 0)$ are continuous functions defined on a desired interval. If $r(t) = 0$, the RDE reduces to a first-order linear differential equation. However, the quadratic term in y, y^2 , when $r(t) \neq 0$, makes the RDE nonlinear. Because of the non-linearity, solving the Riccati differential equation has become more complicated. Obtaining analytical solutions of the RDE is challenging due to the lack of closed-form solutions, complex solution forms, and singularity issues (Sunday, 2017). Consequently, numerical methods are often preferred for solving the form Riccati equations (Dieci, 1992; File & Aga, 2016). Recently, File and Aga (File & Aga, 2016)

employed the classical fourth-order Runge-Kutta method to obtain numerical solutions with an accuracy of order 4 for the RDE, establishing its stability and convergence analysis. Numerical solutions with greater accuracy are still of importance in many applications.

A numerical method is stable if the errors introduced during computations do not grow unbounded as the calculations proceed. A numerical method is consistent if the local truncation error tends to zero as the step size $h \rightarrow 0$. This study aims to apply a fifth-order Runge-Kutta method to numerically solve the RDE. The Butcher's fifth-order Runge-Kutta approximation (BRK5) is utilized, as derived in (Butcher, 2016), to obtain numerical solutions for the RDE. The stability and convergence of the proposed method are analyzed, and several numerical test examples are provided to illustrate the effectiveness of the BRK5.

The remaining sections of this paper are presented as follows. Section 2 presents literature review. Section 3 presents a fifth order scheme and its analysis. Numerical tests and results are presented in Section 4, Section 5 concludes the paper.

2 LITERATURE REVIEW

In recent literature, several approaches have been proposed to solve the Riccati equation numerically, with a focus on obtaining accurate solutions. (Chu et al., 2006) applied generalization of the generalized eigenvalue approach for the classical algebraic Riccati equations to get numerical solutions for the RDE. Mehrdad and Mehdi (Lakestani & Dehghan, 2010) applied Cubic B-spline scaling functions and Chebyshev cardinal

functions to solve Riccati equation numerically expanding the required approximate solution as the elements of cubic B-spline scaling function or Chebyshev cardinal functions. In 2024, a new two-step second derivative block method (TSDBM) using Bernstein polynomials of convergence order six is proposed for solving Riccati Differential Equations (Ezekiel et al., 2024). The TSDBM is constructed through collocation and interpolation techniques at specific points, and it is executed in block mode to calculate approximate solutions at two points per phase, thereby reducing computation time. Juan Zhang explored the utilization of machine learning techniques for solving the numerical solutions of continuous-time differential Riccati equations. Specifically, by focusing on generating a reduction matrix capable of transforming a high-order matrix into a low-order matrix (Zhang et al., 2024).

3 METHODOLOGY

3.1 Riccati Initial-Value Problem

The initial-value problem for the quadratic form of the Riccati equation, with the initial condition $y(t_0) = \alpha \in \mathbb{R}$, is given by,

$$\frac{dy}{dt} = p(t) + q(t)y + r(t)y^2 \quad (1)$$

$$= f(t, y),$$

$$y(t_0) = \alpha, \quad (2)$$

where $p(t), q(t)$, and $r(t) (\neq 0)$ are continuous functions defined on the real interval domain $[t_0, T]$.

3.2 A Fifth-Order Runge-Kutta Approximation

The Butcher's fifth-order Runge-Kutta approximation (BRK5)(Butcher, 2016) has the following formulas,

$$y(t+h) = y(t) + \frac{h}{90}(7K_1 + 0.K_2 + 32k_3 + 12k_4 + 32k_5 + 7k_6), \quad (3)$$

Where,

$$\begin{aligned} K_1 &= f(t, y), \\ K_2 &= f\left(t + \frac{h}{4}, y + \frac{hK_1}{4}\right), \\ K_3 &= f\left(t + \frac{h}{4}, y + \frac{hK_1}{8} + \frac{hK_2}{8}\right), \\ K_4 &= f\left(t + \frac{h}{2}, y - \frac{hK_2}{2} + hK_3\right), \\ K_5 &= f\left(t + \frac{3h}{4}, y + \frac{3hK_1}{16} + \frac{9hK_4}{16}\right), \\ K_6 &= f\left(t + h, y - \frac{3hK_1}{7} + \frac{2hK_2}{7} + \frac{12hK_3}{7} - \frac{12hK_4}{7} + \frac{8hK_5}{7}\right) \end{aligned} \quad (4)$$

and $h > 0$ is the grid size. This approximates the derivative $y'(t)$ at the point $(t, y(t))$ with a local truncation error $O(h^6)$. Therefore, the overall order of the approximation is 5.

3.3 Discretization of the RDE

To discretize the RDE, the interval $[t_0, T]$ is partitioned into N equally spaced sub-intervals, each with a constant grid length h . Then, a typical grid point $t_j \in [t_0, T]$ is given by $t_j = t_0 + jh$, where $j = 0, 1, \dots, N$. An approximation of the exact solution $y(t_j)$ of the RDE at the point t_j is denoted by y_j . Then the discretized form of the RDE using the BRK5 method gives:

$$y_{j+1} = y_j + \frac{h}{90}(7K_1 + 32k_3 + 12k_4 + 32k_5 + 7k_6), \quad j = 0, 1, \dots, N-1, \quad (5)$$

where the terms K_i for $i = 1, 3, 4, 5, 6$ are calculated at the point (t_j, y_j) for $j = 0, 1, 2, \dots, N-1$ using the formulas in (4).

3.4 Analysis of the Method

To study absolute stability of the proposed method, the following linear test equation, a linearized form of (1) is used:

$$\frac{dz}{dt} = \lambda z, \quad z(t_0) = z_0.$$

Now, BRK5 given by (5) is exploited to the preceding test equation at point (t_j, y_j) to get the following scheme:

$$\begin{aligned} K_1 &= \lambda y_j, \\ K_2 &= (\lambda + 1/4\lambda^2 h)y_j, \\ K_3 &= (\lambda + 1/4\lambda^2 h + 1/32\lambda^3 h^2)y_j, \\ K_4 &= (\lambda + 1/2\lambda^2 h + 1/8\lambda^3 h^2 + 1/32\lambda^4 h^3)y_j, \\ K_5 &= (\lambda + 3/4\lambda^2 h + 9/32\lambda^3 h^2 + 9/128\lambda^4 h^3 + 9/512\lambda^5 h^4)y_j, \\ K_6 &= (\lambda + \lambda^2 h + 1/2\lambda^3 h^2 + 9/56\lambda^4 h^3 + 3/112\lambda^5 h^4 + 9/448\lambda^6 h^5)y_j \end{aligned} \quad (7)$$

Now, on substituting K_i for $i = 1, 2, \dots, 6$ into (5) and simplifying yields the following equation:

$$\begin{aligned} y_{j+1} &= \left(1 + z + \frac{z^2}{2} + \frac{z^3}{6} + \frac{z^4}{24} + \frac{z^5}{120} + \frac{z^6}{640}\right)y_j, \\ &= 0, 1, \dots, N-1. \end{aligned} \quad (8)$$

Let $z = \lambda h$ and

$$R(z) = \left(1 + z + \frac{z^2}{2} + \frac{z^3}{6} + \frac{z^4}{24} + \frac{z^5}{120} + \frac{z^6}{640}\right)y_j,$$

Then, we have:

$$y_{j+1} = R(z)y_j, \quad j = 0, 1, \dots, N-1. \quad (9)$$

It is worth mentioning that the BRK5 is absolutely stable if and only if $|R(z)| \leq 1$. Figure 5 shows the region of absolute

Table 1: Maximum errors for different step sizes: Examples1 3

h	Ex1		Ex2		Ex3	
	RK4	BRK5	RK4	BRK5	RK4	BRK5
1/5	8.8818e-16	8.8818e-16	1.9794e-04	4.7419e-06	9.3617e-05	2.0406e-09
1/10	8.8818e-16	4.4409e-16	1.3245e-05	1.6695e-07	6.2225e-06	3.1028e-11
1/40	1.3323e-15	1.7764e-15	5.4441e-08	1.8010e-10	2.5327e-08	7.1054e-15
1/70	4.8850e-15	5.3291e-15	5.8545e-09	1.1124e-11	2.7154e-09	8.8818e-16
1/100	2.6645e-15	3.1086e-15	1.4105e-09	1.8797e-12	6.5340e-10	8.8818e-16
1/200	3.5527e-15	3.5527e-15	8.8507e-11	5.8842e-14	4.0941e-11	1.3323e-15
1/400	2.5757e-14	2.5757e-14	5.5440e-12	1.6653e-14	2.5606e-12	1.7764e-15

stability of the BRK5 method. It is found that the interval of absolute stability is $(-3.35, 0)$. This means that h needs to be selected such that $\lambda h \in (-3.35, 0)$. Therefore, the stability condition is $h < \frac{3.35}{|\lambda|}$. Let

$$\phi = \phi(x, y, h) = \frac{1}{90}(7K_1 + 32k_3 + 12k_4 + 32k_5 + 7k_6).$$

To check the consistency of BRK5 with the RDE, consider $\phi(x, y, 0)$ (Burden & Faires, 1997). When $h = 0$, from Equation (4), we have $K_i = f(x, y)$ for all $i = 1, 2, \dots, 6$. Then,

$$\begin{aligned} \phi(x, y, 0) &= \frac{1}{90}(7f(x, y) + 32f(x, y) \\ &\quad + 12f(x, y) \\ &\quad + 32f(x, y) \\ &\quad + 7f(x, y)) = f(x, y). \end{aligned} \quad (10)$$

Therefore, the BRK5 is consistent with the RDE. Since that BRK5 is both stable and consistent, therefore we conclude that BRK5 method is convergent.

4 RESULTS

We consider the following set of test examples (File & Aga, 2016):

Example 1

$$y' = 16t^2 - 5 + 8ty(t) + y^2(t), 0 \leq t \leq 1; y(0) = 1 \text{ The exact solution } y(t) = 1 - 4t$$

Example 2

$$y'(t) = 1 + 2y(t) - y^2(t), 0 \leq t \leq 1; y(0) = 0 \text{ The Exact solution}$$

$$y(t) = 1 + \sqrt{2} \tanh(\sqrt{2}t + 0.5 \ln(\frac{\sqrt{2}-1}{\sqrt{2}+1}))$$

Example 3

$$y'(t) = e^t - e^{-3t} + 2e^{2t}y(t) - e^ty^2(t), 0 \leq t \leq 1; y(0) = 1.$$

The exact solution $y(t) = \exp(t)$.

Example 4

$$y'(t) = \frac{-1}{1+t} + y(t) - y^2(t), 0 \leq t \leq 1; y(0) = 1$$

Table 2: Maximum errors for different step sizes: Example 4

h	Ex4	
	RK4	BRK5
1/5	1.5010e-05	2.6267e-07
1/10	7.9961e-07	7.8626e-09
1/40	2.7304e-09	7.3281e-12
1/70	2.8533e-10	4.4309e-13
1/100	6.7954e-11	7.4052e-14
1/200	4.2071e-12	2.3315e-15
1/400	2.6129e-13	6.6613e-16

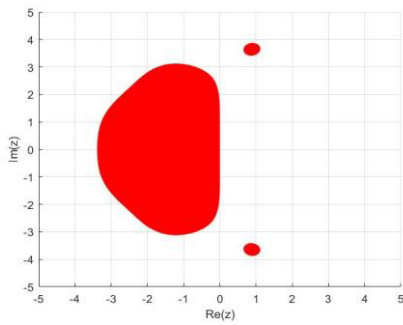


Figure 1: Region of Absolute Stability Of BRK5

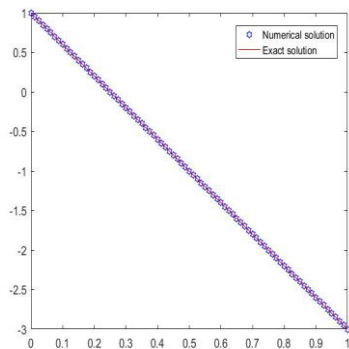


Figure 2: Example 1: Numerical and exact solutions for N=80.

To demonstrate numerical accuracy of the BRK5 method, we present the maximum error on the grid $G = \{t_j | j = 0, 1, 2, \dots, N\}$, defined $\max_{t_j \in G} |y_j - y(t_j)|$, where y_j and $y(t_j)$ represent the numerical and exact

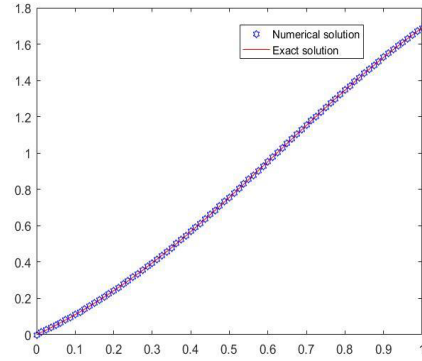


Figure 3: Example 2: Numerical and exact solutions for N=80.

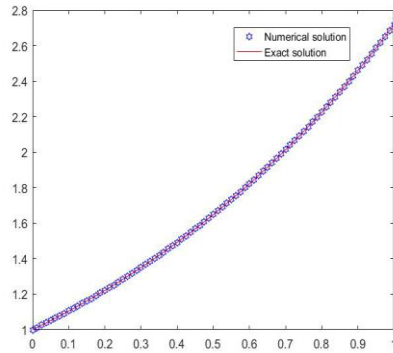


Figure 4: Example 3: Numerical and exact solutions for N=80.

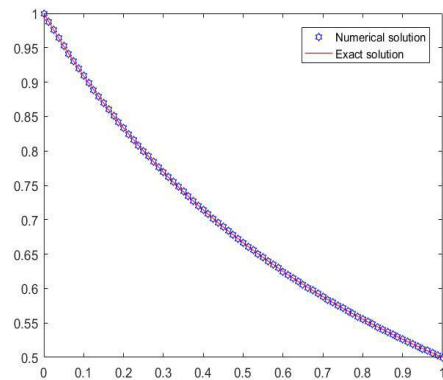


Figure 5: Example 4: Numerical and exact solutions for N=80.

solutions at $t_j, j = 0, 1, 2, \dots, N$, respectively. The maximum errors of the BRK5 with those of the classical fourth-order Runge-Kutta method (RK4) are compared at various grid sizes (h) Tables 1 and 2 depict

the maximum errors of RK4 and BRK5 for Examples 1-3 and Example 4, respectively. Fig. 2-5 displays the graphs of the numerical and exact solution for each example when $N=80$.

5 CONCLUSION

In this study, Butcher's fifth-order Runge-Kutta approximation has been applied to obtain numerical solutions for quadratic Riccati equations. The convergence and stability of the proposed method have been analyzed, and the region of absolute stability for the proposed RK5 has been determined. Numerical test examples presented confirm the accuracy of the proposed order 5 method.

REFERENCES

- Boyle, P. P., Tian, W., & Guan, F. (2002). The Riccati Equation in Mathematical Finance. *Journal of Symbolic Computation*, 33(3), 343–355. <https://doi.org/https://doi.org/10.1006/jSCO.2001.0508>
- Burden, R. L., & Faires, J. D. (1997). *Numerical Analysis* (6th ed.). Brooks/Cole Publishing Company.
- Butcher, J. C. (2016). *Numerical Methods for Ordinary Differential Equations*. Wiley. <https://books.google.lk/books?id=JISvDA AAQBAJ>
- Chu, D., Lin, W. W., & Tan, R. C. E. (2006). A numerical method for a generalized algebraic Riccati equation. *SIAM Journal on Control and Optimization*, 45(4), 1222–1250. <https://doi.org/10.1137/050625035>
- Dieci, L. (1992). Numerical Integration of the Differential Riccati Equation and Some Related Issues. *SIAM Journal on Numerical Analysis*, 29(3), 781–815. <https://doi.org/10.1137/0729049>
- Ezekiel, O., Ige, O., Onu, P., Florence, A., Akinwumi, T., & Ajewole, K. (2024). *On the Numerical Approximation of First-order Riccati Differential Equations by Two-step Second Derivative Block Method with Bernstein Polynomial Basis*. 1–9. <https://doi.org/10.1109/SEB4SDG60871.2024.10629916>
- File, G., & Aga, T. (2016). Numerical solution of quadratic Riccati differential equations. *Egyptian Journal of Basic and Applied Sciences*, 3(4), 392–397. <https://doi.org/10.1016/j.ejbas.2016.08.006>
- Kengne, E., Hamouda, F. Ben, & Lakhssassi, A. (2013). Extended Generalized Riccati Equation Mapping for Thermal Traveling-Wave Distribution in Biological Tissues through a Bio-Heat Transfer Model with Linear/Quadratic Temperature-Dependent Blood Perfusion. *Applied Mathematics*, 04(10), 1471–1484. <https://doi.org/10.4236/am.2013.410199>
- Kozyrev, S. (2023). Learning by Population Genetics and Matrix Riccati Equation. *Entropy*, 25(2). <https://doi.org/10.3390/e25020348>
- Kravchenko, V. V. (2009). Complex riccati equation. *Frontiers in Mathematics*, 2009, 65–72. https://doi.org/10.1007/978-3-0346-0004-0_6
- Lakestani, M., & Dehghan, M. (2010). Numerical solution of Riccati equation using the cubic B-spline scaling functions and Chebyshev cardinal functions. *Computer Physics Communications*, 181(5), 957–966. <https://doi.org/10.1016/j.cpc.2010.01.008>
- Sunday, J. (2017). Riccati Differential Equations: A Computational Approach. *Archives of Current Research International*, 9(3), 1–12. <https://doi.org/10.9734/acri/2017/36267>
- Zhang, J., Zou, W., & Sui, C. (2024). Backward differentiation formula method and random forest method to solve continuous-time differential Riccati equations. *Asian Journal of Control*, n/a(n/a). <https://doi.org/https://doi.org/10.1002/asjc.3494>



Exploring a Modular Arithmetic-Based Primality Testing Method Using Cubes of Primes

Sankalpani WLT¹, Dharmawardane PMN¹

Department of Mathematical Sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka

tharushisankalpani150@gmail.com

ABSTRACT

Prime numbers play a crucial role in number theory, cryptography, and secure communication. This study introduces a novel modular arithmetic-based primality testing algorithm, focusing on the cubic residues of prime numbers greater than 11. The research identifies unique modular patterns, demonstrating that cubes of such primes are one more or one less than a multiple of selected divisors (3, 4, 6, 7, 9, 14, and 18). Utilizing this property, a new primality testing method is proposed and evaluated against established algorithms like the Sieve of Eratosthenes, Miller-Rabin, and the Sieve of Atkin. The efficiency of the algorithm is assessed based on execution time, space complexity, and scalability across different input ranges, including large prime numbers. Results indicate that the proposed method significantly reduces memory usage while maintaining high accuracy, making it a viable alternative for prime identification, especially in cryptographic applications. The findings offer practical applications in cryptography, where the rapid and efficient identification of large primes is critical for enhancing encryption strength. In addition, the findings contribute to the ongoing quest for efficient primality tests, offering insights into the mathematical properties of primes and potential advancements in computational number theory. Future work may focus on further optimizing the algorithm and exploring its applications in secure key generation for encryption systems.

KEYWORDS: Cubes of Prime, Prime Numbers, Modular Arithmetic, Number Theory

1 INTRODUCTION

In light of their special characteristics and vital importance in number theory and real-world applications like encryption, prime numbers have captivated mathematicians for ages. These numbers are the basis of many mathematical theories and computational methods since they are only divisible by one and themselves. Even though prime numbers seem straightforward, they include complex patterns that experts still find difficult to understand. The increasing dependence on secure communication systems and cryptographic algorithms that use huge primes has increased the need for effective prime identification techniques.

Although prime discovery has been made possible by classical methods like as the Sieve of Eratosthenes, Miller-Rabin, and Sieve of Atkin, their efficiency and scalability are limited when used with very large numbers. This challenge has led to the creation of novel approaches that blend computational methods with theoretical understanding. By examining modular arithmetic features and concentrating on cubes of primes, this study presents a novel method for identifying prime numbers. The goal of the project is to create a scalable and effective primality testing algorithm that uses less memory than conventional techniques.

2 LITERATURE REVIEW

By iteratively marking multiples of primes as composite, the classical procedure known as Sieve of Eratosthenes efficiently finds all primes up to a certain integer. Its memory needs grow unaffordable for huge datasets, despite its efficiency for limited ranges (Burton, 2011).

A probabilistic algorithm called the Miller Rabin test is effective in testing individual numbers, although it can provide false positive results. It works especially well in situations where a high degree of confidence is appropriate (Ginni, 2022).

The Sieve of Atkin is a modern, theoretically effective approach for finding primes that makes use of quadratic forms and modular arithmetic. Due to its resource-intensive and intricate implementation, it is better suited to generating huge datasets (Geeksforgeeks.org, 2016).

Porras (2022) investigated the structure of primes greater than or equal to five in order to work on the fundamentals of prime number theory. Any prime greater than, 3 can be written in the form of $6k+1$ or $6k-1$ for some integer k .

By focusing on a novel pattern relating to the squaring of primes, Parker (2024) expanded on Porras's seminal work. He found that when primes (apart from 2 and 3) are squared, the outcome is always one more than a multiple of 24.

3 METHODOLOGY

a. Identification of Modular Patterns in Prime Numbers

Initially, cubes of prime numbers were calculated and those cubes of primes were divided by different divisors. Thus,

some unique patterns were identified under specific modular 3, 4, 6, 7, 9, 14, and 18.

b. Comparison the time complexity, space complexity and scalability

Accuracy, time complexity and space complexity of each method were developed using those divisors and were measured and compared in order to find the best method to check whether the given number is prime or not. Execution time and memory usage of each method were measured within different input ranges (0, 1000), (0,10000), (0, 100000), (0, 500000) and (0, 1000000). Moreover, execution time and memory usage were computed to measure the scalability of each method, by checking whether the $2^{82589933} - 1$ is prime or not.

c. Comparison of Time Complexity and Space complexity between the New Algorithm and Current Algorithms

Execution time and memory usage of the new primality testing algorithm and current primality testing and prime generating algorithms such as Sieve of Eratosthenes, Miller-Rabin and Sieve of Atkin were measured within different input ranges viz. (0,1000), (0,10000), (0,100000), (0,500000) and (0,1000000).

4 DATA COLLECTION & ANALYSIS

The first thousand prime numbers were collected from the 'Prime Pages' web site for the analysis of cubes of those primes. All computational algorithms were implemented on the Google Colab online platform and Pycharm Community Edition software.

5 RESULTS AND DISCUSSION

a. Congruence Relations

Table 1: Residues of cube of primes under different divisors (2 to 9))

Primes	Cube	Modulo Operation	Residues							
			$n=2$	$n=3$	$n=4$	$n=5$	$n=6$	$n=7$	$n=8$	$n=9$
2	8	$8 \bmod n$	0	2	0	3	2	1	0	8
3	27	$27 \bmod n$	1	0	3	2	3	6	3	0
5	125	$125 \bmod n$	1	2	1	0	5	6	5	8
7	343	$343 \bmod n$	1	1	3	3	1	0	7	1
11	1331	$1331 \bmod n$	1	2	3	1	5	1	3	8
13	2197	$2197 \bmod n$	1	1	1	2	1	6	5	1
17	4913	$4913 \bmod n$	1	2	1	3	5	6	1	8
19	6859	$6859 \bmod n$	1	1	3	4	1	6	3	1
23	12167	$12167 \bmod n$	1	2	3	2	5	1	7	8
29	24389	$24389 \bmod n$	1	2	1	4	5	1	5	8

Table 2: Residues of cube of primes under different divisors(9 to 18))

Prim es	Cube	Modulo Operation	Residues								
			$n=10$	$n=11$	$n=12$	$n=13$	$n=14$	$n=15$	$n=16$	$n=17$	$n=18$
2	8	$8 \bmod n$	8	8	8	8	8	8	8	8	17
3	27	$27 \bmod n$	7	5	3	1	13	12	11	10	1
5	125	$125 \bmod n$	5	4	5	8	13	5	13	6	17
7	343	$343 \bmod n$	3	2	7	5	7	13	7	3	1
11	1331	$1331 \bmod n$	1	0	11	5	1	11	3	5	17
13	2197	$2197 \bmod n$	7	8	1	0	13	7	5	4	1
17	4913	$4913 \bmod n$	3	7	5	12	13	8	1	0	17
19	6859	$6859 \bmod n$	9	6	7	8	13	4	11	8	17
23	12167	$12167 \bmod n$	7	1	11	12	1	2	7	12	1
29	24389	$24389 \bmod n$	9	2	5	1	1	14	5	11	1

The residues of cubes of primes under different modules (2 to 18) are presented in Table 1 and Table 2.

Above Table 1 and 2 indicate that all cubes of primes greater than 11 are one more than or one less than a multiple of 3, 4, 6, 7, 9, 14 and 18. Then any prime number greater than 11 can be written in following forms. Let p be a prime number. Then, for some positive integer m ,

- $p = (3m \pm 1)^{1/3}$
- $p = (4m \pm 1)^{1/3}$
- $p = (6m \pm 1)^{1/3}$
- $p = (7m \pm 1)^{1/3}$
- $p = (9m \pm 1)^{1/3}$
- $p = (14m \pm 1)^{1/3}$
- $p = (18m \pm 1)^{1/3}$

Therefore, it can be checked whether the given number is prime or not by checking whether cubes of primes are one more than or one less than a multiple, of 3, 4, 6, 7, 9, 14, or 18.

These modular patterns arise because primes greater than 3 follow specific forms, such as $6k+1$ or $6k-1$, which influence the cubic residues in modular arithmetic. So, this behavior is rooted in both the cyclical nature of modular systems and the structural properties of prime numbers.

b. Performance of Each Method

Table 3: Execution time and memory usage of each method for different input ranges

Methods	Input Ranges	Execution time(s)	Memory Usage (MiB)
Method 1 (divisor 3)	1000	27.1123	27.31
	10000	2.0924	27.33
	100000	2.0042	27.33
	500000	4.3289	27.33
	1000000	23.8412	27.39

Method 2 (divisor 4)	1000	5.2440	13.36
	10000	1.7279	13.37
	100000	1.5142	13.37
Method 3 (divisor 6)	500000	4.410	13.51
	1000000	17.2698	14.97
	1000	4.7464	14
Method 4 (divisor 7)	10000	1.3742	14.01
	100000	1.8692	14.16
	500000	4.3356	14.98
Method 5 (divisor 9)	1000000	10.8251	15.58
	1000	7.9911	37.14
	10000	3.1608	37.27
Method 6 (divisor 14)	100000	1.4214	37.58
	500000	4.3969	39.05
	1000000	10.4032	41.38
Method 7 (divisor 18)	1000	4.4811	14.29
	10000	1.6379	13.12
	100000	0.9531	13.34
Method 8 (divisor 21)	500000	3.7971	14.02
	1000000	9.9571	13.34
	1000	12.8082	41.36
Method 9 (divisor 25)	10000	10.0368	41.36
	100000	1.3608	41.37
	500000	3.8743	41.40
Method 10 (divisor 27)	1000000	18.6247	41.56
	1000	4.7618	27.13
	10000	1.9907	27.17
Method 11 (divisor 31)	100000	1.9243	27.18
	500000	5.9090	27.20
	1000000	12.0367	27.25

Table 4: Execution time and memory usage of each methods for the largest known prime number

Methods	Execution time(s)	Memory Usage(MB)
Method 1	325.34837	178.53304
Method 2	328.99918	178.55178
Method 3	319.22421	178.53304
Method 4	318.60373	178.53789
Method 5	318.36196	178.53239
Method 6	319.14248	178.53335
Method 7	324.72933	178.53480

According to Table 3 and 4, Method 5 with minimum execution time and memory usage, is the best method to test whether the given number is prime or not.

c. New Algorithm for Checking Primality

Step 1: Small primes are checked. i.e. If the number n is 2 or 3, then it is prime.

Step 2: Next, The cube of number n is taken. If cube of n is one more than or one less than a multiple of 9, then it is a prime.

It is noteworthy to point out that all cubes of primes are in the form of $9k+1$ or $9k-1$. But all cubes of positive integers which can be written in the form of $9k+1$ or $9k-1$ are not prime numbers. So a method has to be used to identify numbers which are not prime numbers, but cube in the form of $9k+1$ or $9k-1$. Hence, basic concept of Seive of Eratosthenes is used as follows.

Step 3: Prime divisors up to $\sqrt{n}$ are checked. If any divisors are found, n is not prime.

Step 4: If the corresponding condition was satisfied and no divisors are found, n is prime.

d. Performance of the New Algorithm Vs. Current Algorithm

Table 5: Execution time and memory usage of current methods and the new method

Algorithm	Input Ranges	Execution time(s)	Memory Usage (MiB)
	1000	7.0500	21.18
	10000	2.8920	21.52
	100000	1.5634	22.78
	500000	1.6567	28.95
	1000000	1.4851	33.62
Sieve of Eratosthenes	1000	3.1263	21.25
	10000	1.4067	21.54
	100000	1.2348	22.41
	500000	3.9502	24.54
	1000000	6.3621	26.01
Miller-Rabin	1000	3.4232	21.26
	10000	2.9300	21.57
	100000	1.0211	23.18
	500000	3.8503	28.36
	1000000	3.0326	33.65
Sieve of Atkin	1000	28.276	21.10
	10000	10.489	21.37
	100000	1.2124	21.97
	500000	5.6695	23.74
	1000000	17.9470	25.65
New Algorithm			

It can be concluded that the new algorithm use low memory for large input size rather than current methods.

6 CONCLUSION

This research project introduces innovative methods for prime number identification. Cubes of primes (greater than 11) are one more than or one less than multiples of 9, according to thorough testing. Compared to conventional algorithms, the new technique uses significantly less memory. The significance of further research into the characteristics of prime numbers is increased by the project's success. The results lay the groundwork for further investigation, especially in the area of optimizing the method for primality testing. In addition to testing primality, the suggested methodology opens up new research directions with consequences for computer science, cryptography, and secure communication systems.

REFERENCES

- Burton, D. M. (2011). Elementary Number Theory. Mcgraw-Hill.
- Geeksforgeeks.org (2016). Sieve of Atkin, Retrieved from <https://www.geeksforgeeks.org/sieve-of-atkin/> (2024.06.14)
- Ginni. (2022). What are the Miller-Rabin Algorithm for Testing the Primality of a Given Number? <https://www.tutorialspoint.com/what-are-the-miller-rabin-algorithm-for-testing-the-primality-of-a-given-number>
- Parker, M. (2024). - YouTube. Youtu.be. <https://youtu.be/ZMkLiFs35HQ?si=DsnDjy83fdGCr6ty>
- Porras, W. (2022). Study about the Pattern of Prime Numbers. Book Publisher International (a Part of SCIENCE DOMAIN International), 9, 83–93. <https://doi.org/10.9734/bpi/ramrcs/v9/15662d>



Image Processing-Based Fabric Defect Detection: Reducing Human Intervention in Textile Inspection

Weerarathne WLM¹, Dahanayaka SD¹, Disanayake AAL¹

Department of Mathematical Sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka
madu.pabani1998@gmail.com

ABSTRACT

Quality control is a crucial part of the textile industry to compete in the intensely competitive global market. In most of the textile sectors, manual fabric inspection is followed to find fabric defects which is time-consuming and less accurate. Fabric defects lead to higher financial losses and costs of rework. A computer-aided defect system based on image processing can be utilized to resolve this issue easier, faster, and more accurate inspection. Fabric defects can occur at any stage of the fabric manufacturing process which includes knitting, dyeing, and finishing. This research project aims to develop a detection system to detect fabric defects at any stage of this process. This research work proposes a method to reduce human interaction in manual inspection. This method is based on the image processing technique using MATLAB which consists of a few steps: grayscale converting, filtering, binarization, region properties extraction, and alert message displaying. The input images had three main types of defects: holes, stains, and yarn breaks. There were defects of small, medium, and large sizes. This system detects defects regardless of its size. It can display an alert message when the defect is found and its details such as size, location, and penalty points which should be allocated. This method accomplished 87.70% accuracy and can be emphasized as a tool that can assist the user in decision-making and following corrective actions.

KEYWORDS: Fabric Defects, Image Processing, Quality Control, Yarn Break

1 INTRODUCTION

The textile & apparel industry has been Sri Lanka's major gross export earner. There are around 300 apparel manufacturers and only a few textile manufacturing facilities which adds significant value to Sri Lanka's apparel value chain. Like other industries, the apparel industry is also focusing on high quality. The apparel's quality is mainly based on the quality of the fabric that it is made of. Therefore, manufacturing fabrics with high quality has become a primary objective in the textile industry.

Fabric quality inspection is mainly done by manual inspection in textile manufacturing companies which is more time-consuming, less accurate, and high

labor cost. Therefore, fabric defect identification using a computer-aided detection system is much needed. Using the image processing technique in MATLAB, developing an automated system can be possible. Using this method the defects in an image which is taken from a digital device can be identified. This research aims to empower the textile sector with an accurate and improved defect detection system to increase the productivity and efficiency of their performance.

a. Research Objective

The main objective of this research is to develop a computer-aided detection (CAD) system using taken images of fabric defects: holes, dye stains, dust

stains, and yarn breaks. After the defect is detected send a warning message as a defect is detected and evaluate and show the size (Area) and the location. Finally, the system allocates penalty points according to the industry standards.

2 LITERATURE REVIEW

As explained by Desai¹ and Kesarkar (2023) automation of the detection of fabric faults using MATLAB's image processing technique is possible. In this study the faults in the fabric are identified after the steps of grayscale conversion, filtering using Median Filter or Weiner Low Pass Filter, binarization, and its data representation is done using a histogram. To measure the size of the fault, the very fine noise was removed using some functions in MATLAB. Then the approximate fault size was measured in pixels and centimeters and displayed in the command window. The distance line was used to identify the fault area. It explained further that there would be a single data representation in the histogram if there was no fault with the fabric under test.

The experimental results of Singh et al. (2015) explained a supervised defect detection approach. The images were converted to 8-bit gray level format and noises were removed. With the Gabor filter, the defect areas were prepared into more visible, and the Gaussian operator was used to smooth the image. Then the filtered images were converted into bi-level images. A double thresholding method was used to binarize the image. The Gabor filter followed by thresholding was used to find the location of the defect in this method. This also concluded that the algorithm has 83.5% overall accuracy.

Thilepa and Thanikachalam (2010) explain developing a fabric GUI for defect detection. A defective fabric image was taken and noise was filtered using linear and nonlinear filtering techniques. Then the filtered image was converted into a grayscale image. Then it was processed for the histogram process. To do that two output arguments were given to the function for histogram equalization. Finally, the global thresholding method was used to binarize the image. This method was also performed using MATLAB 7.3 software. The findings emphasize that the overall efficiency of this system is 85%.

3 METHODOLOGY

This research project explains the development of a computer-aided fabric defect detection system using image processing to identify the presence of defects and other properties. The primary steps of the proposed method are mentioned below.

1. The image was converted into a grayscale image
2. Filtering was performed to remove noises from the image
3. Noise removed image was converted into a binary image
4. The defects identified in the binary image were bounded from a box
5. Displaying a dialog box indicating whether the fabric image presents a defect
6. Measurements of the defects such as size, location (x, y), and penalty points were calculated and indicated in the dialog box.

IMAGE PROCESSING-BASED FABRIC DEFECT DETECTION: REDUCING HUMAN
INTERVENTION IN TEXTILE INSPECTION

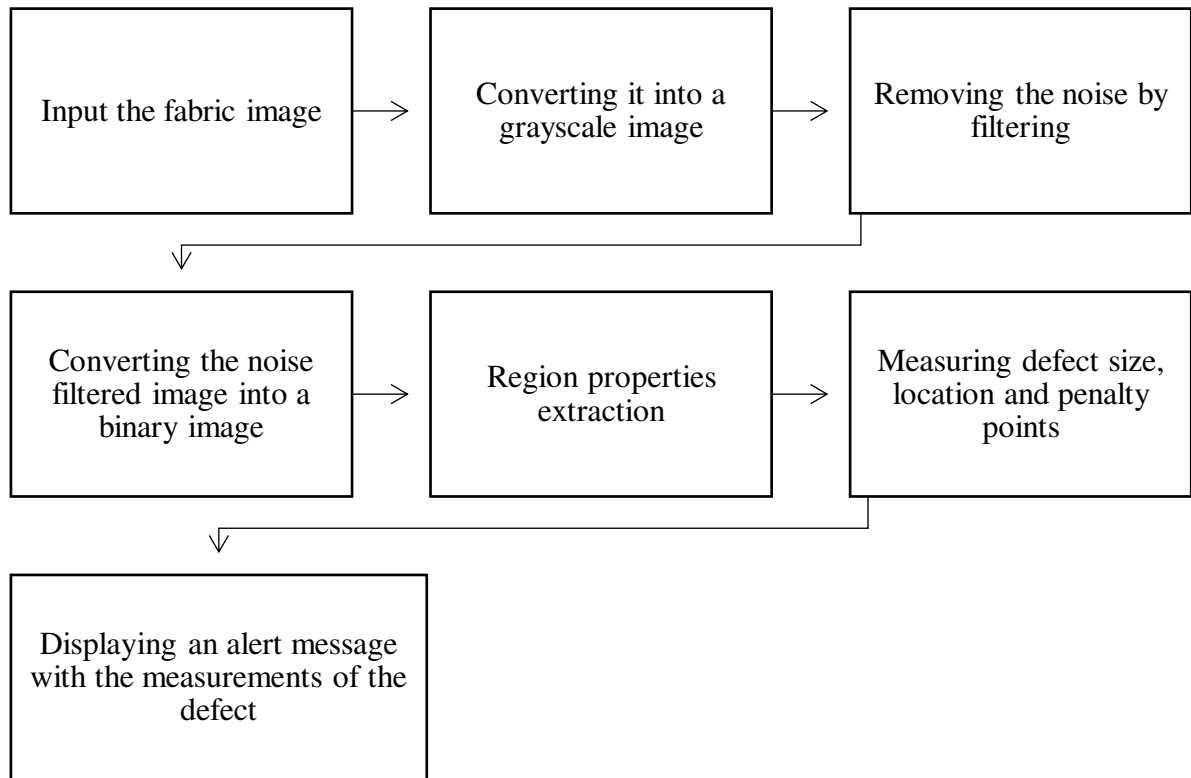


Figure 1: Flow chart of the proposed method

a. Image Acquisition

The basic idea of Image Acquisition is to convert a real-world image into an array of numerical data that could be operated on a computer. For this research project, the defect images were captured in the fabric under test in the ABC company using an electronic device. Each image was between 150KB and 8.5MB in size.

b. Initialization of the program

In this project, MATLAB software is used in image processing. MATLAB is an advanced language that makes it easier for rapid prototyping and visualization of image processing algorithms.

c. Image Processing

Converting the input image into a grayscale image: The input images come as RGB images, including three colors (Red, Green, and Blue). Since there is a large amount of data in this image format, continuing it as a grayscale image simplifies and speeds up the process.

Converting the noise-filtered image into a binary image: The ‘imbinarize’ function was used for binary conversion and uses Otsu’s thresholding which selects the threshold value automatically.

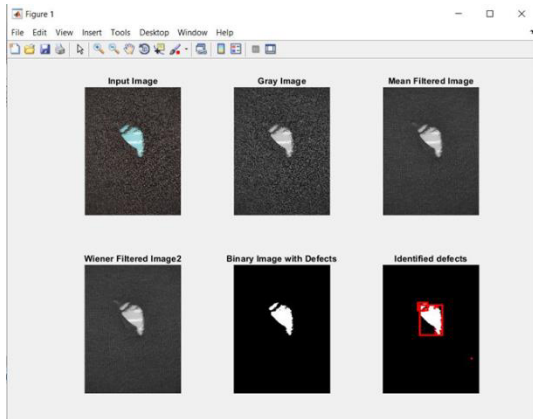


Figure 2: Hole Defect Detection

Region properties extraction: The 'regionprops' function was used to extract properties of the region (defect as white) identified in the binary image. This analysis used only 'BoundingBox', 'Area', and 'Centroid' strings under 'regionprops'.

'BoundingBox' was used to highlight the detected defects in the image and visualize its location and size. 'Area' measured the number of pixels included in each defect. 'Centroid' was used to get the center of the defect which is useful for getting the location

Measuring defect size, location, and penalty points: The total area of the defects is measured in pixels and centimeters using the 'Area' string. Using the 'Centroid' string, the location of the presented defect was calculated. The centroid indicates the geometric center of the defect and the horizontal & vertical coordinates were extracted from the centroid calculation. Penalty points are based on the length of the defect which was calculated using the width of the bounding box (rectangle) around the defects in pixels. Then based on the defect length and industry standards the penalty points (1-4) were allocated.

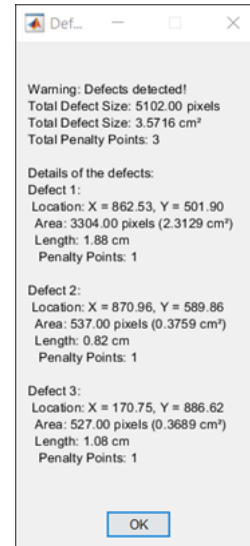


Figure 3: Alert message when the defect found

Displaying an alert message with the measurements of the defect: This detection system determines whether defects are present in the fabric or not and displays it as an alert message. If defects are present, message is displayed with their measurements, and if no defect only the message is displayed as shown in Fig 5.

Histogram of the binary image: A histogram of a binary image represents pixel intensity distribution in the image. The pixel value 0 represents the background and the value 1 represents the defect area in the binary image.

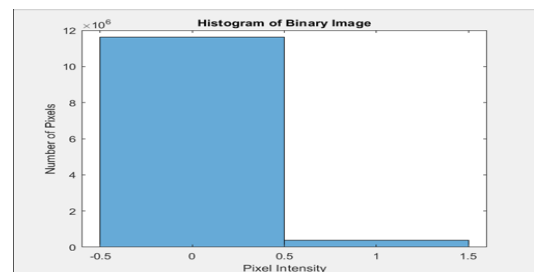


Figure 4: Histogram of the binary image in Figure 2

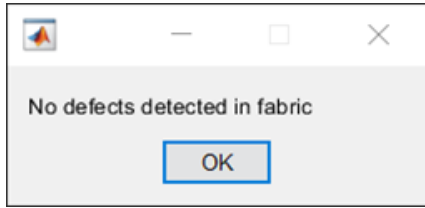


Figure 5: Alert message of a defect free image

4 RESULTS AND DISCUSSION

a. Results

Table 1: Test Results

Defect Type	Number of tests	False Detection	Accuracy
Holes	8	0	100.00%
Stains	12	1	91.67%
Yarn Break	7	2	71.43%
Average Accuracy			87.70%

According to the above table, the proposed method has an average accuracy of 87.70%, which is high.

b. Discussion

The proposed computer-aided fabric defect detection system demonstrates significant potential for implementation in textile manufacturing facilities. The methodology was evaluated using fabric samples containing three distinct categories of defects: holes, stains, and yarn breaks. This automated approach offers substantial advantages over traditional manual inspection methods in terms of operational efficiency and quality control. The system's primary benefits derive from its capacity to reduce inspection time, minimize human intervention, and decrease the incidence of operator error. These improvements can significantly enhance manufacturing productivity while ensuring more consistent quality control standards. Implementation of this system could

potentially lead to a reduction in defective product releases, customer complaints, and merchandise returns, thereby protecting both individual manufacturers' reputations and the broader Sri Lankan apparel industry's market position. Experimental results yielded both accurate and false detections during system validation. Analysis suggests that detection accuracy could be enhanced through the utilization of higher quality input images with reduced noise levels. This improvement could be achieved through the deployment of advanced digital imaging equipment in the inspection process.

5 CONCLUSION

The current research focuses primarily on defect detection without addressing defect classification. Future research directions could explore the integration of more sophisticated computational approaches, including machine learning algorithms, neural networks, and deep learning methodologies. However, implementation of these advanced techniques would necessitate enhanced computational resources to ensure effective processing and analysis. Future developments should focus on the implementation of high-resolution imaging systems, development of robust defect classification capabilities, integration of advanced machine learning methodologies, and enhancement of computational infrastructure to support these advanced features.

REFERENCES

- Desai1, K. R., and Kesarkar, S. S. (2023). Fabric Fault Detection Using Image Processing In MATLAB. *ReserachGate*, 77-84.
- Singh, U., Moitra, T., Dubey, N., and Patil, M. V. (2015, June). Automated Fabric Defect Detection Using MATLAB. *International Journal of*

Advanced Technology in Engineering and Science, 03(06), 294-299.

- Thilepa , R., and Thanikachalam, M. (2010, December). A Paper on Automatic Fabrics Fault Processing using Image Processing Technique in MATLAB. *Signal & Image Processing : An International Journal(SIPIJ)*, 1(2), 88-99.



New Generalized Mathematical Model for Incidence Coloring of Ladder Related Graphs

Nuwanthi SS¹, Perera AAI¹, Mohommad MAM²

Department of Physical Science, Faculty of Applied Sciences, Rajarata University of Sri Lanka

nuwanthishyamika@gmail.com¹

Department of Mathematics, Faculty of Science, University of Peradeniya, Sri Lanka

aaip@sci.pdn.ac.lk²

ABSTRACT

Graph coloring is a fundamental area of research in graph theory. Here, we discuss a version of graph coloring, known as incidence coloring, which involves assigning colors to the incidences while ensuring that adjacent incidences do not share the same color. This research explores the incidence coloring of ladder graphs, a class of graphs resembling the rungs of a ladder, and extends this concept to subdivided and circular ladder graphs. In this study, we develop a generalized mathematical model for incidence coloring of ladder graphs and Further exploration reveals that this model can also be applied to subdivided ladder graphs with any finite number of vertices, and it is found that the incidence chromatic number $\chi_i(G)$ of a ladder graph remains unchanged when subdivisions are introduced. Furthermore, we demonstrate that the developed mathematical model can be extended to effectively color some circular ladder graphs also. So, the incidence chromatic number of subdivided ladder graphs and certain circular ladder graphs is also 4, similar to that of ladder graphs. Our findings contribute to a deeper understanding of the incidence chromatic number in ladder related graph structures. In real world scenarios, incidence coloring is useful for network design, scheduling tasks, and resource allocation. However, when discussing specific graph types such as ladder, subdivided ladder, and circular ladder graphs, we encounter limitations in applying these concepts to such scenarios.

KEYWORDS: Incidence coloring, Ladder graphs, Graph theory, Graph coloring

1 INTRODUCTION

Graph theory is a fundamental area in discrete mathematics, with applications in computer science, urban planning, transportation, and network optimization. It studies graphs that represent relationships between vertices and edges, with graph coloring playing a key role in optimizing, resource allocation and minimizing conflicts. This research explores incidence coloring, a variation of graph coloring introduced by Brualdi and Quinn Massey in 1993 (Brualdi, 1993), which involves assigning colors to incidences such that adjacent incidences receive different colors, while non-

adjacent incidences may share the same color. An incidence is described as a pair (v, e) , where $v \in V(G)$ denotes a vertex that acts as an endpoint of $e \in E(G)$, an edge in the graph. This implies that the vertex v is incident to the edge e . Two incidences (v, e) and (w, f) are said to be adjacent if at least one of the following conditions hold:

- (i) $v = w$
- (ii) $e = f$
- (iii) the edge $vw = e$ or $vw = f$

We propose a mathematical model to simplify incidence coloring of ladder graphs, which is traditionally complex due

to three specific conditions and lack existing algorithms or mathematical models. As vertex count increases, manual verification becomes impractical. Our model replaces this with an efficient equation-based approach. Incidence coloring is crucial in network design, scheduling, and optimization, with ladder graphs frequently used in task scheduling and flow organization. This study extends to analyze the incidence coloring of subdivisions and circular ladder graphs, adapting the mathematical model to these variations.

2 LITERATURE REVIEW

The formal concept of incidence coloring was introduced by Richard A. Brualdi and J. J. Massey in their 1993 paper. They extended the idea of vertex and edge coloring by focusing on incidences, which are pairs (v, e) , where v is a vertex and e is an edge incident to v . The goal in incidence coloring is to assign colors to these incidences such that no two incidences that share a common vertex or a common edge receive the same color. They found the incidence chromatic numbers for certain types of graphs, such as trees, complete bipartite graphs, and complete graphs. They proposed the Incidence Coloring Conjecture (ICC), proved that every graph G can be incidence colored with $\Delta(G) + 2$ colors, where $\Delta(G)$ is the maximum degree of the graph (Brualdi & Massey, 1993).

The incidence coloring conjecture was disproved by Guiduli, who showed that the incidence coloring concept is a directed star arboricity case, introduced by Alon and Algor, and proved that the conjecture that the incidence chromatic number is always less than or equal to the $\Delta(G) + 2$ is false using Paley graphs. His

counter example showed that incidence chromatic number is at most $\Delta(G) + O(\log \Delta(G))$ (Guiduli, 1997).

The study conducted by Wang et al. (2002) proved that the incidence coloring number for Halin graphs of maximum degree greater than or equal to 5 and outerplanar graphs of maximum degree greater than or equal to 4 is equal to the maximum degree of the graph plus 1 ($\Delta(G) + 1$) (Wang et al., 2002).

A paper published in 2004 introduced several algorithms for incidence coloring of different mesh structures, including square meshes, honeycomb meshes, and hexagonal meshes. These algorithms are optimal, providing incidence coloring in linear time with the fewest number of colors. It was established that $\Delta(G) + 1$ colors are required for incidence coloring of these meshes. Specifically, the incidence chromatic numbers of a square mesh was found to be 5, a hexagonal mesh was 7, and a honeycomb mesh was 4 (Huang et al., 2004).

3 METHODOLOGY

First, we must identify the structures of these ladder - related graphs. A ladder graph consists of two parallel paths (rails) connected by rungs (edges), denoted as L_n for n rungs, and is equivalent to a $2 \times n$ grid graph, where, n is a finite positive integer. Subdivisions of a ladder graph involve adding vertices along its edges. A circular ladder graph is a variation of the ladder graph where the two parallel paths (rails) are connected in a circular manner.

First, assign distinct numerical values to each incidence, representing a unique color. For example, initial values such as 1, 2, 3, etc., are assigned to incidences at each vertex following incidence coloring conditions. Then, label the vertices

systematically, using preliminary color assignments as a guide. For example, in a ladder graph, label the vertices sequentially from one end to the other as $U_1, U_2, U_3, \dots, U_n$.

Then, label the incidences corresponding to the first vertex as $U_{1,1}, U_{1,2}, U_{1,3}$, and so on. Each incidence is represented in relation to its corresponding vertex, and the labeling can be done in a clockwise or anticlockwise manner. Using the labels assigned to the incidences and the numerical values corresponding to these labels, we identify a pattern in the incidence coloring process. Generalize the identified patterns into mathematical equations and develop an mathematical model.

The developed model is then applied to subdivided ladder graphs and circular ladder graphs to evaluate its applicability.

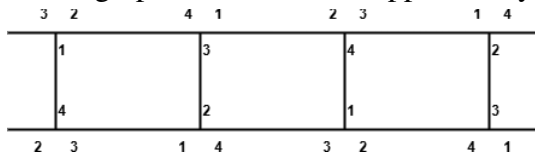


Figure 1: Assigning numerical values

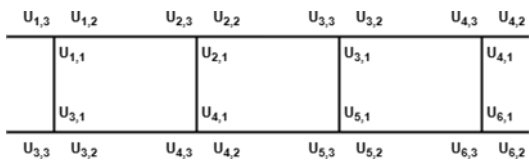


Figure 2: Labelling the incidences

4 RESULTS AND DISCUSSION

During the analysis, five distinct patterns were observed recurring in the incidence coloring process, with the bottom line of the ladder graph consistently starting with the third color set. Based on these patterns, incidences were labeled systematically.

The developed mathematical model for ladder graphs follows a general

equation given by $U_{4n-m, a}$, where the parameters $m = 0, 1, 2, 3$ and $a = 1, 2, 3$. Here, n ranges from 1 to $(P+2)/4$, where P represents the total number of vertices in the top horizontal line. If $(P+2)/4$ results in a decimal value, the maximum integer value is considered.

4.1 Developed Mathematical model for ladder graph

For Color (1),

$$u_{4n-m, a} \begin{cases} m = 3, a = 1 \\ m = 2, a = 2 \\ m = 0, a = 3 \end{cases} \quad (1)$$

For Color (2),

$$u_{4n-m, a} \begin{cases} m = 0, a = 1 \\ m = 3, a = 2 \\ m = 1, a = 3 \end{cases} \quad (2)$$

For Color (3),

$$u_{4n-m, a} \begin{cases} m = 2, a = 1 \\ m = 1, a = 2 \\ m = 3, a = 3 \end{cases} \quad (3)$$

For Color (4),

$$u_{4n-m, a} \begin{cases} m = 1, a = 1 \\ m = 0, a = 2 \\ m = 2, a = 3 \end{cases} \quad (4)$$

n	(m, a)											
	Color (1)			Color (2)			Color (3)			Color (4)		
1	3,1	2,2	0,3	0,1	3,2	1,3	2,1	1,2	3,3	1,1	0,2	2,3
2	u _{1,1}	u _{2,2}	u _{4,3}	u _{4,1}	u _{1,2}	u _{3,3}	u _{2,1}	u _{3,2}	u _{1,3}	u _{3,1}	u _{4,2}	u _{2,3}
3	u _{5,1}	u _{6,2}	u _{8,3}	u _{8,1}	u _{5,2}	u _{7,3}	u _{6,1}	u _{7,2}	u _{5,3}	u _{7,1}	u _{8,2}	u _{6,3}

Figure 3: Incidence labels and their assigned colors

Using the above equations, we can efficiently perform incidence coloring for ladder graphs, subdivided ladder graphs,

and certain circular ladder graphs without violating the conditions of incidence coloring. An example of a ladder graph that has been incidence colored using this mathematical model is shown in the figures 3.

Using the labels given to incidences, we have colored a ladder graph with 6 vertices in the top horizontal line, where $n=2$ in figure 4.

The same procedure for incidence coloring of ladder graphs can also be applied to subdivided ladder graphs. Subdivided ladder graphs can be labeled just like ladder graphs, following the same steps as illustrated in figure 5.

So, using the developed model, we can color the subdivided ladder graph without violating any conditions of incidence coloring. The incidence chromatic number of the subdivided ladder graph remains 4, and even as the number of subdivisions increases, the incidence chromatic number does not change. This model can also be applied effectively as the number of subdivisions increases.

By using the developed model, we can color certain circular ladder graphs with 8, 16, 24, 32, ... and so on vertices. The same procedure used for ladder graphs and subdivided ladder graphs can be applied here as well. As shown in the figure 7 below, you can see how the incidences of a circular ladder graph with 8 vertices are labeled.

Other circular ladder graphs can also be incidence colored in the same way. Thus, the incidence chromatic number of these circular ladder graphs (with vertices 8, 16, 24, 32, ...) is also 4.

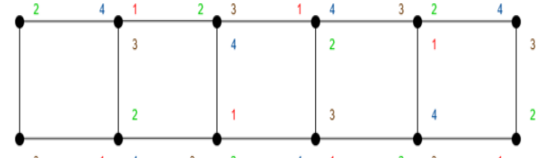


Figure 4: Incidence coloring of ladder graph

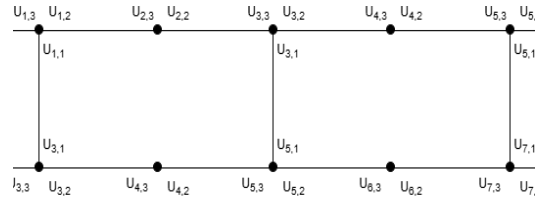


Figure 5: Subdivided Ladder Graph labelling

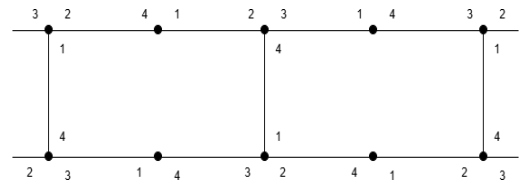


Figure 6: Assigning numerical values to subdivided ladder graph

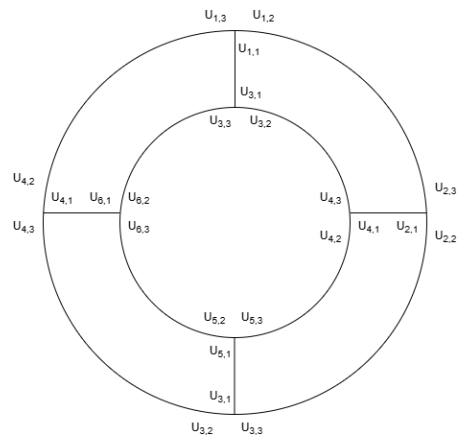


Figure 7: Labeling incidences of circular ladder graph

5 CONCLUSION

We developed a generalized mathematical model for the incidence coloring of ladder graphs. This mathematical model can also be applied to incidence color subdivided ladder graphs and certain circular ladder graphs (with vertices 8, 16, 24, 32, ...), without

violating the conditions of incidence coloring. Furthermore, this mathematical model works for these specific graph types with any finite number of vertices. By applying this mathematical model, we conclude that the incidence chromatic number of subdivided ladder graphs is 4 and remains unchanged, even as the number of vertices or subdivisions increases. Similarly, the certain circular ladder graphs discussed here also have an incidence chromatic number of 4. In future studies, we hope to apply this for a real-world scenario.

REFERENCES

- Brualdi, R. A., & Quinn Massey, J. J. (1993). Incidence and strong edge colorings of graphs. *Discrete Mathematics*, 122(1-3), 51–58.
- Guiduli, B. (1997). On incidence coloring and star arboricity of graphs. *Discrete Mathematics*, 163(1-3), 275–278. [https://doi.org/10.1016/0012-365x\(95\)00342-t](https://doi.org/10.1016/0012-365x(95)00342-t) *Discrete Mathematics*, 163, 275--278.
- Wang, S.-D., Chen, D.-L., & Pang, S.-C. (2002). The incidence coloring number of Halin graphs and outerplanar graphs. *Discrete Mathematics*, 256(1-2), 397–405.
- Huang, Cheng-I., Wang, Y.-L., & Chung, S.-S. (2004). The incidence coloring numbers of meshes. *Computers & Mathematics with Applications*, 48(10-11), 1643–1649.



On the Precision of Zernike Polynomials in Modeling Lower-Order Aberrations

Nanayakkara NWDLD¹, Karunarathna SPDSSK¹
Department of Mathematical Sciences, Wayamba University of Sri Lanka
lakruwanidiana@gmail.com

ABSTRACT

The measurement and reconstruction of ocular aberrations (OAs) are critical for diagnosing and correcting visual distortions caused by imperfections in the optical system of the eye. This study focuses on reconstructing lower-order aberrations, due to the majority of people experiencing lower-order aberrations, using Zernike polynomials (ZPs), a widely adopted mathematical basis in ophthalmology. Synthetic data were generated to simulate aberrated wavefronts, and Zernike coefficients (ZCs) were calculated using least-squares fitting. The reliability of reconstructed wavefronts was evaluated using a bootstrap approach to compute 95% confidence intervals. Results showed that the maximum confidence band width for the reconstructed wavefronts was 2.2796×10^{-11} mm, demonstrating the high accuracy of ZPs in representing lower-order aberrations. To assess robustness, noise was introduced to the synthetic data, varying the signal-to-noise (S/N) ratio from 30 dB to 80 dB. An exponential increase in confidence band widths was observed as S/N ratios decreased, with maximum widths ranging from 10^{-11} to 10^{-3} mm. These findings confirm the precision of ZPs for lower-order aberrations under ideal conditions but highlight their sensitivity to noise. The study underscores the potential of ZPs for wavefront reconstruction while emphasizing the need for noise-resilient methodologies in clinical applications.

KEYWORDS: Aberrometer, Bootstrap, Ocular Aberration, Zernike Polynomials.

1 INTRODUCTION

The quality of retinal images, can be diminished by imperfections within the eye leading to visual distortions. Ocular aberrations (OAs) have been utilized to quantify these visual defects. OAs are mainly categorized into two parts, namely, low-order and high-order ocular aberrations. Lower order aberrations, including defocus, and regular astigmatism, can usually be corrected with eyeglasses or contact lenses. However, higher order aberrations like spherical aberration and coma are less familiar due to their individualized nature and involve distortions that cannot be easily corrected by standard lenses. These aberrations can arise following corneal surgeries, in eyes with a conical corneal

shape (keratoconus), or in cases of corneal ectasia and can impact on vision quality. However, lower-order aberrations are the most common defects in human eyes. Aberrometers provide an objective means to quantify the overall refractive error caused by these imperfections (Dai, 2008). To correct these aberrations, proper OAs (wavefronts) analysis is needed.

The Shack-Hartmann aberrometry is the most widely used method to measure OAs due to the simplicity and performance characteristics like sensitivity and dynamic range (Atchison, 2005). Reconstruction is indeed a critical component in the measurement of ocular aberrations. Accurate wavefront reconstruction is essential for

understanding the optical imperfections of the eye and for developing effective solutions for their correction. This study specifically focuses on reconstruction of quadratic wavefront (lower-order aberrations) since lower-order aberrations are common optical imperfections that occur in most optical systems, including the human eye. The following literature review explores into the advancements in wavefront reconstruction techniques, the effectiveness of Shack-Hartmann aberrometry, and its application in analyzing lower-order aberrations.

2 LITERATURE REVIEW

2.1 Wavefront Reconstruction

The wavefront can be decomposed into set of basis functions in the modal approach and can be represented mathematically as,

$$W(x, y) = \sum_{i=0}^{\infty} a_i F_i(x, y), \quad (1)$$

where a_i 's are known as expansion coefficients, and $F_i(x, y)$'s are complete basis functions (Salverda, 2016). In general, the set of basis functions such as Zernike polynomials (ZPs), Fourier series, Taylor monomials and cubic B-splines are used (Dai, 2008; Iyer et al., 2016). Fourier series and B-splines are alternative methods for wavefront reconstruction, each with unique advantages and limitations. Fourier series efficiently approximate structured wavefronts and filter high-frequency noise but struggle with non-periodic or complex wavefronts, potentially introducing edge artifacts. B-splines, on the other hand, offer localized control and adaptability to irregular wavefronts while being less sensitive to noise, though they require careful knot selection and are

computationally demanding. While these methods provide viable alternatives, their practical application remains limited. Therefore, the use of ZPs in wavefront reconstruction has become standard in ophthalmology, primarily due to their ability to capture both the magnitude and spatial pattern of aberrations with high accuracy. Also, ZPs provide a robust and reliable fit for the central pupil region of the eye (Dai, 2008; Ares, 2006; Salverda, 2016). While ZPs are commonly used due to their mathematical properties and practical applications, the lack of sufficient quantitative evaluation of their reconstruction accuracy is a notable limitation in the existing literature. Therefore, this study aims to conduct a statistical analysis to explore both the accuracy of fitting and their sensitivity to noise.

2.2 Zernike Fitting

The wavefront representation with single indexed Zernike polynomials is given by,

$$W(r, \theta) = \sum_{i=0}^n a_i Z_i(\rho, \theta) \quad (2)$$

where, $W(r, \theta)$ is an ocular wavefront with pupil radius R , c_i is the i^{th} Zernike coefficient (ZC), and $Z_i(\rho, \theta)$ is the ZP respectively.

Wavefront height at specific points (N grid points) on the optical surface, providing a set of known values. Each height data is expressed using (2). All the equations from the measurement points are organized into a matrix system:

$$Za = w, \quad (3)$$

where w is the $N \times 1$ data matrix, a is the $L \times 1$ vector containing the ZCs to be determined, and Z is the $N \times L$ matrix

containing the values of the ZPs at each sampling point. The ZCs are calculated using least-squares fitting (Dai, 2008).

3 METHODOLOGY

In this study, synthetic data is used, and generated using mathematical model given in the section 3.1 since the corneal shapes is highly contributing to ocular aberrations.

a. Generating an Arbitrary Wavefront

The synthetic human eye aberrations are created using following model:

$$\begin{aligned} x &= x_0 + r\cos(\theta)\cos(\varphi) \\ &\quad + r\sin(\theta)\sin(\varphi) \\ y &= y_0 - r\cos(\theta)\sin(\varphi) \\ &\quad + r\sin(\theta)\cos(\varphi) \end{aligned}$$

$$Z = \frac{(x - x_0)^{\frac{2}{R_1}} + (y - y_0)^{\frac{2}{R_2}}}{1 + \sqrt{1 - \frac{\left((x - x_0)^{\frac{2}{R_1}} + (y - y_0)^{\frac{2}{R_2}}\right)^2}{(x - x_0)^2 + (y - y_0)^2}}}$$

where (x_0, y_0) is the center of the wavefront, r, θ, φ are spherical coordinates, R_1 and R_2 are the radii of curvature along the respective axes.

b. Bootstrap Process

The bootstrap process is used for creating large number of "bootstrap samples" and obtained by resampling with replacement, allowing for multiple reconstructions that generate a distribution of reconstructed wavefronts. This distribution is then analyzed to estimate the variability of estimates, providing standard errors and confidence intervals that indicate the reliability of the reconstructed wavefront (Karunaratna, 2018).

c. Computation of Confidence Bands

The validation is performed using the 95% confidence intervals and biases of estimates using a bootstrapping approach. Using generated synthetic data, we validate that the proposed method improves the accuracy of the wavefront constructed.

The parameter $\alpha = 0.05$ represents the significance level for a 95% confidence interval. In addition these are the lower and upper bounds of the confidence interval, calculated from the percentiles of the bootstrap samples.

Assuming wavefrontBootstrap is a 3D array where the third dimension contains bootstrap samples of surface predictions, we can express Z_{lower} and

Lower Bound (Z_{lower}):

$$Z_{\text{lower}} = \text{Percentile}_{\frac{\alpha}{2} * 100}(\text{wavefrontBootstrap}).$$

This represents the 2.5th percentile of the bootstrap distribution for each point on the surface, calculated along the third dimension. Mathematically:

$$\begin{aligned} Z_{\text{lower}} \\ &= \text{Percentile}_{2.5}(\text{wavefrontBootstrap}) \end{aligned}$$

Upper Bound (Z_{upper})

$$\begin{aligned} Z_{\text{upper}} \\ &= \text{Percentile}_{(1 - \frac{\alpha}{2}) * 100}(\text{wavefrontBootstrap}) \end{aligned}$$

This represents the 97.5th percentile of the bootstrap distribution for each point on the surface, which is:

$$\begin{aligned} Z_{\text{upper}} \\ &= \text{Percentile}_{97.5}(\text{wavefrontBootstrap}) \end{aligned}$$

d. Noise Addition

In this study, we introduce the normally distributed very small random numbers on

the height data for representing the variability (noise). Then,

$$w + \varepsilon = Z\hat{a},$$

where $\varepsilon \sim N(0, \alpha^2)$ is a normal distribution with mean zero and variance α^2 . The least-squares approach can be applied to estimate the vector $\hat{a}$ and enabling wavefront reconstruction under different noise level. Once the wavefronts are estimated at each noise level, confidence bands can be calculated as described in section 3.3.

4 RESULTS

Using the model discussed in section 3.1, we have obtained an arbitrary wavefront that includes lower and higher order aberrations. The pupil radius was set to 2.5 mm, and the radius of curvatures R_1 , R_2 are set to 150 mm and 170 mm, respectively. Fig. 1 shows the scatter plot of the generated data set. Applied the process discussed in section 2.2 to calculate the ZCs related to data set shown in Fig. 1. These coefficients quantify various optical aberrations in the wavefront. Among them, defocus (9.8045×10^{-3} mm), astigmatism (y -astigmatism: 1.0615×10^{-3} mm x -astigmatism: -6.1283×10^{-4} mm), and spherical aberration (2.0224×10^{-7} mm) are notable. Therefore, generated wavefront consists of lower-order aberrations which are y -astigmatism defocus and x -astigmatism terms. In addition, wavefront includes spherical aberration lightly.

As we have only one measurement and one model to obtain the arbitrary wavefronts, we have applied bootstrapping 100 times for creating 100 different arbitrary data sets and found

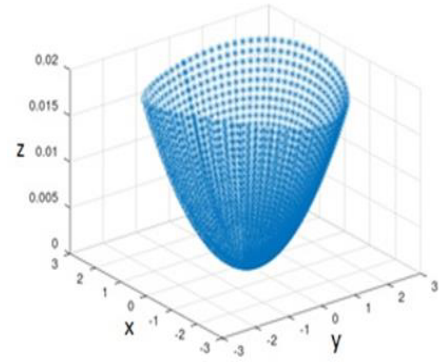


Figure 1: Scatter plot of the synthetic data set and units are in mm.

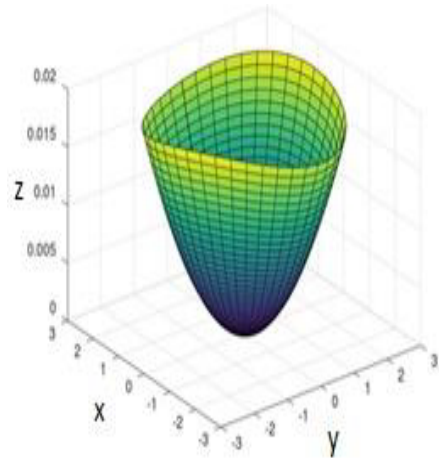


Figure 2: Reconstructed wavefront and units are in mm.

reconstructed the wavefront for the each dataset. The 95% confidence band interval was computed for the reconstructed wavefronts. The maximum width of the confidence band was 2.2796×10^{-11} mm which is close to zero. Therefore, the ZPs are more accurate for representing the lower-order aberration.

As we discussed in section 3.4, noise was added to the generated data set in such a way that the signal-to-noise (S/N) ratio was changing from 30 dB to 80 dB. Then, we have computed the maximum confidence interval for each signal-to-noise (S/N) ratio. The distribution of the maximum width with the signal-to-noise

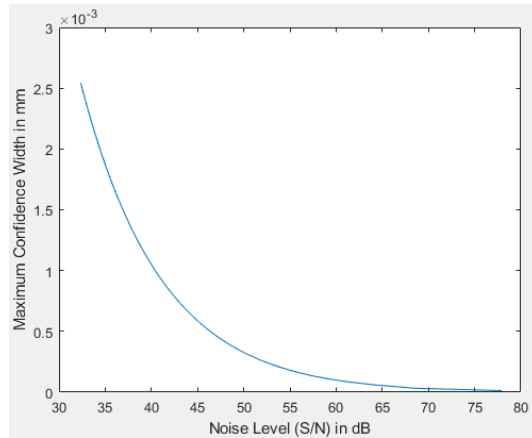


Figure 3: The distribution of the maximum widths of confidence bands against S/N ratio is shown.

(S/N) ratio is shown in Fig. 3. From Fig. 2, it can be observed that when the signal-to-noise (S/N) ratio is decreasing, the maximum width of the confidence width is increasing exponentially, which is from 10^{-11} to 10^{-3} mm.

5 CONCLUSION

This study demonstrates the effectiveness of ZPs in reconstructing lower-order ocular aberrations, highlighting their robustness and precision under ideal conditions. Apply a bootstrap method to compute a confidence band for reconstructed wavefronts. The maximum confidence band width was 2.2796×10^{-11} mm, which validates the reliability of reconstructed wavefronts. However, the study also showed a sensitivity to noise, with confidence intervals widening exponentially as the signal-to-noise (S/N) ratio decreased from 80 dB to 30 dB, reaching widths up to 10^{-3} mm. These findings confirm that while ZPs are highly accurate for representing lower-order aberrations, their performance is impacted by noise levels, necessitating consideration of noise resilience in practical implementations. This work

contributes to advancing wavefront reconstruction methodologies, with implications for both ophthalmic diagnostics and corrective lens design. Also, further research could explore its application to real clinical data and the impact of higher-order aberrations.

REFERENCES

- Ares, M., and Royo, S. (2006). Comparison of cubic B-spline and Zernike-fitting techniques in complex wavefront reconstruction. *Applied optics*, 45(27), 6954-6964.
- Atchison, D. A. (2005). Recent advances in representation of monochromatic aberrations of human eyes. *Clinical and Experimental Optometry*, 87(3), 138-148
- Dai, G. (2008). Wavefront Optics for Vision Correction. *SPIE-Intl Soc Optical Eng. Science and Business Media*, Vol. 38, 2nd ed.
- Iyer, R. V. (2016). Smoothing splines on unit ball domains with application to corneal topography. *IEEE Transactions on Medical Imaging*, 518-526.
- Karunarathna, S. P. D. S. S. K. (2018). *Customized Contact Lens Design for Regular and Irregular Vision Defects*.
- Lakshmi MPDS and Karunarathna. S. P. D. S. S. K. (2020). A smoothing spline approach to represent ocular aberrations.
- Salverda, J. (2016). Comparison of different wavefront reconstruction methods: With Zernike polynomials.



Optimization of Inventory Cost Under Trapezoidal Demand with Constant Deterioration and No Shortages

NawarathnaNMNAK¹, KarunanandaGACM¹, Karunarathna SPDSSK¹

Department of Mathematical Sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka

nayomianuradha98@gmail.com

ABSTRACT

The inventory management is a major concept in business world. Demand rate of the inventory is a basic term in inventory control. In the practical world situation, demand for the inventory is not constant. It varies with time and has several patterns. In many inventories, such as seasonal products and agricultural products, there is a trapezoidal-type demand. This study will be obliging to minimise the total cost of the inventories that have a trapezoidal demand rate and a constant deterioration rate without shortages, such as agricultural products like harvest and seasonal products like clothes. As these are very costly it is necessary to reduce the price of these inventories. In this research paper, the demand rate is considered trapezoidal type, and the deterioration is considered constant. This study focuses on optimising inventory costs under the trapezoidal demand, constant deterioration, and no shortages. Cycle lengths for three cases are considered, assuming constant ordering costs, infinite storage, and no inflation. A total variable cost is calculated by finding, ordering, holding, deterioration, and purchasing costs for each inventory. Numerical examples are given for optimum cycle length for each case considered in this study.

KEYWORDS: Deterioration Rate, Inventory Control, Shortage, Total Variable Cost, Trapezoidal Type Demand Rate.

1 INTRODUCTION

Nowadays, inventory control in business is really affecting the future of the business. To get a maximum benefit, inventory control should be handled properly. Companies must maintain stock levels to meet demand while minimising deterioration and storage costs. Most inventories, such as seasonal products like clothes and agricultural products like harvest, have a trapezoidal type of demand pattern. In this demand pattern, in the first time period demand increased. In the second time period, demand is constant. It decreased in the third time period. Deterioration is another factor that affected the inventory control. Weather conditions, spoilages, damage caused by

animals, and many other factors affected the deterioration of items. In this study it is considered that there is no shortage, since in the practical world, businesses do not wait until inventory becomes zero. They fill the stock when it reaches a minimum level. Then there is no shortage in the inventory.

To control the inventory, it is needed to minimise the cost of the inventory. The total variable cost consists various costs, namely, holding cost, deterioration cost, ordering cost, and purchasing cost. Ordering cost is based on the documental tasks, which is constant for the inventory. The purchasing cost of an inventory depends on the stock quantity that is purchased. The other two costs depend on demand and deterioration rate

respectively. This study helps to manage the inventory that has a trapezoidal demand rate and a constant deterioration rate without shortages. Then businesses having this type of inventory can reduce their loss and decrease the number of deteriorated items. The equations obtained from this study could be used to minimize the loss and profit.

2 LITERATURE REVIEW

Misra enhanced the classical economic order quantity (EOQ) model by introducing a discounted cost approach that incorporates inflation rates as parameters within the inventory system (1979). His study demonstrated how including inflation rates can refine inventory management strategies, ensuring that order quantities are optimised not only for cost but also for the impact of inflation.

Mishra et al. (2012) studied an EOQ model for perishable items with a power demand pattern. They had used a two-parameter Weibull distribution to model degradation. Their goal was to minimise the average total cost per unit time while considering inflation and the time value of money. The model assumes deterioration begins after a fixed time interval.

Mondal et al. (2021) examined an inventory model with trapezoidal demand and deteriorating prevention technology. They considered products with demand that initially increases, then remains stable, and finally decreases a trapezoidal pattern. The model accounts for inventory parameters that vary due to customer behaviour uncertainty. They include preservation technology to prevent deterioration. The study derived the

corresponding formula to maximise profit and converts it into an interval optimisation problem. They used quantum-behaved particle swarm optimization (QPSO) techniques to solve the model.

Kumar and Paikray developed a cost optimisation model for deteriorating items with a trapezoidal demand rate (2022). They focused on inventory systems where demand follows a trapezoidal pattern. They point out the limitations of traditional models by assuming uniform demand patterns. Their model also includes fuzzy environments to account for indistinct cost factors. Three cases of completely backlogged shortages were analyzed. The study found that the fuzzy model provided results more aligned with real world situations compared to classical models.

Among the above studies Mondal et al. (2021) and Kumar and Paikray (2022) only discussed items under trapezoidal demand and constant deterioration. They have considered that there is no left stock from the previous cycle, and cycles end when decreasing parts of demand occur. In contrast, this study, considered all possible cases where the length of the cycle can occur and there is left stock from the previous cycle.

3 METHODOLOGY

The general formula for inventory rate is given by the equation (Kumar, 2022):

$$\frac{dI(t)}{dt} + \theta(t)I(t) = -D(t) \quad (1)$$

where, $I(t)$ is inventory level at time t , $\theta(t)$ is deterioration rate, and $D(t)$ demand rate. The demand

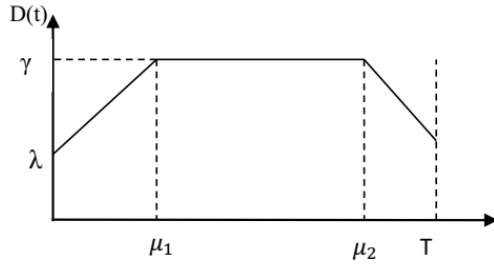


Figure 1: Visualization of demand distribution

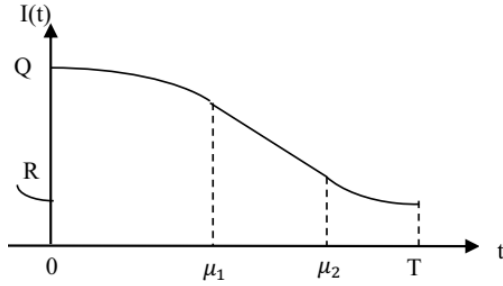


Figure 2: Graph of inventory level verses time

distribution is categorized into three possible cases based on the pattern between the time intervals 0, μ_1 (time when demand stops increasing) and μ_2 (time when demand starts decreasing).

These three cases are analyzed since the businesses can be planned better for their operations and strategies to align with the lifecycle of the demand.

3.1 Computation of Inventory Level in the Interval $0 \leq t < \mu_1$: Case I

Inventory rate for the case I,

$$\frac{dI_1(t)}{dt} + \tau I_1(t) = -(\alpha t + \lambda) \quad (1)$$

Consider initial condition $I(0) = Q$,

$$I_1(t) = -\frac{(\tau\lambda + (\tau t - 1)\alpha)}{\tau^2} + e^{-\tau t}(Q + \frac{\tau\lambda - \alpha}{\tau^2}) \quad (2)$$

Using (2) we can calculate costs,

Deterioration cost (Dc)

$$Dc = k \int_0^T \theta(t) I(t) dt$$

$$= k \left(Q - e^{-\tau T} Q + \frac{\tau\alpha}{\tau} - \frac{T^2\alpha}{2} - \frac{(\alpha - e^{-\tau T}\alpha)}{\tau^2} - \frac{(e^{-\tau T} - 1)\lambda}{\tau} - T\lambda \right) \quad (3)$$

Ordering Cost (Oc)

$$Oc = A \quad (4)$$

Holding cost (Hc)

$$Hc = h \int_0^T I(t) dt = \frac{1}{2\tau^3} e^{-\tau T} h \left(-2\tau(\lambda + \tau Q) + 2\alpha + e^{\tau T} \left(-2\alpha + \tau(2\tau Q + 2(T\alpha + \lambda) - \tau T(T\alpha + 2\lambda)) \right) \right) \quad (5)$$

Purchasing cost (Pc)

$$Pc = p(Q - R) \quad (6)$$

Summation of equation (3), (4), (5) and (6), gives the Total variable cost for the case I,

$$TVC = A + p(Q - R) + k \left(Q - e^{-\tau T} Q + \frac{\tau\alpha}{\tau} - \frac{T^2\alpha}{2} - \frac{(\alpha - e^{-\tau T}\alpha)}{\tau^2} - \frac{(e^{-\tau T} - 1)\lambda}{\tau} - T\lambda \right) + \frac{1}{2\tau^3} e^{-\tau T} h \left(-2\tau(\lambda + \tau Q) + 2\alpha + e^{\tau T} \left(-2\alpha + \tau(2\tau Q + 2(T\alpha + \lambda) - \tau T(T\alpha + 2\lambda)) \right) \right) \quad (7)$$

3.2 Computation of Inventory Level in the Interval $\mu_1 \leq t < \mu_2$: Case II

Inventory rate for the case II,

$$\frac{dI_2(t)}{dt} + \tau I_2(t) = -(\alpha t + \lambda) \quad (8) ; 0 \leq t < \mu_1$$

$$\frac{dI_3(t)}{dt} + \tau I_3(t) = -\gamma \quad (9) ; \mu_1 \leq t < T < \mu_2$$

Consider condition $I_1(\mu_1) = I_2(\mu_1)$

$$I_2(t) = e^{-\tau t} \left(Q + \frac{\tau\lambda - \alpha}{\tau^2} - \frac{(\tau t - 1)\alpha + \tau\lambda}{\tau^2} \right) ; 0 \leq t < \mu_1 \quad (10)$$

$$I_3(t) = e^{-\tau t} \left(\frac{((1 - \tau\mu_1)\alpha - \tau\lambda + \tau\gamma)e^{\tau\mu_1}}{\tau^2} + \left(Q + \frac{\tau\lambda - \alpha}{\tau^2} \right) \frac{\gamma}{\tau} \right) ; \mu_1 \leq t < T < \mu_2 \quad (11)$$

Costs can be calculated using (10) & (11).

Total variable cost can be obtained by adding all costs in this case together.

$$\begin{aligned} \text{TVC} = & k \left(Q - e^{-\tau\mu_1}Q + (\mu_1 - T)\gamma + \frac{(e^{-\tau\mu_1} - e^{-\tau T})(\tau^2 Q - \alpha)}{c^2} + \frac{(e^{\tau\mu_1}(\alpha - \tau\mu_1\alpha + \tau(\gamma - \lambda)) + \tau\lambda)}{c^2} \right) - \\ & \frac{(2 - 2e^{-\tau\mu_1} - 2\tau\mu_1 + (\tau\mu_1)^2)\alpha}{2\tau^2} + \frac{\lambda(e^{\tau\mu_1} - 1 + \tau\mu_1)}{\tau} + \\ & h \left(\frac{e^{-\tau\mu_1}}{2\tau^3} (2\alpha - 2\tau(\tau Q + \lambda) + e^{\tau\mu_1}(\tau(2\tau Q + 2(\mu_1\alpha + \lambda) - \tau\mu_1(\mu_1\alpha + 2\lambda)) - 2\alpha)) + \frac{1}{\tau^2} \left(\frac{e^{-\tau\mu_1} - e^{-\tau T}}{\tau} (\tau^2 Q + (e^{\tau\mu_1} - 1)\alpha + \tau(\lambda - e^{\tau\mu_1}(\mu_1\alpha - \gamma + \lambda))) \right) + \gamma \log(e^{-\tau T}) - \gamma \log(e^{-\tau\mu_1}) \right) \right) + p(Q - R) + A \end{aligned} \quad (12)$$

3.3 Computation of Inventory Level in the Interval $\mu_2 < T$: Case III

Inventory rate for case III

$$\frac{dI_4(t)}{dt} + \tau I_4(t) = -(\alpha t + \lambda) \quad ; 0 \leq t < \mu_1 \quad (13)$$

$$\frac{dI_5(t)}{dt} + \tau I_5(t) = -\gamma \quad ; \mu_1 \leq t < \mu_2 \quad (14)$$

$$\frac{dI_6(t)}{dt} + \tau I_6(t) = \beta t - \eta \quad ; \mu_2 \leq t < T \quad (15)$$

Consider conditions $I_4(0) = Q$,

$I_4(\mu_1) = I_5(\mu_1)$, $I_5(\mu_2) = I_6(\mu_2)$

$$I_4(t) = e^{-\tau t} \left(Q + \frac{\tau\lambda - \alpha}{\tau^2} \right) - \frac{(\tau t - 1)\alpha}{\tau^2} - \frac{\lambda}{\tau} \quad ; 0 \leq t \leq \mu_1 \quad (16)$$

$$\begin{aligned} I_5(t) = & \left(e^{-\tau\mu_1} \left(Q + \frac{\tau\lambda - \alpha}{\tau^2} \right) + \frac{\gamma}{\tau} - \frac{(\tau\mu_1 - 1)\alpha}{\tau^2} - \frac{\lambda}{\tau} \right) e^{\tau(\mu_1 - t)} - \frac{\gamma}{\tau} \end{aligned}$$

$$; \mu_1 \leq t \leq \mu_2 \quad (17)$$

$$\begin{aligned} I_6(t) = & \frac{t\beta}{\tau} - \frac{\beta + \tau\eta}{\tau^2} + \frac{e^{-\tau t}}{\tau^2} \left((e^{\tau\mu_1} - 1)\alpha + \tau(\tau Q - e^{\tau\mu_2}\gamma + \lambda - e^{\tau\mu_1}(\mu_1\alpha - \gamma + \lambda)) \right) + \left(\frac{(\beta + \tau\eta)}{\tau^2} - \frac{\mu_2\beta}{\tau} \right) e^{\tau(\mu_2 - t)} \quad ; \mu_2 \leq t < T \quad (18) \end{aligned}$$

Costs can be calculated using (16), (17), (18). Total variable cost can be obtained by adding all these costs together.

$$\begin{aligned} \text{TVC} = & k \left(Q - e^{-\tau\mu_1}Q - \frac{\tau\beta}{\tau} + \frac{\tau^2\beta}{2} + \frac{\mu_2\beta}{\tau} - \frac{\mu_2^2\beta}{2} - T\eta + \mu_2\eta + (\mu_1 - \mu_2)\gamma + \frac{(e^{-\tau\mu_1})(\tau^2 Q - \alpha + e^{\tau\mu_1}(\alpha - \tau\mu_1\alpha + \tau(\gamma - \lambda)) + \tau\lambda)}{\tau^2} - \frac{e^{-\tau\mu_2}(\tau^2 Q - \alpha + e^{\tau\mu_1}(\alpha - \tau\mu_1\alpha + \tau(\gamma - \lambda)) + \tau\lambda)}{\tau^2} - \frac{(2 - 2e^{-\tau\mu_1} - 2\tau\mu_1 + (\tau\mu_1)^2)\alpha}{2\tau^2} + \frac{(e^{-\tau\mu_1} - 1 + \tau\mu_1)\lambda}{\tau} + \frac{1}{\tau^2} (e^{-\tau\mu_2} - e^{-\tau T}) \left((e^{\tau\mu_1} - 1)\alpha + e^{\tau\mu_2}(\beta - \tau\mu_2\beta + \tau(\eta - \gamma)) + \tau(\tau Q + \lambda - e^{\tau\mu_1}(\mu_1\alpha - \gamma + \lambda)) \right) \right) + A + p(Q - R) + h \left(\frac{1}{\tau^2} \left(\frac{\tau T^2\beta}{2} - T\beta + \mu_2\beta - \frac{\tau\mu_2^2\beta}{2} - \tau T\eta + \tau\mu_2\eta + \frac{e^{-\tau\mu_2} - e^{-\tau T}}{\tau} \left((e^{\tau\mu_1} - 1)\alpha + e^{\tau\mu_2}(\beta - \tau\mu_2\beta + \tau(\eta - \gamma)) + \tau(\tau Q + \lambda - e^{\tau\mu_1}(\mu_1\alpha - \gamma + \lambda)) \right) \right) + \frac{e^{-\tau\mu_1}}{2\tau^3} (2\alpha - 2\tau(\tau Q + \lambda) + e^{\tau\mu_1}(-2\alpha + \tau(2\tau Q + 2(\mu_1\alpha + \lambda) - \tau\mu_1(\mu_1\alpha + 2\lambda)))) \right) + \end{aligned}$$

$$\frac{(e^{-\tau\mu_2} - e^{-\tau\mu_1})}{\tau^3} (-\tau^2 Q + \alpha - e^{\tau\mu_1} \alpha - \tau\lambda) + \frac{(e^{-\tau\mu_2} - e^{-\tau\mu_1})}{\tau^3} \tau e^{\tau\mu_1} (\mu_1 \alpha - \gamma + \lambda) \quad (19)$$

Equations (7), (12) and (19) for the total variable cost are used to find the minimum value of the TVC by applying the 1st & 2nd derivative tests.

4 RESULTS

Three numerical examples will be considered to calculate cycle length that minimize the total variable cost. The parameters used in the three numerical examples were carefully chosen based on existing research (Mondal, 2021 and Kumar, 2022) and extracted from the relevant literature since it ensures that the selected parameters are grounded in well-established studies and adds credibility to the analysis. By relying on parameters with documented relevance and precedence, the analysis is more likely to accurately reflect real-world conditions or theoretical frameworks. This not only enhances the robustness of the findings but also guarantees that the results are interpretable and meaningful.

4.1 Example 1

$\tau = 0.1$, $\mu_1 = 15$ weeks, $\mu_2 = 19$ weeks, $k = \$ 7.50$ per unit, $A = \$ 95.00$ per order, $h = \$ 0.90$ per unit, $p = \$ 12.00$ per unit, $Q = 2000$, $R = 100$, $\alpha = 3.667$, $\beta = 15$, $\lambda = 15$, $\eta = 355$, $\gamma = 70$. After 28 weeks 3 days and 4 hours, company should have to make a new order to minimize the total variable cost for this example. The new order should be made at there. \$ 40896.70 is the minimum total variable cost of this inventory.

4.2 Example 2

$\tau = 0.01$, $\mu_1 = 8$ weeks, $\mu_2 = 12$ weeks, $k = \$ 2.00$ per unit, $A = \$ 500.00$ per order, $h = \$ 3.00$ per unit, $p = \$ 8.00$ per unit, $Q = 583$, $R = 10$, $\alpha = 5$, $\beta = 9$, $\lambda = 30$, $\eta = 178$, $\gamma = 70$. After 28 weeks 4 days and 16 hours company should have to make a new order for minimize the total variable cost for this example. \$1025.13 is the minimum total variable cost.

4.3 Example 3

$\tau = 0.1$, $\mu_1 = 3$ weeks, $\mu_2 = 13$ weeks, $k = \$ 9.50$ per unit, $A = \$ 105.00$ per order, $h = \$ 1.10$ per unit, $p = \$ 14.00$ per unit, $Q = 3000$, $R = 105$, $\alpha = 40$, $\beta = 3$, $\lambda = 15$, $\eta = 171$, $\gamma = 135$. After 66 weeks 5 days and 8 hours company should have to make a new order for minimize the total variable cost for this example. \$ 13149.10 is the minimum total variable.

5 CONCLUSION

This work builds an economic order quantity model of items that have a trapezoidal pattern demand rate and a constant deterioration rate. Three possible cases are considered with respect to the increasing, constant, and decreasing parts of the demand. According to the results, minimum total variable cost is obtained only in case $\mu_2 < T$. That means, to minimize the total variable cost of an inventory, the next order must be made after decreasing part of the demand rate is started.

REFERENCES

- Anil Kumar, B., and Paikray, S. K. (2022). Cost optimization inventory model for deteriorating items with trapezoidal demand rate under completely backlogged shortages in crisp and fuzzy environment. *RAIRO - Operations Research*, 56(3), 1969–1994

- Mishra, S., Raju, L. K., Misra, U. K., & Misra, G. (2012). A study of EOQ model with power demand of deteriorating items under the influence of inflation. *General Mathematics Notes*, 10(1), 41-50.
- Misra, R. B. (1979). A note on optimal inventory management under inflation. *Naval Research Logistics Quarterly*, 26(1), 161–165.
- Mondal, R., Ali Akbar Shaikh, Asoke Kumar Bhunia, Hezam, I. M., and Chakraborty, R. K. (2021). Impact of Trapezoidal Demand and Deteriorating Preventing Technology in an Inventory Model in Interval Uncertainty under Backlogging Situation. *Mathematics*, 10(1), 78–78.



Proper Super Edge Magic Total Labeling for Special Graph

Sandarekha GLN¹, Perera AAI¹, Mohommad MAM²

Department of Physical Science, Faculty of Applied Sciences, Rajarata University of Sri Lanka
asp2019060@as.rjt.ac.lk

Department of Mathematics, Faculty of Science, University of Peradeniya, Sri Lanka
aaip@sci.pdn.ac.lk

ABSTRACT

In graph theory, there are different types of techniques for labeling graphs, like radio labeling, harmonious labeling, graceful labeling, magic and antimagic labeling, etc. Among these labeling methods, we use a special version of magic labeling called super edge-magic total labeling. Since, graph theory provides great insight into diverse mathematical structures and their uses, this study deals with the problem of super edge-magic total labeling, limited to the triangle snake graph. The aim is to present a new labeling scheme for this graph that helps extend knowledge in both theoretical and practical terms in graph theory. This work is valuable academically as it brings out new concepts on edge magic and super edge magic labeling which can be used in future studies and applications within related fields. The purpose is to come up with a new pattern following the super edge-magic labeling rules and study its properties. In terms of methodology, the research focuses on finite simple undirected graphs whose sets of vertices and edges will be denoted by $V(G)$ and $E(G)$ respectively. In addition to that, the magic number can be obtained, $k = p + q + 3 = 3(n + 2)$. Therefore, this research validates a new super edge-magic labeling pattern for the triangle snake graph, opening avenues for further studies on similar graphs and potential real-world applications. Future work will explore extending these findings to other graph structures.

KEYWORDS: Magic Labeling, Edge Magic Total Labeling, Super Edge Magic Total Labeling, Triangle Snake Graph

1 INTRODUCTION

These are interesting since relationships between super edge-magic labeling and previously well-studied labeling has been found by the authors (Gallian J. A., 2022), The concept of edge-magic total labeling was given by *Kotzig and Rosa*. (Ivančo, 2002)) Super edge-magic total labeling was originally defined by *Enomoto et al.* (Ngurah, 2007, June) This concept's history is closely connected with the larger field of graph labeling research, which began in the middle of the 20th century. This leads to amazing combinatorial features and applications in fields such as coding theory, network design, etc.

This research explores into graph theory with a focus on super edge-magic total labeling, aiming to introduce and validate a new pattern, thus expanding theoretical and practical understanding. The study aims to fill the gap in the new knowledge of labeling patterns by identifying a new pattern, demonstrating its conformance to super edge-magic total labeling rules, and examining its characteristics. The main results that have been achieved are: there is a special new pattern for the super edge-magic total labeling for the triangle snake graph, it has been mathematically proved using combinatorial proof technique, and it has a significant implication for theoretical

research and practical applications in graph theory.

2 LITERATURE

Super Edge-Magic Total (SEMT) labeling is a concept in graph theory that focuses on assigning labels to both edges and vertices of a graph such that certain conditions hold. In SEMT labeling, the goal is to assign integers to the vertices and edges of a graph such that the sum of the labels of the incident vertex and edge at each vertex results in a constant value across the entire graph. This property is of particular interest because of its applications in areas like network design, cryptography, and traffic flow optimization, where the structured assignment of values to graph components can lead to efficient solutions.

In the literature, SEMT labeling has been widely studied for various graph types. For cycle graphs C_n SEMT is known to exist if and only if n is odd. In the case of complete bipartite graphs $K_{m,n}$ SEMT labeling holds when either $m = 1$ or $n = 1$. Similarly, complete graphs K_n have SEMT labeling for $n = 1, 2$ or 3 . Caterpillar graphs, which are trees with a central path, have been shown to admit SEMT labeling (Gallian J. A., 2022) (Ivančo, 2002)). For specific products of graphs such as $m(P_2 \times P_n)$ SEMT is valid if both m and n are odd (Singgih, 2015).

The conditions for SEMT labeling also extend to more complex graphs. For example, the join of a complete graph K_1 with any graph admits SEMT (Chen, 2001). The fan graphs F_n are known to have SEMT for $n \leq 6$ (Figueroa-Centeno, 2002), and books B_n can be labeled with SEMT if n is even. Additionally, for star graphs and other

regular graphs, the SEMT condition holds under specific constraints such as $k \leq 3$ for k -regular graphs (Chen, 2001) and friendship graph of n triangles if $n = 3, 4, 5$, or 7 (Lin, 2002) (Lin, 2002) where SEMT is valid under particular configurations. Moreover, SEMT labeling has been explored for more intricate graph structures, including generalized Petersen graphs where SEMT is valid under particular configurations (Gallian J. A., 2022).

In summary, while significant progress has been made in identifying SEMT labeling conditions for various graph types, many challenges remain in fully characterizing its applicability. This research aims to contribute to the understanding of SEMT labeling by exploring new graph structures, refining existing conditions, and investigating the practical applications of SEMT labeling in real-world networks

3 METHODOLOGY

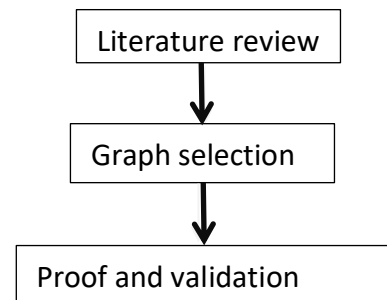


Figure 01: Super Edge Magic Total Labeling for a Triangle Snake Graph

The methodology for our research on "Super Edge Magic Total Labeling for a Triangle Snake Graph" begins with a Literature Review, providing a thorough review of existing work on graph theory, specifically focusing on super edge-magic total labeling. This review helps identify research gaps and establishes the relevance of the study. Next, the Graph

Selection step involves choosing a "Triangle Snake Graph," aligning with research goals and setting a foundation for exploring labeling patterns unique to this graph type. Following this, Proof and Validation require developing a formal proof that confirms the labeling approach adheres to super edge-magic total labeling principles, ensuring the correctness of this methodology.

In this research, super edge total magic labeling of a special type of graph is given by the following definition.

a. Definition 1 (Super edge total magic labeling)

Let only finite, simple, connected and undirected graphs. We denote the vertex set and edge set of a graph G by $V(G)$ and $E(G)$, respectively. Let (1). $|V(G)| = p$ and (2). $|E(G)| = q$. An edge-magic total labeling of a graph G is a bijection f from $V(G) \cup E(G)$ to $\{1, 2, 3, \dots, p + q\}$ is called an edge-magic total labeling of G if there exists a constant k (called the magic number of f) such that; (3). $f(u) + f(v) + f(uv) = k$ for any edge of G . An edge-magic total labeling f is called super edge-magic total labeling if (4). $f(V(G)) = \{1, 2, 3, \dots, p\}$ and (5). $f(E(G)) = \{p + 1, p + 2, p + 3, \dots, p + q\}$ Magic number k always belongs to $[p + q + 3, 2(p + q)]$. (Li, 2020)

4 RESULTS & DISCUSSION

Using above super edge magic total labeling theorem we found the new theorem.

b. Definition(Triangle Snake Graph)

Suppose that T be a graph, triangle snake graph is a connected graph whose vertex set

$$\{v_1, v_3, v_5, v_7, \dots, v_{2i-1},$$

$$u_2, u_4, u_6, u_8, \dots, u_{2i}\}$$

and edge set is

$$\{w_{(3n+3)-0}, w_{(3n+3)-1}, \dots, w_{(3n+3)-j}\}$$

. The vertex set of triangle snake graph is

$$\{v_{2i-1}, u_{2i} : i = 1, 2, 3, \dots\}$$

, and edge set of triangle snake graph is $\{w_{(3n+3)-j} : j = 0, 1, 2, 3, \dots; n = \text{number of triangles}\}$.

Let (6). $|E(T)| = 2n + 1$ and (7). $|V(T)| = n + 2$. Magic number k always belongs $[p + q + 3]$.

4.2 Theorem

The Triangle Snake graph is a super edge-magic total labeling graph.

4.3 Proof:

The Triangle Snake graph as in the Figure 1,

top vertices denoted by $u_2, u_4, u_6, u_8, \dots, u_{2i} ; i = 1, 2, 3, \dots$

bottom vertices denoted by $v_1, v_3, v_5, v_7, \dots, v_{2i+1} ; i = 1, 2, 3, \dots$

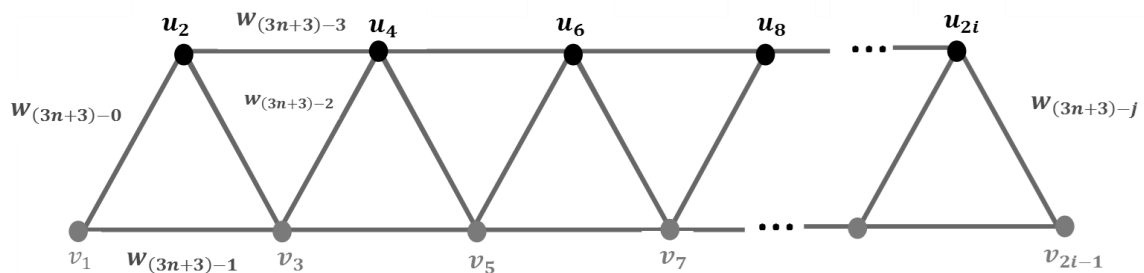


Figure 02: Labeled Triangle Snake

In this graph, the edges can be labeled as the letter 'W' shape. The labeling pattern is obtained starting from left corner top vertex and all connected edges in that vertex and the edge in the bottom vertices that belongs to triangle made with top vertex are labeled counter clockwise. After that move to the next neighbour vertex at the top vertices and edges labeled as similar pattern. In this way we can label all edges of this triangle snake graph.

This labeling pattern for the edges denoted by,

$w_{(3n+3)-0}, w_{(3n+3)-1}, w_{(3n+3)-2}, \dots, w_{(3n+3)-j}$
; $j = 0, 1, 2, 3, \dots$, and n = indicates the number of triangles in that pattern.

Note that,

$$(8) \_f(u) + f(v) + f(uv) = k$$

$$(9) \_u_{2i} + v_{2i-1} + w_{(3n+3)-j} = k$$

$$(10) \_u_{2i} + v_{2i+1} + w_{(3n+3)-(j+2)} = k$$

$$(11) \_v_{2i-1} + v_{2i+1} + w_{(3n+3)-(j+1)} = k$$

$$(12) \_u_{2i} + u_{2i+2} + w_{(3n+3)-(j+3)} = k,$$

where $i = 1, 2, 3, \dots$, $j = 0, 1, 2, 3, \dots$
, n = number of triangles in that pattern.

Also,

$$(13). |V(T)| = n + 2 = p$$

and

$$(14). |E(T)| = 2n + 1 = q$$

Hence,

$$\begin{aligned} (15) \_k &= p + q + 3 \\ &= (n + 2) + (2n + 1) + 3 \\ &= 3n + 6 \end{aligned}$$

Table 1: Number of vertices & edges

<i>Number of triangles</i>	$ V(G) $	$ E(G) $
1	3	3
2	4	5
3	5	7
4	6	9
.	.	.
.	.	.
N	$n + 2$	$2n + 1$

The special number k always falls within the range $[p + q + 3, 2(p + q)]$. However, in the analyzed graph, k consistently (always) equals $[p + q + 3]$. It is crucial to emphasize that the sum of labels of two adjacent vertices should never be the same. The vertices of edges labeled with the highest values are labeled with the lowest values, and vice versa: the vertices of edges labeled with the lowest values are labeled with the highest values. The labeling pattern creates a "W" shape (reverse "M" shape starting between ending 2 vertices) with edges and an "M" shape with vertices. The graph consists of $n + 2$ vertices and $2n + 1$ edges, where n represents the number of triangles. It can be clearly seen in the Table 1.

The following example gives a better idea about this labeling pattern. When, $n = 4$ there are four triangles in the triangular snake graph.

In this graph,

$$(16). p = |V(G)| = n + 2 = 4 + 2 = 6$$

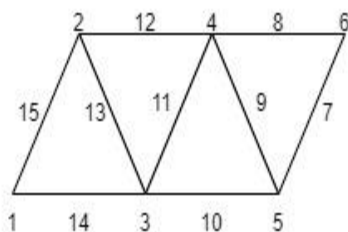


Figure 03: The super edge-magic total labeling graph with 4 triangle

$$(17). q = |E(G)| + 1 = 2n + 1 = 2(4) + 1 = 9$$

$$(18). k = p + q + 3 = 6 + 9 + 3 = 18$$

Therefore, according to the labeling method, we can obtain the following super edge-magic total labeling graph.

5 CONCLUTION

In this paper, we prove that the triangular snake graph can be labeled according to the selection of left corner top vertex and all connected edges in that vertex and the edge in the bottom vertices that belongs to triangle made with top vertex are labeled counter clockwise and then select the next neighbor vertex to continue this labeling pattern, and it is shown that the triangular snake graph has the super edge-magic total labeling. It is given that as a general theorem. Investigating similar theorems for other graphs remains an open area of research. We aim to utilize this super magic label snake graph to identify potential applications in real-world scenarios in the future.

This research successfully introduces a new super edge-magic labeling scheme for the triangle snake graph, contributing to theoretical advancements and practical applications in graph theory. By adhering to the established rules of super edge-magic labeling, the study uncovers the unique properties of this specific graph, offering a foundation for future exploration. We hope to, the results not only validate the

labeling pattern but also highlight its potential for solving real-world problems and developing applications, particularly in areas requiring efficient network management and optimization. This research paves the way for extending super edge-magic labeling to other graph structures, fostering further academic inquiry and practical innovations

REFERENCES

- Chen, Z. (2001). *super edge-magic graphs*. . Journal of Combinatorial Mathematics and Combinatorial Computing, 38, 55-64.
- Figueroa-Centeno, R. M.-B. (2002). *On super edge-magic graphs*. Ars Comb., 64, 81.
- Gallian, J. (2022). *A dynamic survey of graph labeling*.
- Gallian, J. A. (2022). *A dynamic survey of graph labeling*. Electronic Journal of combinatorics, 6(25), 4-623.
- Ivančo, J. &. (2002)). *On edge-magic disconnected graphs*. . SUT Journal of Mathematics, 38(2), 175-184.
- Li, J. W. (2020). *Super edge-magic total labeling of combination graphs*. . Engineering Letters, 28(2), 412-419.
- Lin, Y. M. (2002). *Edge-magic total labelings of wheels, fans and friendship graphs*. . Bulletin of the ICA, 35, 89-98.
- Ngurah, A. A. (2007, June). *On super edge-magic strength and deficiency of graphs*. Berlin.
- Singgih, I. (2015). *New methods for magic total labelings of graphs*. (Master's thesis, University of Minnesota).



Temperature Based Topological Indices of Breast Cancer Drugs

Perera KKKR

Department of Mathematics, University of Kelaniya

kkkrperera@kln.ac.lk

ABSTRACT

Cancer, the result of rapid abnormal growth of cells in the human body, is a major cause of death in the world, and breast cancer is the most common form of cancer among women. Anticancer drugs are used to cure or prevent the growth of tumors. Various drugs have been designed to treat cancers, and many laboratory experiments have been conducted to identify the physical properties of those drugs, and it is very time consuming and expensive to measure those properties. The structure of drug compounds can be represented as molecular graphs, where a vertex represents an atom, and an edge represents a bond between atoms. Topological indices are graph invariants or numerical quantities used to estimate the physical characteristics of molecular structure in drugs. These indices are categorized according to the topology of the graph, including vertex degree, diameter, distance etc. Most widely studied topological indices are based on vertex degree relationships. This study computed temperature-based topological indices for basic graphs and selected anticancer drugs proposed for breast cancer, such as Letrozole, Toremifene, Abemaciclib, and Tamoxifen. The physical properties such as boiling point, flash point, molar volume, molar refractivity and polarizability of these drugs were compared with the temperature topological index values to determine which topological indices are closely related with their physiochemical properties.

KEYWORDS: Anticancer Drugs, Temperature indices, Topological indices

1 INTRODUCTION

Breast cancer is a disease in which abnormal breast cells grow uncontrollably and form tumors. Various drugs have been designed to treat cancers. Many expensive and time-consuming laboratory experiments have been conducted to identify the physical properties of those drugs. The structure of chemical compounds can be explained by using invariant properties of graphs. The structure of a drug can be represented as a molecular graph, where a vertex represents an atom, and an edge represents a bond between atoms. By calculating graph invariants or numerical quantities called topological indices, attributes of the molecular structure can be studied. These

indices are categorized according to the topology of the graph, including its vertex degree, diameter, distance between vertices, and its eigen values. By introducing the temperature of a vertex of a graph, temperature-based topological indices were formulated. Degree-based topological indices on anticancer drugs were studied in (Shanmukha, M.C. *et al.*, 2020). Molecular graphs of some anticancer drugs were studied in (Shi, X. *et al.*, 2024 and Singh, O., *et al.*, 2024) by using temperature-based indices. Several researchers have considered temperature-based topological indices of different molecules (Khan, A.R. *et al.*, 2022; Hayat, S. *et al.*, 2024). In this study, first, we build up formulae for temperature

based topological indices of basic graphs and then computed formulae for temperature based topological indices of four anticancer drugs, which were not considered in the literature to identify their physical properties.

2 METHODOLOGY

In this paper, all graphs are simple and connected and denoted by $G(V, E)$ or simply G , with vertex set $V(G)$ and edge set $E(G)$. Order of V is denoted by $|V| = n$ and the cardinality of the set of edges is denoted by $|E|$. Degree of a vertex u is the number of edges adjacent to it. Temperature of a vertex u of a graph G with n vertices is defined by (Fajtlowicz, S., 1988) as

$$T_u = \frac{d_u}{n-d_u}, \quad 0 \leq d_u \leq n-1, \quad (1)$$

where d_u represents the degree of a vertex u . By replacing vertex degrees with vertex temperatures, temperature-based topological indices or temperature indices were introduced.

2.1 Defining Temperature Indices

(Rajasekharaiah, G.V. and Murthy, U.P. 2021) showed that the linear model, based on the Hyper-Zagreb indices, performed well than the models corresponding to the other distance-based topological indices. Based on that (Kulli, V.R., 2019) introduced a generalized first hypertemperature index $HT_1^k(G)$, $k \in \mathbb{R}$ as

$$HT_1^k(G) = \sum_{uv \in E(G)} (T_u + T_v)^k \quad (2)$$

Hence, the first hypertemperature index is $HT_1^2(G) = \sum_{uv \in E(G)} (T_u + T_v)^2$ (3) where we replaced HT_1^k by $k = 2$.

The generalized second hypertemperature index is $HT_2^k(G) = \sum_{uv \in E(G)} (T_u T_v)^k$ (4)

Then the second hypertemperature index can be written as

$$HT_2^2(G) = \sum_{uv \in E(G)} (T_u T_v)^2 \quad (5)$$

where we replace HT_2^k by $k = 2$.

By replacing HT_1^k by $k = -1/2$, the sum connectivity temperature index can be written as

$$ST(G) = \sum_{uv \in E(G)} \frac{1}{\sqrt{(T_u + T_v)}} \quad (6)$$

By replacing HT_2^k by $k = -1/2$, the reciprocal product connectivity temperature index can be written as

$$RPT(G) = \sum_{uv \in E(G)} \frac{1}{\sqrt{(T_u T_v)}} \quad (7)$$

Arithmetic geometric temperature index (Kulli, V.R., 2019) is defined as

$$AGT(G) = \sum_{uv \in E(G)} \frac{T_u + T_v}{2\sqrt{T_u T_v}} \quad (8)$$

by combining both $HT_1^k(G)$ and $HT_2^k(G)$.

2.2 Basic Graphs

Regular graph is a graph, where each vertex has the same degree.

Cycle graph $(C_n, n \geq 3)$ is a regular, non-trivial path that starts and ends at a same vertex without repeating edges.

Complete graph $(K_n, n \geq 3)$ is a regular graph, where each vertex is connected to all other vertices.

2.3 Temperature Indices of Basic Graphs

In this section, we will derive temperature index formula for some basic graphs.

PROPOSITION 1: For a regular graph G with degree $r \geq 1$, generalized first hypertemperature index is $HT_1^k(G) = \left(\frac{2r}{n-r}\right)^k \frac{nr}{2}$, $0 < r \leq n-1$.

Proof: The number of edges of regular graph is $\frac{nr}{2}$, and $T_u = \frac{d_u}{n-d_u}$, $0 \leq d_u \leq n-1$, for $\forall u$. Then

$$\begin{aligned} HT_1^k &= \sum_{uv \in E(G)} (T_u + T_v)^k \\ &= \left(\frac{r}{n-r} + \frac{r}{n-r}\right)^k \left(\frac{nr}{2}\right) = \left(\frac{2r}{n-r}\right)^k \left(\frac{nr}{2}\right). \end{aligned} \quad (9)$$

PROPOSITION 2: For a regular graph G with degree $r \geq 1$, generalized second hyper temperature index is $HT_2^k(G) = \frac{r^{2k+1}n}{2(n-r)^{2k}}$.

Proof: The number of edges of regular graph is $\frac{nr}{2}$.

$$HT_2^k = \sum_{uv \in E(G)} (T_u T_v)^k = \left(\frac{r}{n-r} \times \frac{r}{n-r} \right)^k \left(\frac{nr}{2} \right) = \left(\frac{r^2}{(n-r)^2} \right)^k \left(\frac{nr}{2} \right) = \frac{r^{2k+1}n}{2(n-r)^{2k}} \quad (10)$$

Using proposition 1 and proposition 2, we derived temperature indices of some basic graphs and tabulate in Table 1.

Table 1: Temperature indices of basic graphs

Gra ph	Regular graph ($r \geq 1$)	C_n , ($n \geq 3$)	K_n , $n \geq 3$
HT_1^2	$\frac{2r^3n}{(n-r)^2}$	$\frac{16n}{(n-2)^2}$	$2n(n-1)^3$
HT_2^2	$\frac{r^5n}{2(n-r)^4}$	$\frac{16n}{(n-2)^4}$	$\frac{n(n-1)^5}{2}$
ST	$\frac{nr}{2} \sqrt{\frac{n-r}{2r}}$	$\frac{n\sqrt{n-2}}{2}$	$\frac{n\sqrt{n-1}}{2\sqrt{2}}$
RPT	$\frac{n(n-r)}{2}$	$\frac{n(n-r)}{2}$	$\frac{n}{2}$
AGT	$\frac{nr}{2}$	n	$\frac{n(n-1)}{2}$

2.4 Temperature Indices of Drugs Used to Treat Breast Cancers

In this section, we obtain the temperature based topological indices of molecular graphs of Letrozole, Toremifene, Abemaciclib, and Tamoxifen.

1: Letrozole

Letrozole shown in Figure 1 is used to treat certain types of breast cancers in women who have already reached post menopause.

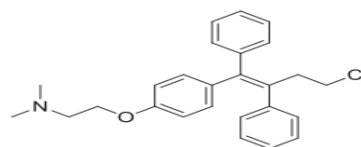


Figure 1: Structure of Letrozole

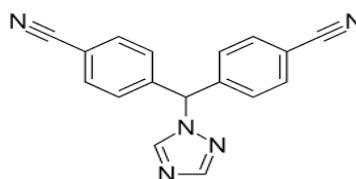


Figure 2: Structure of Toremifene

Edge set of the molecular graph can be partitioned as follows:

$$\begin{aligned} E_1 &= \{(u, v) | d_u = 1, d_v = 3\} \\ E_2 &= \{(u, v) | d_u = 2, d_v = 2\} \\ E_3 &= \{(u, v) | d_u = 2, d_v = 3\} \\ E_4 &= \{(u, v) | d_u = 3, d_v = 3\} \\ |E_1| &= 2, |E_2| = 7, |E_3| = 10, |E_4| = 3 \\ \text{and } |V| &= 21. \end{aligned}$$

2: Toremifene

Toremifene shown in Figure 2 is an anti-oestrogen hormone used in the treatment of breast cancer. Edge set can be partitioned as follows:

$$\begin{aligned} E_1 &= \{(u, v) | d_u = 1, d_v = 3\} \\ E_2 &= \{(u, v) | d_u = 1, d_v = 2\} \\ E_3 &= \{(u, v) | d_u = 2, d_v = 2\} \\ E_4 &= \{(u, v) | d_u = 2, d_v = 3\} \\ E_5 &= \{(u, v) | d_u = 3, d_v = 3\} \\ |E_1| &= 2, |E_2| = 1, |E_3| = 13, \\ |E_4| &= 11, |E_5| = 4 \text{ and } |V| = 29. \end{aligned}$$

3 : Abemaciclib

Abemaciclib shown in Figure 3 is a drug used to treat adults with certain types of breast cancer, which blocks certain proteins and help to avoid the growth of cancer cells.

Edge set can be partitioned as follows:

$$E_1 = \{(u, v) | d_u = 1, d_v = 3\}$$

$$E_2 = \{(u, v) | d_u = 1, d_v = 2\}$$

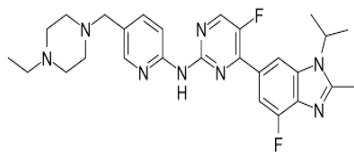


Figure 3: Structure of Abemaciclib

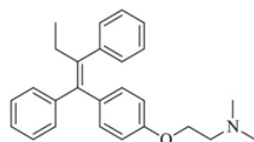


Figure 4: Structure of Tamoxifen

$$E_3 = \{(u, v) | d_u = 2, d_v = 2\}$$

$$E_4 = \{(u, v) | d_u = 2, d_v = 3\}$$

$$E_5 = \{(u, v) | d_u = 3, d_v = 3\}$$

$$|E_1| = 5, |E_2| = 1, |E_3| = 6, \\ |E_4| = 21, |E_5| = 8 \text{ and } |V| = 41.$$

4: Tamoxifen

Tamoxifen shown in Figure 4 is a hormone therapy used to treat hormone receptor-positive breast cancer.

Edge set can be partitioned as follows:

$$E_1 = \{(u, v) | d_u = 1, d_v = 3\}$$

$$E_2 = \{(u, v) | d_u = 1, d_v = 2\}$$

$$E_3 = \{(u, v) | d_u = 2, d_v = 2\}$$

$$E_4 = \{(u, v) | d_u = 2, d_v = 3\}$$

$$E_5 = \{(u, v) | d_u = 3, d_v = 3\}$$

$$|E_1| = 2, |E_2| = 1, |E_3| = 12, \\ |E_4| = 11, |E_5| = 4 \text{ and } |V| = 30.$$

From the definitions given for temperature topological indices in section 2.1 and the edge partitions of molecular graphs, corresponding temperature index values can be calculated.

3 RESULTS AND DISCUSSION

We have derived formulae for temperature topological indices of basic graphs as described in section 2.3. Temperature topological indices of those

anticancer drugs are calculated and tabulated in Table 3. Physical properties such as boiling point(BP), flash

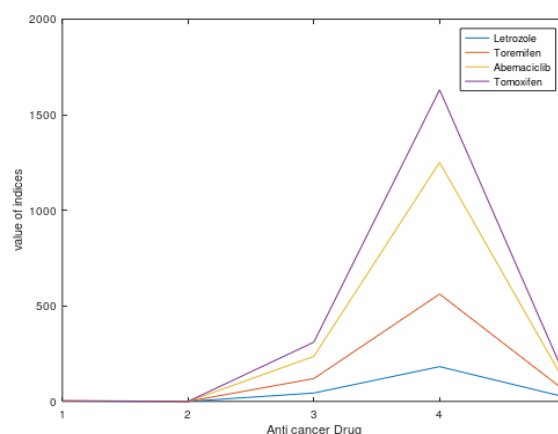


Figure 5: Temperature topological indices of anticancer drugs

point(FP), molar volume(MV), molar refractivity(MR) and polarizability(PB)

of four anticancer drugs are tabulated in Table 4. For each of the anticancer drugs,

we have fitted the temperature topological index values and represented in Figure 5. Table 5 gives the correlation coefficients between topological indices of drug molecules and their physical properties.

Table 2: Temperature topological index values of anticancer drugs

Drug	HT_1^2	HT_2^2	ST	RPT	ATG
Letrozo-	1.477	6.391	4.393	1.810	2.264
Toremi-	2.429	8.336	1.195	5.617	5.433
Abema-	3.106	9.054	2.357	1.251	9.674
Tamoxi-	3.969	1.070	3.099	1.630	1.274

4 CONCLUSIONS

In this study, temperature topological indices were calculated for anticancer drugs recommended for breast cancers

and compared the correlations between temperature topological indices and their physical properties. According to the results, molar volume and molar refractivity are correlated with first hyper temperature index, polarizability and boiling point are correlated with the

arithmetic geometric index and flash point is correlated with second hyper temperature index. The outcome of the study is beneficial for drug designers to determine which topological indices are closely related with their physiochemical properties.

Table 3: Physical properties of anticancer drugs taken from Chemspider Royal Society of Chemistry

Drug	BP	FP	MV	MR	PB
Tamoxifen	482	140	356	118	44
Abemaciclib	689	370	382	140	54
Toremifene	535	277	367	49	46
Letrozole	563	294	234	87	29

Table 4:Correlation coefficient between physical properties and temperature indices

Drug	BP	FP	MV	MR	PB
HT_1^2	-0.16	-0.51	0.75	0.55	0.67
HT_2^2	0.75	0.94	0.1	-0.21	0.26
$ST(G)$	-0.1	-0.15	-0.83	0.31	-0.75
$RPT(G)$	-0.33	-0.01	0.22	-0.89	0.07
$AGT(G)$	0.88	0.82	0.56	0.26	0.74

REFERENCES

- Fajtlowicz, S. (1988). On conjectures of Graffiti, *Annals of Discrete Mathematics*. 38,113-118.
- Hayat, S., Malik, M.Y.H. and Fazal, S.(2024). Novel Temperature-Based Topological Indices for Certain Convex Polytopes. *Contemporary Mathematics*. 5(4),4726-4762.
- Kahn, A.R., Ghani, M.U., Ghaffer, A., Asif, H.M. and Inc, M.(2023). Characterization of temperature indices of silicates, *Silicon*.15,6533-6539.
- Kulli, V.R. (2019). Computation of Some Temperature Indices ofHC5C7 [p, q] Nanotubes. *Annals of Pure and Applied Mathematics*.20(2),69-74.
- Rajasekharaiah, G.V. and Murthy, U.P. (2021). Hyper-Zagreb indices of graphs and its applications, *Journal of Algebra Combinatorics Discrete Structures and Applications*, 8(1), 9-22.
- Shanmukha, M.C., Basavarajappa, N.S., Shilpa, K.C. and Usba, A.(2020).Degree based topological indices on anticancer drugs with QSPR analysis. *Helvion*. 6(6),e04235.
- Shi, X., Cai, R., Tousi, J.R. and Talebi, A.A.(2024).Quantitative Structure-Property Relationship Analysis in Molecular Graphs of Some Anticancer Drugs with

Temperature Indices Approach.
Mathematics.12,1953-1964.

- Singh, O., Garg, P., Kansal,N. and Sharma, G. (2024). On Analysis of Temperature Based Topological Indices of Anti-Cancer Drugs, *European Chemical Bulletin*, 12(10), 9522-9541.



Toward Accurate Visual Acuity Prediction: Selecting the Optimal Image Quality Assessment Metric

Samarasooriya HGVN¹, Karunarathna SPDSSK¹

Department of Mathematical Sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka
vidusarisamarasooriya@gmail.com

ABSTRACT

Visual acuity (VA) is a fundamental measure of the eye's ability to resolve fine details, traditionally assessed using subjective methods such as vision charts. However, these methods are prone to observer bias, leading to variability in outcomes. The optical imperfections of the eye, described by ocular aberrations (OAs), degrade retinal image quality (IQ), which can be analyzed objectively using Zernike coefficients (ZCs). While ZCs are effective in describing OAs, their relationship with VA remains complex. Existing works have therefore utilized IQ metrics to explore the relationship between ZCs and VA. However, these IQ metrics do not fully capture the IQ variations. In contrast, this study emphasizes image quality assessments (IQAs) such as SSIM, MSE, and PSNR, providing a more comprehensive approach to fully capture IQ and investigating the correlation between Neural Sharpness (logNS), a known predictor of VA, and IQAs to determine the most suitable metric for objectively representing VA. In this study synthetic data was used to simulate myopic conditions by incrementally varying the defocus term up to -4 diopters, and retinal image quality was modeled using Point Spread Function (PSF) and IQ metrics. By using scatter plots and Pearson correlation coefficients, we analyzed the relationship between logNS and each IQA. The results showed that SSIM demonstrated the strongest positive correlation with logNS across multiple images, outperforming MSE and PSNR in sensitivity and consistency. These findings suggest that SSIM is a reliable metric for predicting VA, paving the way for objective models that can better quantify the relationship between ZCs and visual performance.

KEYWORDS: Mean Square Error, Peak Signal to Noise Ratio, Structural Similarity Index, Visual Acuity, Zernike Coefficients

1 INTRODUCTION

Visual acuity (VA) is a critical measure of the eye's ability to resolve fine details and is often used to assess overall visual performance. Traditionally, VA has been measured subjectively through vision charts, but this method can be influenced by observer interpretation, leading to inconsistencies. The imperfections of the eye cause to degradation of the image quality of the retina, which is described by ocular aberrations (OAs). The Shack-Hartmann aberrometer is a widely used instrument for diagnosing and monitoring these aberrations, providing objective data that

can be analyzed through Zernike coefficients (ZCs). ZCs are numbers that help describe the shape of light waves as they pass through optical systems. While there is a well-established relationship between ZCs and OAs, the relationship between these coefficients and image quality (IQ) remains complex. Investigating the relationship between VA and ZCs is crucial for improving vision correction, early detection of eye conditions, and enhancing optical design. Recent studies (Ravikumar et al., 2013; Marsack et al., 2004; Applegate et al., 2003) have made strides in understanding the correlation between ZCs and visual

VA, but it is still insufficient to fully elucidate this relationship. On the other hand, image processing has introduced objective methods, namely, the structural similarity index metric (SSIM), mean square error (MSE), and peak signal-to-noise ratio (PSNR) for assessing the IQ. MSE is a common metric used to evaluate image quality, especially for measuring the difference between a reference image and a test image. PSNR is a common measure used in image processing and signal compression to evaluate the quality of a reconstructed or compressed image compared to its original version. These image quality assessments (IQAs) are widely used in image processing to quantify image quality independently of human interpretation.

1.1 Importance of the Study

In this study, we aim to determine which of these IQAs is the most highly correlated with VA since it leads to the goal of developing an objective model for predicting VA based on ZCs. This approach seeks to overcome the limitations of traditional subjective assessments and provide a more consistent, reliable framework for evaluating visual performance.

2 LITERATURE REVIEW AND THEORETICAL BACKGROUND

Vision defects are described by OAs objectively. In vision science, widely expand these OAs using Zernike polynomials and magnitudes of expansion coefficients (ZCs) have been used to explain the quality of images on the retina. However, they have limitations when it comes to quantifying IQ on the retina (VA). One key issue is that ZCs primarily

focus on the shape of the OAs and may not fully capture the impact of these aberrations on the perceived IQ. Therefore, IQ metrics are introduced for quantifying IQ on the retina because they provide objective, quantitative measures of how well the optical system is functioning. In contrast, traditionally, subjective assessments, often based on human perception (asking patients to read the eye chart), have been widely used for evaluating VA, but they are prone to biases and inconsistencies (Varnan et al., 2011).

The root mean square error (RMSE) is commonly used to represent the IQ on the retina. However, the relationship between the RMSE and magnitude in a specific mode and its impact on VA is not well understood (Applegate et al., 2003). For example, an increase in RMSE does not always lead to a reduction in VA because (a) the effect of individual aberrations on VA can vary, and (b) the potential of these aberrations to either improve or worsen visual performance differs (Ravikumar, 2013). As a result, alternative IQ metrics have been developed to assess optical quality, such as neural sharpness (NS), visual Strehl ratio, and light in the bucket (Cheng et al., 2010; Thibos, 2004; Ravikumar, 2013).

Previous studies (Cheng et al., 2010; Ravikumar et al., 2012; Rouger et al., 2010; Schoneveld et al., 2009; Dai, 2008) have explored the correlation between IQ metrics and VA, reporting the coefficient of determination for both normal and highly aberrated eyes. (Ravikumar et al., 2013) used 29 IQ metrics to identify the best ones for representing VA. They found that eight IQ metrics have strong correlations with VA in both normal and keratoconus eyes. The

logNS was highly correlated metric with VA.

As VA is directly related to the IQ on the retina, and image processing methods aim to detect objective changes in images, unlike previous studies, we aim to investigate how IQAs, SSIM, MSE and PSNR can be utilized to study VA. To achieve this, we analyze the correlation between logNS and these IQAs for identifying the metric that demonstrates the strongest correlation.

3 METHODOLOGY

a. Data Collection

Synthetic data is used in this study. In particular, the defocus term is incrementally adjusted in steps to achieve a myopic eye condition of up to -4 diopters. For each defocus value, Neural Sharpness (NS) and IQAs are computed. The sections 3.2, 3.3 and 3.4 describe mathematical formulations and processes involved.

3.2 Point Spread Function

The point spread function (PSF) represents the response of an optical system to a point source of light, describing how light is distributed in the image plane. The PSF is derived from the Fourier transform of the system's pupil function, incorporating aberrations like Zernike coefficients. The PSF is calculated:

$$\text{PSF} = |F\{P(x, y)\}|^2, \quad (1)$$

where F is the Fourier transform operator and $P(x, y)$ is the generalized pupil function for the wave aberration.

b. Neural Sharpness

Neural Sharpness (NS) is an image-quality metric that quantifies the

sharpness of the retinal image by integrating the Point Spread Function (PSF) weighted with a bivariate Gaussian function that simulates neural sensitivity. The mathematical formulation of NS is given by:

$$\text{NS} = \frac{\iint \text{PSF}(x, y) G(x, y) dx dy}{\iint \text{PSF}_{\text{DL}}(x, y) G(x, y) dx dy}, \quad (2)$$

Where $G(x, y)$ is bivariate Gaussian distribution. After calculating NS, convert NS to logNS by taking the logarithm base 10 of NS.

c. SSIM, MSE and PSNR Computation

Once the PSF is calculated for each defocus value, an image has been convolved with the PSF to create the VA measurement model (blur image). The IQAs (SSIM, MSE, PSNR) are then computed for each blurred image using the standard formulas (Varnan et al., 2011).

3.4 Selecting the Optimal Image Quality Assessment

A descriptive analysis is conducted to investigate the behavior of SSIM, MSE, and PSNR with respect to the logNS since such analysis provides a visual representation of the relationships between logNS and these metrics, allowing for the identification of trends, patterns, and potential correlations. To quantify how closely relate logNS and IQAs, investigate the variation in Pearson correlation coefficients.

4 RESULTS AND DISCUSSION

In this study, six standard benchmark images (Lena, Barbara, Peppers, Einstein, Cameraman and Cartoon) in image processing were used, and for each image, IQAs against logNS were obtained. For

instance, in Figure 1, the original images Lena and Cameraman are shown.

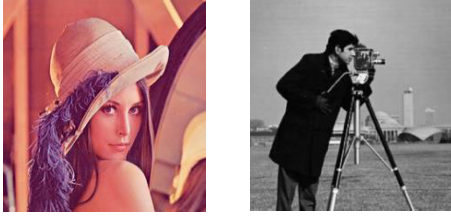


Figure 1: The original images of Lena and Cameraman.

4.1 Descriptive Analysis

As descriptive analysis enables the detection of trends, patterns, and possible correlations, scatter plots were obtained. Due to the space limitation, we present only the SSIM distribution against logNS for each image on the same axes which is illustrated in Figure 2. From Figure 2, it can be observed that the SSIM values appear to follow a similar overall trend across different images, with a consistent positive relationship between logNS and SSIM. Moreover, we notice that SSIM demonstrates **higher correlation and sensitivity** to image characteristics compared to PSNR and MSE.

4.2 Correlation Analysis

A comprehensive correlation analysis was conducted for each IQA, as summarized in Table 1. The analysis included the calculation of Pearson correlation coefficients to evaluate the strength and direction of the relationship between each IQA and logNS, thereby assessing how well the logNS correlated with IQAs.

The Pearson correlation coefficients for SSIM ranged from 0.566

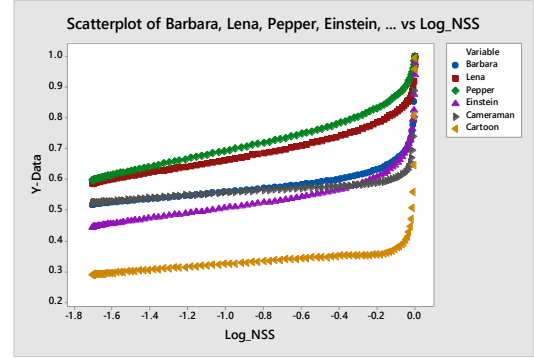


Figure 2: The distribution of SSIM versus logNS for each image.

to 0.961, indicating a strong positive correlation with logNS across all images. This reflects SSIM's sensitivity to variations in structural similarity and its ability to capture image-specific characteristics effectively. The correlation values for MSE ranged from -0.989 to -0.884, highlighting a strong negative relationship with logNS. However, the inconsistency in these values suggests that MSE is less reliable for capturing image quality trends compared to SSIM. The PSNR correlation values were relatively stable, ranging from 0.597 to 0.747, indicating moderate to strong positive correlations. However, the limited variation suggests that PSNR may not be as sensitive to structural changes as SSIM.

Table 1: Pearson Correlation Values

	LogNS	SSIM	MSE	PSNR
Image				
Lena		0.938	-0.958	0.689
Einstein		0.846	-0.884	0.597
Peppers		0.961	-0.959	0.690
Barbara		0.792	-0.945	0.688
Cameraman		0.641	-0.967	0.688
Cartoon		0.566	-0.989	0.747

5 CONCLUSION

This study demonstrates that IQAs can serve as effective tools for objectively analyzing VA. Among the metrics investigated, SSIM exhibited the strongest and most consistent correlation with logNS, making it the most reliable IQA for representing VA across various images. MSE and PSNR, while correlated, were less sensitive to structural variations in image quality. These results underscore the potential of SSIM as a robust metric for integrating objective VA evaluation into optical system design, vision correction methods, and early diagnosis of visual impairments. By bridging the gap between Zernike coefficients and VA, this approach offers a pathway to more precise and consistent assessments of visual performance.

REFERENCES

- Applegate, R. A., Marsack, J. D., Ramos, R., and Sarver, E. J. (2003). Interaction between aberrations to improve or reduce visual performance. *Journal of Cataract and Refractive Surgery*, 29, 1487–1498.
- Cheng, X., Bradley, A., and Thibos, L. N. (2010). Predicting subjective judgments of best focus with objective image quality metrics. *Journal of Vision*, 10(9), 1–21.
- Dai, G., Sun, X., and Thibos, L. N. (2008). Image quality metrics to predict subjective image quality in the presence of optical aberrations. *Journal of the Optical Society of America A*, 25, 2079–2092.
- Marsack, J. D., Thibos, L. N., and Applegate, R. A. (2004). Metrics of optical quality derived from wave aberrations predict visual performance. *Vision Research*, 44, 1225–1233.
- Ravikumar, S., Marsack, J. D., and Applegate, R. A. (2013). Predicting visual performance from wavefront aberrations. *Journal of Vision*, 13(5), 10.
- Rouger, H., Legras, R., and Chateau, N. (2010). Can the best image quality metric predict visual acuity? *Optometry and Vision Science*, 87, E613–E620.
- Schoneveld, P. G., Pesudovs, K., and Coster, D. J. (2009). Predicting visual performance from optical quality metrics in keratoconus. *Clinical and Experimental Optometry*, 92, 355–363.
- Thibos, L. N., Hong, X., Bradley, A., and Cheng, X. (2004). Statistical variation of aberration structure and image quality in a normal population of healthy eyes. *Journal of the Optical Society of America A*, 19, 2329–2348.
- Varnan, S., Mallikarjuna, R., and Krishnan, N. (2011). A review on image quality assessment metrics. *International Journal of Engineering Science and Technology*, 3(10), 3731–3736.



Analysis of Factors Affecting Sri Lankan Undergraduates' Decision on Pursuing Postgraduate Studies Abroad

Hathurusinghe HADSH¹, Francisco GS¹, Panahatipola PMOP¹

Department of Mathematical Sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka
hansamalihathurusinghe99@gmail.com

ABSTRACT

This research examines the key factors affecting Sri Lankan undergraduates' decision to pursue postgraduate studies abroad. The main factors considered here are age, GPA, family income, personal income, degree fee, course duration, gender, A/L stream, job opportunity, political situation and overall frustration towards the country. Data were collected from 300 undergraduate students in state universities in Sri Lanka using a structured questionnaire. RStudio software is used to analyze the data and a logistic regression model was employed to examine the relationships. The best-fitted model, selected using stepwise regression explains 82.7% of the variability with high predictive power. Also, the model has a high accuracy level of 97.35%. Obtained results indicate that better academic performance, perceived overseas job prospects, and dissatisfaction with local conditions strongly motivate undergraduates to seek postgraduate opportunities abroad. Further, these findings highlight the impact of local economic conditions, educational quality and employment opportunities on student migration.

KEYWORDS: Logistic Regression, Postgraduate Studies, Undergraduate

1 INTRODUCTION

In a developing country like Sri Lanka, education plays a vital role. According to the Ministry of Education and Cultural Affairs (2018), there are 18 state universities in the country. With the high demand, private universities and private degree-granting institutions offer degrees as well. After completing their Bachelor's, some of the undergraduates go abroad for their postgraduates. The growing interconnectedness of the world due to globalization has notably encouraged the academic aspirations of students in Sri Lanka. Also, technology and scholarships offered by foreign universities play important roles in facilitating international education (<https://monitor.icef.com/2023/08/higher-education-supply-demand-gap-a-major-driver-of-sri-lankan-outbound-student-mobility/>). The frustration of

undergraduates towards the current state of the country, economic crisis, limited job opportunities and the political situation also play key roles in Sri Lankan undergraduates' decision to pursue their postgraduate studies abroad. This study provides important insights into the complex interplay of socio-cultural, demographic, academic and economic elements that influence the educational decisions of undergraduates in Sri Lanka by examining these dynamics in detail. In addition, this study highlights key factors shaping undergraduates' decision to study abroad, providing valuable insights for educators, policymakers, and institutions to enhance local education systems.

2 LITERATURE REVIEW

The overall socioeconomic structure as well as the futures of its citizens are highly influenced by the overall education system of developing countries like Sri

Lanka. Jayawardena (2020) has identified five key waves of Sri Lankan out-migration since independence. In that study, it is identified the fifth wave as students' migration for educational purposes. Also, Joseph and Dissanayake (2022) have identified that family commitments, sound financial background, cultural barriers, and not having enough funds as factors affecting the migration intention of the youth in Sri Lanka. Recent data from the Australian Government (2022) shows a substantial increase in the number of Sri Lankan students enrolling in Australian institutions, driven by the prospect of enhanced career prospects and long-term residency options. Further, De Alwis (2022) concludes that the number of Sri Lankan students looking for opportunities overseas has significantly increased as a result of the current economic crisis, high unemployment rates, and instability in politics. Perera and Pratheesh (2018), highlights the importance of family and social networks in shaping the educational choices of the students. Further, they argue that the academic quality and reputation of institutions are key considerations for students choosing their study destinations. Abeygunawardena (2018) concludes that students are influenced by the perceived quality of academic programs and institutional reputation. All these studies confirm that undergraduates in Sri Lanka make their overall decisions to study abroad based on a complex interplay of socioeconomic, academic, professional, personal factors, and support systems.

3 METHODOLOGY

This research employs a quantitative approach to explore the factors

influencing Sri Lankan undergraduates' decision to pursue postgraduate studies abroad. Convenience sampling was used to collect data from 300 undergraduates across state universities in Sri Lanka through a structured questionnaire. The sample included 5 to 30 students from each university, ensuring representation from various state universities and fields of study.

The dependent variable is the undergraduates' decision to pursue on pursuing postgraduate studies abroad (Yes/No), while the independent variables are age, GPA, family income, personal income, degree fee, duration, gender (Male/Female), A/L stream (Physical Science/ BioScience/ Arts/ Technology/ Commerce), job opportunity (Yes/No), political situation (Yes/No), and frustration toward the country (Yes/No). Data were analyzed using logistic regression in RStudio to examine these relationships effectively. Before fitting the logistic regression model, point-biserial correlation values were assessed to ensure significant relationships between variables. Model diagnostics, including AIC, multicollinearity checks, and assumption testing, were rigorously conducted to ensure the validity and reliability of the results.

4 RESULTS AND DISCUSSION

a. Point-Biserial Correlation

Table 1 shows the Point-Biserial Correlation values used to check the correlation between the dependent variable and independent variables.

Table 1: Point-Biserial Correlation Matrix

Variable Name	Decision	GPA	Family Income	Personal Income	Age	Duration	Degree Fee	p-value
Decision	1.000	0.487	0.441	0.268	0.062	-0.327	-0.024	-
GPA	0.488	1.000	0.179	0.237	0.005	-0.236	-0.004	0.000
Family Income	0.441	0.179	1.000	0.405	-0.071	-0.253	0.033	0.000
Personal Income	0.268	0.237	0.405	1.000	0.057	-0.090	0.073	0.000
Age	0.062	0.005	-0.071	0.057	1.000	0.054	-0.049	0.028
Duration	-0.326	-0.236	-0.252	-0.090	0.054	1.000	-0.024	0.000
Degree Fee	-0.024	-0.004	0.033	0.072	-0.049	-0.024	1.000	0.025

According to the correlation values in Table 1, each independent variable has a considerable relationship with the dependent variable and the p-values (<0.05) indicate that the variables are significant at a 5% level of significance. Therefore, it is continued to build the best-fitted model using stepwise regression.

b. Stepwise Regression

After comparing the AIC values of obtained stepwise models, a model with the minimum AIC value (145.98) is selected as the best-fitted model. Then the obtained model is as follows.

$$\begin{aligned} \text{Logit (P)} = & -17.16 + 3.039 \times \text{GPA} + \\ & 0.00002198 \times \text{FamilyIncome} + \\ & 0.00003374 \times \text{PersonalIncome} - 0.8643 \times \\ & \text{Duration} + 1.983 \times \text{ALBioScience} - \\ & 0.2098 \times \text{ALCommerce} + 0.7748 \times \\ & \text{ALPhysicalScience} - 0.8632 \times \\ & \text{ALTechnology} + 3.272 \times \\ & \text{JobOpportunityYes} + 2.287 \times \\ & \text{PoliticalSituationYes} + 3.879 \times \\ & \text{FrustrationYes} \end{aligned} \quad (1)$$

This model predicts the log-odds of the outcome variable based on the independent variables. For further analysis, model assumptions are checked.

c. Linearity of the Logit for Continuous Variables

H_0 : Independent variables are linearly related to the log odds

H_1 : Independent variables are not linearly related to the log odds

The p-value from the Chi-square test is 0.069. Since it is greater than 0.05, H_0 is not rejected and it is concluded that the fitted model satisfies the linearity.

d. Goodness of Fit Test Data

To check the goodness of fit, a Pseudo R-squared value fit is used and the R^2 value of 0.8274. It suggests that the model explains approximately 82.74% of the variability in the outcome.

e. Multicollinearity

The Correlation matrix represented in Table 1 indicates that there is minimal multicollinearity between the variables. Also, the GVIF analysis in Table 2 reveals that none of the independent variables in the fitted model exhibits multicollinearity as all GVIF values are less than 5.

Table 2: Goodness of Fit Test Data

Variable	GVIF
GPA	1.209151
FamilyIncome	1.119542
PersonalIncome	1.181307
Duration	1.490856
AL	1.590882
JobOpportunity	1.284007
PoliticalSituation	1.196636
Frustration	1.451196

4.6 Accuracy of the Model

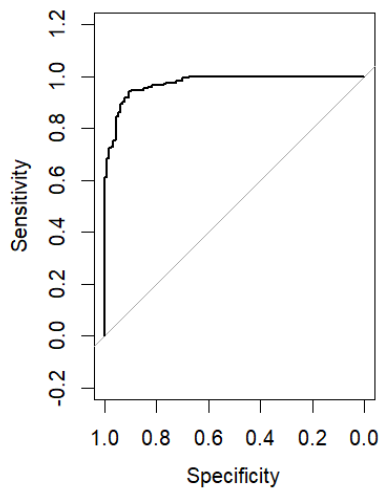


Figure 1: ROC Curve

AUC Value: 0.9735

Fig 1 and the area under the curve (AUC) value for the ROC analysis close to 1 indicate an exceptional level of discrimination between two outcome

classes; students who decide to study abroad and those who do not, hence a better model performance.

According to this AUC value, the accuracy level of the model is 0.9735. It indicates that the model correctly predicts the decision of undergraduates 97.35% of the time.

f. Interpretation of the Model using Odd Ratios and Coefficients

Table 3: Odd Ratios

Variable Name	Odds Ratio
Intercept	3.512617e-08
GPA	2.088495e+01
FamilyIncome	1.000022e+00
PersonalIncome	1.000034e+00
Duration	4.213616e-01
ALBioScience	7.262508e+00
ALCommerce	8.107445e-01
ALPhysicalScience	2.170156e+00
ALTechnology	4.217904e-01
JobOpportunityYes	2.636869e+01
PoliticalSituationYes	9.844144e+00
FrustrationYes	4.837829e+01

OR values in Table 3 indicate that variables like GPA, job opportunity, political influence, and frustration strongly affect decision-making, while family and personal income have minimal impact.

According to the fitted model in (1), academic performance (measured by GPA), plays a vital role. A higher GPA increases the likelihood of deciding to pursue postgraduate studies abroad. Additionally, students who perceive

better job opportunities abroad are significantly more likely to make this decision. Conversely, the variable "Duration" has a negative impact. Moreover, the model explains that students from specific A/L streams like Bio Science and Physical Science, have higher odds of choosing to pursue postgraduate studies abroad.

5 CONCLUSION

The findings of this study provide valuable insights into the factors influencing Sri Lankan undergraduates' decision to pursue postgraduate studies abroad. Key factors such as GPA, job opportunity, and frustration towards the country play significant roles, while course duration and A/L stream further impact these decisions. Obtained results highlight that better academic performance, perceived overseas job prospects, and dissatisfaction with local conditions strongly motivate undergraduates to seek opportunities abroad.

These findings contribute to the existing knowledge on student mobility and offer guidance to policymakers, educators, and institutions aiming to improve the local education system, reduce brain drain, and foster economic growth and innovation within Sri Lanka. Future studies should examine the long-term outcomes of study abroad for Sri Lankan students, including career success and personal development.

REFERENCES

- Abeygunawardena, K. V. (2018, August). Influential factors in selecting a bachelor's degree from international degree programmes offered in Sri Lanka: perspectives of lecturers and graduates. In *Proceedings of the International*

Conference on Education (Vol. 4, No. 1, pp. 51-61).

- De Alwis, D. (2022). The impact of economic crisis on international education trends in Sri Lanka. *Sri Lankan Journal of Education Research*, 15(2), 123-135.
- ICEF. (2023, September 12). Higher education supply-demand gap a major driver of Sri Lankan outbound student mobility. Retrieved from <https://monitor.icef.com/2023/08/higher-education-supply-demand-gap-a-major-driver-of-sri-lankan-outbound-student-mobility/>
- Jayawardena, P. (2020). Sri Lankan out-migration: Five key waves since Independence. *University of Colombo Review (Series III)*, 1(1), 101-118.
- Joseph, S., & Dissanayake, D. M. K. T. (2022). The Migration Intention of the Youth of Sri Lanka: A Concept Paper.
- Ministry of Higher Education and Cultural Affairs (MHECA). (2018). Sri Lanka higher education development strategy for the proposed sectoral plan, 2017–2025. Forthcoming.
- Perera, R. H. A. T., & Pratheesh, P. (2018). Factors influence on student course selection: a case of Trincomalee campus. *International Journal of Innovative Science and Research Technology*, 3(5).



Determinants of Undergraduate Students' Intentions to Work Abroad: A Study on the Influence of Salary Expectation, Career Prospect, Quality of Life, Family, and Friends

Madhara GS¹, Maduwansha NANJ¹

*Department of Social Statistics, Faculty of Humanities and Social Sciences,
University of Sri Jayewardenepura
gsmadhara@gmail.com*

ABSTRACT

The main objective of this article is to examine the factors influencing the foreign employment intentions of undergraduates. Based on the current literature review, a proposed conceptual framework has been developed. Accordingly, the factors of salary expectation, career prospects, quality of life, family and friends influence the foreign employment intentions of undergraduates were studied. The target population for this research was undergraduates of the University of Sri Jayewardenepura. A sample of 361 out of 6109 undergraduates in the third and fourth years of the faculties of Humanities and Social Sciences, Management Studies and Commerce and Applied Sciences, where the majority of undergraduates of the University of Sri Jayewardenepura are engaged in academic activities, was selected based on the stratified random sampling method. An online questionnaire method was used to collect data. Partial Least Square Structural Equation Modeling (PLS-SEM) was employed to derive the inferences. Among the factors studied, the study was able to identify factors that significantly correlate with undergraduate candidates' foreign employment intentions. The study highlighted potential improvement areas for future research.

KEYWORDS: Salary Expectation, Career Prospects, Quality of life, Influence of family and friends, Foreign employment intentions

1 INTRODUCTION

The emigration of Sri Lankan scholars, intellectuals, and professionals is rapidly increasing. This situation has arisen against the backdrop of countries like Australia and China implementing large-scale projects to attract people with high intellectual and innovative abilities. The emigration of professionals is known as a brain drain, a recognized social phenomenon in Sri Lanka. Talented Sri Lankans have continuously migrated to developed countries, driven by the economic and political instability in Sri Lanka. Other contributing factors include

the lack of recognition for talent and ability, inadequate support for research, and the failure to benefit from the country's talented individuals. The departure of highly skilled professionals such as doctors, engineers, scientists, lawyers, and graduates has a significant impact on Sri Lanka. These individuals are in high demand globally, and developed countries attract them by offering high salaries and privileges. Currently, 27% of Sri Lankans are willing to go abroad if given the opportunity, with the majority being young and educated (Institute for Health Policy, 2021). Sri

Lanka has a migration culture, with millions of Sri Lankans having left for work, either permanently or temporarily, over the past few decades. The desire to go abroad is not new, but the SLOTS data shows that this desire has grown in recent years. Men (34%) are more willing to migrate than women, but the group most willing to migrate is youth aged 18–29 years (48%). Among them, university graduates (53%) with degrees and higher educational qualifications are the most willing to go abroad (Sri Lanka Opinion Tracker Survey, 2021). Much of Sri Lanka's highly skilled human capital is produced through the local education system. A highly skilled workforce is crucial for supporting Sri Lanka's economic growth and moving towards a knowledge-based economy, particularly in the development of innovative technology. However, this has become a challenging task for the Sri Lankan government due to the ongoing brain drain. While research has focused on the brain drain of professionals, limited studies have been conducted on undergraduates' perceptions of expatriation. It is important for the country to understand the decisions and attitudes of undergraduate students regarding foreign employment during their university education. Accordingly, this study seeks to identify the foreign employment intentions of undergraduate students.

1.1 Research Objective

To identify the influence of salary expectation, career prospects, quality of life, family, and friends on the foreign employment intention of undergraduate students.

2 LITERATURE REVIEW

Migration is the temporary or permanent movement of a person or group of people from one place to another for reasons ranging from persecution to job opportunities (J. Hagen-Zanker, 2008). Dissatisfied with the low salaries and compensation offered by jobs, accounting professionals in Malaysia are choosing to migrate to developed countries in search of higher-paying and better-compensated jobs (Jauhar et al., 2015). Also dissatisfied with their pay, nurses working in Belgium are considering moving abroad for jobs with better pay and compensation (Behar et al., 2007). Furthermore, wage and unemployment differences have been found to positively affect migration to another country (Gani, 1998, as cited in Bashir et al., 2014). The availability of professional development and educational opportunities has strongly influenced the migration of young Sri Lankan engineers to Australia (Wijesinghe & Jayawardane, 2021). Low quality of life, such as environmental safety and cleanliness, has been identified as a factor influencing the migration of Malaysian professionals to other countries (Ishak & Aziz, 2014). Professionally qualified engineers from developing countries migrate to developed countries for various reasons. Young engineers graduating from public universities in Sri Lanka are migrating to Australia at a faster rate. The Skilled Graduate Visa offered by the Australian government encourages young Sri Lankan engineers to immigrate to Australia. The main driving forces for this include the unwillingness of Sri Lankan engineers to expose themselves to new cultures, adverse working conditions, political influence, and corruption (Wijesinghe & Jayawardane, 2021). Unfavourable

conditions in Sri Lanka were the main reason Sri Lankan university lecturers decided to go abroad. The income from employment in Sri Lanka is not sufficient to live a good life, and additional sources of income must be found (Gunawardena & Nawaratne, 2017). The experiences of students who have family and friends living and working abroad also influence their intention to work abroad (Vandenbrande,

2010). Furthermore, family members who work abroad are often encouraged and supported to direct other members of their family to work abroad based on the positive experiences they gain abroad (Wahab, 2014).

3 METHODOLOGY

3.1 Population, Sample, Sampling Method

There was a total of 6109 undergraduate students in the Faculty of Humanities and Social Sciences, Faculty of Management Studies, and Faculty of Applied Sciences of the University of Sri Jayewardenepura in the academic years 2019/2020 and 2018/2019, and a preliminary sample of 361 was selected based on the stratified proportional random sampling method.

3.2 Conceptual Framework

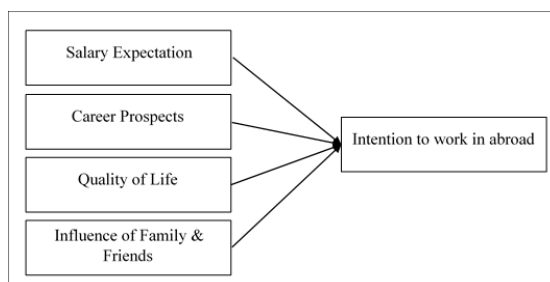


Figure 1: Conceptual Framework

3.3 Data Collection Methods and Analytical Tools

Primary data was collected through a questionnaire. Partial Least Square Structural Equation Modelling (PLS-SEM) analysis was conducted using Smart PLS statistical analysis software to identify the factors affecting the foreign employment intentions of undergraduate students.

4 RESULTS AND DISCUSSION

Table 1: Identifying the factors affecting foreign employment intention

	Coefficient (O)	T statistics	P values
Career Prospects -			
> Intention to work in abroad	0.305	4.47	0
Influence of family & friends -			
> Intention to work in abroad	0.358	6.43	0
Quality of life ->			
Intention to work abroad	0.083	1.225	0.221
Salary Expectation			
-> Intention to work in abroad	0.087	1.532	0.126

Career prospects have a positive relationship with undergraduates' foreign employment intentions ($\beta = 0.305$, $p = 0.000$). The study by Wijesinghe and Jayawardane (2021) also identified professional development opportunities as a major factor influencing the migration of young Sri Lankan engineers to Australia, as skilled workers tend to choose jobs with high career prospects to improve their future lifestyles. Accordingly, the findings from the aforementioned studies align with the current study in recognizing that

professional expectations are a major factor influencing foreign employment intentions. The influence of family and friends also has a positive relationship with undergraduate students' intentions to work abroad ($\beta = 0.358$, $p = 0.000$). This conclusion is confirmed by research conducted in Vietnam by Nghia (2019), which identified that the migration intentions of Vietnamese students depend on the willingness of their colleagues and families. Quality of life does not have a significant effect on undergraduate students' foreign employment intentions; however, there is a positive relationship between quality of life and foreign employment intentions ($\beta = 0.083$, $p = 0.221$). Previous studies by Wijesinghe & Jayawardane (2021) have found that quality of life influences foreign employment intentions. Wijesinghe and Jayawardane (2021) showed that Sri Lankans intend to seek employment abroad in anticipation of a higher standard of living. However, the current study concluded that living conditions do not significantly contribute to foreign employment intentions. Salary expectations do not have a significant effect on undergraduate students' foreign employment intentions, although there is a positive relationship between salary expectations and these intentions ($\beta = 0.087$, $p = 0.126$). Research by Jauhar et al. (2015) found that salary expectations influenced the foreign employment intentions of Malaysians, as higher salaries are offered in developed countries compared to local employment. The findings of Wijesinghe & Jayawardane (2021) contradicted the results of the present study, as they found that salary expectations influenced the foreign

employment intentions of Malaysian and Sri Lankan young engineers who were dissatisfied with the unattractive salaries offered by employers in their home countries. The value of the determined coefficient is 0.440, indicating that 44% of the total variation in the dependent variable is explained by the basic model. It can be concluded that only 44% of the total observed variation in undergraduate students' foreign employment intentions is explained by the basic model.

5 CONCLUSIONS

Career prospects and family and friends' influence have a significant impact on undergraduate students' intentions to work abroad. Salary expectation and quality of life do not have a significant effect on undergraduate students' foreign employment intention, but there is a positive relationship between salary expectation, quality of life factors, and undergraduate students' foreign employment intention. This study identified career prospects, family, and friends as factors that significantly contribute to undergraduates' foreign employment intentions. Therefore, future studies could further explore their impact on undergraduates' foreign employment intentions. Also, the impact of these factors on the foreign employment intentions of undergraduates from other faculties, in addition to the faculties considered in this study at the University of Sri Jayewardenepura, can be further studied.

REFERENCES

- Bashir, M. F., Xu, C., Zaman, K., & Akhmat, G. (2014). Key Factors Determining the Rationale for Brain Drain: An Irony Never Recovered. *International Journal of Economics and*

DETERMINANTS OF UNDERGRADUATE STUDENTS' INTENTIONS TO WORK ABROAD: A
STUDY ON THE INFLUENCE OF SALARY EXPECTATION, CAREER PROSPECT, QUALITY OF
LIFE, FAMILY, AND FRIENDS

Empirical Research (IJEER), 2(8), 308–320.

- Gunawardena, C., & Nawaratne, R. (2017). Brain Drain from Sri Lankan Universities. *Sri Lanka Journal of Social Sciences*, 40(2), 103. <https://doi.org/10.4038/sljss.v40i2.7541>
- Hagen-Zanker, J. (2008). Why Do People Migrate? A Review of the Theoretical Literature. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.1105657>
- Ishak, N., & Aziz, A. R. A. (n.d.). MALAYSIAN CONSTRUCTION PROFESSIONALS: WHY ARE THEY LEAVING? Procs 30th Annual ARCOM Conference, 269–277.
- Jauhar, J., Abdul Ghani, A. B., Joarder, M. H. R., Subhan, M., & Islam, R. (2015). Brain Drain to Singapore: A Conceptual Framework of Malaysians' Diaspora. *The Social Sciences*, 10(6), 702–711.
- Nghia, T. L. H. (2019). Motivations for Studying Abroad and Immigration Intentions: The Case of Vietnamese Students. *Journal of International Students*, 9(3), 758–776. <https://doi.org/10.32674/jis.v0i0.731>
- Vandenbrande, T., Coppin, L., & European Foundation for the Improvement of Living and Working Conditions (Eds.). (2006). *Mobility in Europe: Analysis of the 2005 Eurobarometer survey on geographical and labour market mobility*.
- Wijesinghe, D. P. S., & Jayawardane, V. P. T. (2021). THE DETERMINANTS OF MIGRATION OF SRI LANKAN YOUNG ENGINEERS TO AUSTRALIA – A CASE STUDY. *KDU Journal of Multidisciplinary Studies (KJMS)*, 3(2), 113–122.



Estimating the Sample Production Volume for External Sewing Plants: A Case Study of an Apparel Industry in Sri Lanka

Madhumali RS¹, Dharmawardane PMN¹, Panahatipola PMOP¹

Department of Mathematical Sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka
sanduni.ranawake@gmail.com

ABSTRACT

The growing demand for samples, a crucial element in the apparel manufacturing process, has posed a significant challenge in managing production volumes. Therefore, strategic planning in outsourcing decisions is essential to ensure both efficiency and quality. This study aims to create a model that can be used to estimate the sample production volume supply of ABC Apparel Ltd to the external sewing plants of the Sri Lankan apparel industry in 2024 and 2025. It will determine factors contributing to the reason for outsourcing sample production and assess whether outsourcing sample production in-house can be achieved by minimizing dependence on external plants. Additionally, the study will explore strategies to enhance internal production capabilities, enabling the organization to better respond to fluctuations in demand. By analyzing these factors, the research seeks to provide insights that can inform resource allocation and improve production efficiency. The findings will support creating a more efficient, cost-effective sample production strategy, balancing internal capacity with external outsourcing needs. Ultimately, this study aims to optimize supply chain operations in the apparel sector, enhancing the industry's competitiveness within a volatile global marketplace. Through these insights, apparel manufacturers can better navigate challenges in production management, leading to more sustainable and responsive operational practices. Using the auto. Arima function in R, the ARIMA (0,1,1) model was selected as the best fit for forecasting sample production volumes at ABC Knit Centre's external sewing plants.

KEYWORDS: Apparel Industry, Demand, Sample Production Volume

1 INTRODUCTION

Sri Lanka is a global leader in the textile and apparel sector, renowned for producing high-quality, durable clothing. Among the key players in this industry is ABC Apparel Ltd, a prominent company known for its partnerships with international brands. Established in 1969, ABC Apparel Ltd operates 42 factories across Bangladesh, India, and Sri Lanka, making it a significant contributor to the local economy. Within ABC Apparel Ltd, the Knit Centre is responsible for overseeing the sample production process and managing a dedicated sample room to evaluate the quality and design of clothing

samples. However, the company currently faces operational challenges due to its reliance on third-party plants for sample production. Outsourcing these tasks to external suppliers, rather than handling them in-house, has introduced several complexities in terms of coordination, quality control, and production efficiency. This study aims to address these operational issues by proposing a strategic approach to better manage sample production. Specifically, the research will estimate the number of samples that need to be produced in external factories for the years 2024 and 2025. It will also examine ways to enhance internal production

capabilities by assembling sample production within the company's facilities.

2 LITERATURE REVIEW

Gökalp (2010) created a decision support system that enabled the company to measure its production planning and marketing department, among which there are broad decision-making areas such as pre-cost estimation, capacity planning, master production planning, and production scheduling.

Paneru (2011) investigated the challenges of the garment industry implementing lean manufacturing tools to significantly decrease the production cycle time, rework rates, and work-in-progress inventory.

Syduzzaman & Golder (2015) found that how a sewing machine should be operated at a plant was the most important factor of contention. Feeding materials and parts at the highest speed plays a vital role in this process, as well as work transfer among processes, like reducing cycle time to improve productivity and efficiency in line production.

Jadhav et al. (2017) reported the shift in the garment industry globally because of the growing demand for clothes. Key aspects, such as time management and quality control, which in turn will lead to on-time delivery, are very important criteria for getting to this stage.

Kurnianingtias et al. (2024) studied sewing operation cycle times in Indonesia's garment industry, identifying factors causing delays in men's jacket production. It suggested optimizing production processes and reducing cycle time can improve productivity, efficiency.

3 METHODOLOGY

The main steps of the process included data preprocessing, the scientific notation process, exploratory data analysis, modeling, and visualization. The raw data was presented in Excel format and was processed in the R 4.3.1 statistical software for analysis. The Auto ARIMA method in R software is used in this study because it provides one of the most effective, flexible, and proven ways to model and forecast nonstationary time series data with autocorrelations. The approach employed in this paper Auto ARIMA-automatically selects the best model parameters. The results pointed out that besides upward or downward trends within 10 years, seasonality, as well as anomalies and high-level forecasting, can be employed as mainstream outcomes to explain.

This study primarily looks into the monthly reports on sewing plants, including January 2014 to December 2023, for ten years. The data are collected through the ones' monthly recording and digital reconstruction to ensure high temporal resolution and allow for seasonal and temporal dynamics analysis. The dataset is made up of 120 records, one for each month of ten years. The dataset is chronological in date and has no gaps in the monthly observations.

4 RESULTS AND DISCUSSION

Some of the defined statistics make the given data explicit by showing the maximum and the minimum sample size, the median sample size, the mean sample size, and Q1 and Q3, which are used to calculate the distribution of production within this period.

ESTIMATING THE SAMPLE PRODUCTION VOLUME FOR EXTERNAL SEWING PLANTS: A CASE STUDY OF AN APPAREL INDUSTRY IN SRI LANKA

Table 1: Summary statistics of sample production volume

	Date	Production
Min.	2014-01-01	71032
1st Qu.	2016-06-16	79423
Median	2018-12-16	82290
Mean	2018-12-16	83096
3rd Qu.	2021-06-08	86972
Max.	2023-12-01	96988

As depicted in Table 1, production volume has gradually risen over the years, from a production volume of 71032 units in 2014 to 96988 units in 2023. The median production volume is 82290 units and the mean is 83096 units. The 50% middle values of production values range from 79423 to 86972 units, corresponding to steady gains. This growth might result from operation scaling to a higher level or the increasing demand meaning that there is a healthy production management system and a positive trend in the business. Monthly production volumes range from 70,000 to 100,000 units per month, reflecting the cyclical behavior of such volumes.

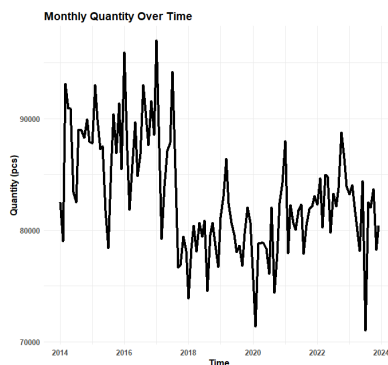


Figure 1: Monthly sample production volume for external sewing plants

The time series plot in Figure 1 indicates the variation in monthly

production quantities, and a sudden drop in the year 2020 mainly caused by COVID-19. After the collapse, the regime trend stabilized from 2021 onwards. Another sudden drop is evident in 2023, which can be attributed to the transfer of product preparation operations to India and Bangladesh. The short to medium-term positive trends, at least, may result from increased capacity, or replenishment of demand. The plot highlights resilience and recovery after disruptions.

The time series plot reveals a significant decline in quantity in mid-2017, followed by a partial recovery. This coincides with the transfer of sample sewing operations to Bangladesh, suggesting a causal link between the relocation and the observed drop in production volumes. This motivated an investigation into whether the particular intervention has caused changes in the observed data using a causal impact analysis.

Table 2: Causal Impact Test Results

	Average	Cumulative
Actual	80597	5802981
Prediction	86710	6243138
(s.d.)	(992)	(71417)
95% CI	[84718, 88578]	[6099687, 6377625]
Absolute effect (s.d.)	-6113 (992)	-440157 (71417)
95% CI	[-7981, -4121]	[-574644, -296706]
Relative effect (s.d.)	-7% (1.1%)	-7% (1.1%)
95% CI	[-9%, -4.9%]	[-9%, -4.9%]
Posterior tail-area probability p: 0.001		
Posterior prob. of a causal effect: 99.9%		

The analysis established a high causal effect of a 99.9% posterior model probability according to Table 2, demonstrating a thus high influence on the time series. The algorithm was fine-tuned with data from 2018-2023, to guarantee a strong foundation for time series analysis and forecasting.

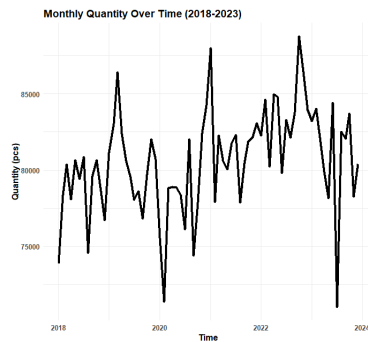


Figure 2: Monthly sample production volume for external sewing plants (2018 to 2023)

a. Augmented Dickey-Fuller Test

Hypothesis:

Null hypothesis: The series is not stationary

Alternative hypothesis: The series is stationary

Table 3: ADF Test Results

Data	Dickey-Fuller	Lag order	P-value
Original Series	-2.7303	4	0.278

The test statistic result given in Table 3 has a p-value of 0.278. As this p-value is higher than the common 0.05, the null hypothesis of a unit root cannot be rejected at a 5% significance level, which means that this series is non-stationary.

The ARIMA (0,1,1) model signifies that the time series was differenced once, $d=1$, to make it stationary, and it includes one moving average, MA, terms given by $q=1$.

Table 4: Final estimates for parameters of ARIMA (0,1,1)

	ma1
Coefficients	-0.7811
Standard Error	0.1001

From Table 4, the model has a first order moving average component where the forecast is based on the error of the previous period with a weight of -0.7811. The relatively small standard error, 0.1001, indicates that this estimate is fairly precise, and the negative coefficient suggests that past errors are inversely related to future values.

Table 5: Summary statistics for ARIMA (0,1,1)

AIC	AICc	BIC
1354.08	1354.25	1358.6

b. Significance of Parameters

Hypothesis:

Null hypothesis: Coefficients of parameters are zero

Alternative hypothesis: Coefficients of parameters are not zero

Table 6: Final Estimates of parameters for the model

	Estimate	Std. Error	Z value	Pr (> z)
ma1	-0.78113	0.10006	-7.8067	<0.001

The related p-value in Table 6, is <0.001, which is extremely low, thus providing ample evidence that the coefficient differs significantly from zero.

ESTIMATING THE SAMPLE PRODUCTION VOLUME FOR EXTERNAL SEWING PLANTS: A CASE STUDY OF AN APPAREL INDUSTRY IN SRI LANKA

c. Randomness of Residuals

Hypothesis:

Null hypothesis: Residuals are random

Alternative hypothesis: Not so

Table 7: Box - Ljung Test Results

Data	X-squared	Degree of Freedom	p-value
Residuals	2.3459	8	0.969

According to Table 7, the p-value of 0.9685 is greater than the significance level of 0.05, indicating no significant evidence to reject the null hypothesis.

d. Normality of Residuals

Hypothesis:

Null hypothesis: Residuals are normally distributed

Alternative hypothesis: Residuals are not normally distributed

Table 8: Shapiro-Wilk normality test

Data	W	p-value
Residuals	0.96811	0.064

Since the p-value in Table 8 is greater than the significance level, 0.05, we do not reject the null hypothesis of normality.

e. Parameter Redundancy

The selected model has the lowest AIC value equals 1354.08, indicating that the parameter redundancy does not exist.

f. Model Acceptance

Table 9: Accuracy measures of the adequate model

Adequate Model	Accuracy	MAPE
ARIMA(0,1,1)	95.9211	4.0788

As in Table 9, MAPE value 4.0788 means that, on average, the ARIMA (0,1,1) forecast values deviate from the actual values by 4.08 percent.

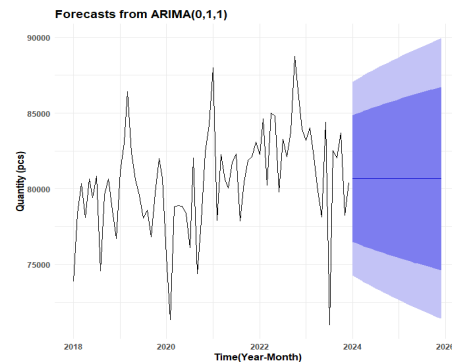


Figure 3: Forecasted Plot for Sample Quantity in 2024 and 2025

The selected model satisfies key assumptions in model adequacy, ensuring the significance of parameters, residual randomness, residual normality, and lack of parameter redundancy. Therefore, ARIMA (0,1,1) can be accepted as the best model for forecasting.

5 CONCLUSION

The analysis focuses on developing a robust forecasting model for external sewing plants within the Knit Centre. The research delved into the dataset by taking a time-series analysis from January 2014 to December 2023. In performing modeling, with an eye on causality, analysis treated exclusively the period of January 2018 to December 2023, where ARIMA (0,1,1) monthly production data were chosen for modeling. Due to the limited availability of data, the entire dataset was utilized for model fitting to ensure sufficient information for the analysis. The model is stationary and has a high forecasting accuracy at a MAPE of 4.08% and accurately predicts future production volume, with a statistically significant coefficient from the MA (1)

term. Statistical tests validate the model, showing minimal bias and low prediction variance. The model predicts a steady state of production for the next few years, 2024-2025, following the general trend of the data. The residuals show no significant autocorrelation, supporting the validity.

Table 10: Forecasted values for 2024 and 2025

Month	Point Forecast	Lo_95	Hi_95
01-24	80676.99	74289.91	87064.07
02-24	80676.99	74138.71	87215.27
03-24	80676.99	73990.93	87363.04
04-24	80676.99	73846.35	87507.63
05-24	80676.99	73704.76	87649.21
06-24	80676.99	73566	87787.98
07-24	80676.99	73429.89	87924.09
08-24	80676.99	73296.29	88057.69
09-24	80676.99	73165.06	88188.91
10-24	80676.99	73036.09	88317.88
11-24	80676.99	72909.26	88444.71
12-24	80676.99	72784.47	88569.51
01-25	80676.99	72661.62	88692.36
02-25	80676.99	72540.62	88813.35
03-25	80676.99	72421.40	88932.57
04-25	80676.99	72303.88	89050.10
05-25	80676.99	72187.98	89166.00
06-25	80676.99	72073.64	89280.33
07-25	80676.99	71960.81	89393.17
08-25	80676.99	71849.41	89504.56
09-25	80676.99	71739.41	89614.57
10-25	80676.99	71630.74	89723.24
11-25	80676.99	71523.36	89830.62
12-25	80676.99	71417.23	89936.75

The ARIMA (0,1,1) model for forecasting the sample production volume for external sewing plants is as follows:

$$Y_t = Y_{t-1} + \varepsilon_t - 0.7811\varepsilon_{t-1}$$

where,

Y_t is the observed value at time t ,

Y_{t-1} is the differenced value at time $t - 1$ (since it's a differenced series, $d = 1$),

ε_t is the white noise error term (also called residuals or innovations) at time t .

ε_{t-1} is the error term at time $t - 1$.

REFERENCES

- Gökalp, E. (2010). A Support system for production planning and pre-cost estimation activities in an apparel company, M.Sc. Thesis, Middle East Technical University.
- Jadhav, S. S., Sharma, G. S., Daberao, A. M., and Gulhane, S. S. (2017). Improving productivity of garment industry with time study. *International journal on textile engineering and processes*, 3, 1–6.
- Kurnianingtias, M., Wibowo, T. A., Khairunnisa, H., Astrini, G. Y., and Purwanningrum, D. (2024). Cycle time study in improving production output in the garment industry sewing line. *Jurnal sains dan aplikasi keilmuan teknik industri (SAKTI)*, 4(1), 47–54. <https://doi.org/10.33479/sakti.v4i1.91>.
- Paneru, N. (2011). Implementation of lean manufacturing tools in the garment manufacturing process focusing sewing section of men's shirts. Master's thesis, Oulu University of Applied Sciences.
- Syduzzaman, M., and Golder, A. S. (2015). Apparel analysis for layout planning in the sewing section. *International Journal of Current Engineering and Technology*, 5(3), 1736–1742.



Forecasting Monthly Domestic Piped Water Consumption in Sri Lanka

Dhanushika MS¹, Panahatipola PMOP¹

Department of Mathematical Sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka
sawanid42@gmail.com

ABSTRACT

Forecasting monthly domestic water consumption plays a crucial role in the effective management of water resources. At present, factors like population growth and urbanization, maybe caused for a significant increase in water consumption, especially in the domestic category of the island. In such a situation, water scarcity can be experienced with rapid population growth, overexploitation of surface water and groundwater, and climate and weather variability. Also, many piped water consumers may experience with water shortages or intermittent supply during the peak water usage times. Therefore, identifying inherent consumption patterns and accurate forecasts to optimize safe water production and distribution is crucial for the National Water Supply and Drainage Board (NWSDB) as the main authority of the provision of piped water in Sri Lanka. In accordance, pure time series approach can predict immediate future demands by capturing the trends, seasonality and cyclic variations relying solely on the historic water consumption data. Therefore, in this study, a forecasting model for domestic piped water consumption in Sri Lanka was developed using the Box-Jenkins methodology. By analyzing historical monthly domestic piped water consumption data in Sri Lanka spans for 122 months, the fitted SARIMA(0, 1, 2)(0, 1, 1)₁₂ model achieved a 97.78% accuracy, providing valuable insights for water resource planning and management. The number of connections has increased up to 2,793,030 by February 2024, and the consumption has also indicated a slight increment. In addition, considering the year 2024 the consumption per connection as at the end of February 2024, has decreased by 13.75% compared to 2014.

KEYWORDS: Box-Jenkins Methodology, Domestic Water, Water Demand Forecasting

1 INTRODUCTION

Water is one of the major requirements of humans and other living things in sustaining a quality of life on Earth (Bhatti & Nasu, 2010). Typically, Sri Lanka is recognized as a country not experiencing water scarcity, since its abundant natural water resources like the extensive network of rivers, lakes, ponds, reservoirs, natural springs, waterfalls and rainwater. However, only having access to water is insufficient, and humans need to access safe water for drinking as well as domestic consumption. In Sri Lanka, water sources deemed safe for drinking include protected wells (both within and outside premises), tap water (inside

homes, within units or premises, and outside premises), water supplied by village water projects, tube wells, bowser water, and bottled water. Conversely, unprotected wells, river water, tank water, stream water, and rainwater are classified as unsafe drinking water sources (Department of Census & Statistics, 2019). The National Water Supply and Drainage Board (NWSDB) is the main authority responsible for the provision of piped water and facilitating the provision of sanitation in Sri Lanka.

Initially, water consumption can be split into two categories as domestic and non-domestic. According to NWSDB, connections in domestic, board quarters,

government quarters, condominiums, tenaman garden¹, domestic Samurdhi, and tenaman Samurdhi² are considered as domestic connections, while other connections in schools, government institutions, hospitals, commercial institutes, industry, religious, tourist/guests, stand post, and others belong to non-domestic connections. In Sri Lanka, domestic consumption is the highest consumption category, and it accounts for 75.47% in 2022 (National Water Supply & Drainage Board, 2022). As NWSDB plays a critical role in ensuring the provision of safe water on the island, they are always ready to supply meet demand. Therefore, the main objective of this research was to obtain the best forecasting model and forecasting the monthly domestic piped water consumption in all island.

2 LITERATURE REVIEW

Many researchers have extensively analyzed water consumption and factors affecting consumption behaviour in diverse regions/countries worldwide while exploring various methodologies. However, regarding domestic water consumption demand in Sri Lanka, recent comprehensive research appears to be lacking.

Mohamed and Al-Mualla (2010) have mentioned that water demand forecasting methods can be divided into six approaches; (i) judgmental forecasting, (ii) regression forecasting, (iii) time series forecasting, (iv) cascade forecasting, (v) artificial neural networks forecasting, and (vi) support vector machine forecasting.

Wen et al. (2013) have used the triple exponential smoothing method under the

time series data mining and the simple exponential smoothing method in SPSS for the same observations to predict the water consumption in Guilin City from 2005 to 2011. The triple exponential smoothing has been concluded as the best method based on the prediction accuracy.

Tripathi et al. (2019) have done demand prediction analysis for the main reservoir tank using Integrated Autoregressive Moving Average (ARIMA) and Least Square Linear Regression (LSLR) models. The obtained Mean Absolute Percentage Error (MAPE) is 64% for ARIMA and 66.69% for LSLR, indicating the accuracy of ARIMA in prediction significantly better than LSLR.

Ristow et al. (2021) have evaluated (i) Exponential smoothing state-space model (ETS), and (ii) ARIMA models using R for forecasting monthly water consumption in Joinville City, Southern Brazil from January 2013 to December 2017, through four consumption categories; residential, commercial, industrial & public. The Seasonal Integrated Autoregressive Moving Average (SARIMA) method has been demonstrated greater accuracy based on model adequacy and forecast error.

Madhurangi and Aponsu (2024) have forecasted monthly treated water production level in Akuressa area in Matara district, Sri Lanka with Box-Jenkins methodology in time series using Minitab software. By analysing data spans for ten years, ARIMA(2,1,3) was obtained as the best model with 95.67% accuracy for forecasting water production level.

¹ Basic housing units of workers in plantation estates in Sri Lanka

² Housing units in tenaman gardens and getting samurdhi benefits

3 METHODOLOGY

Secondary data on domestic water consumption and water connections from January 2014 to February 2024 were collected from the NWSDB, Sri Lanka. Consumption is measured in Cubic Meters, m^3 .

With the aim of identifying trends and seasonal patterns of consumption, and making predictions based on seasonal variations or trends, the time series analysis with Box-Jenkins methodology (ARIMA models) was conducted as the primary statistical technique, using R 4.3.1 software, and 5% significance level was adopted. Initially, the data was transformed into a time series object using the 'tseries' package in R. Subsequently, the time series was visualized using the 'ggplot2' package. To assess stationarity, the Augmented Dickey-Fuller (ADF) test was conducted. In R, the 'auto.arima()' function automatically selects the optimal ARIMA model based on the Akaike Information Criterion (AIC) (Garza et al., 2024). Consequently, the model was fitted by applying 'auto.arima()' directly to the time series data without the need for prior differencing. To assess model adequacy, the four key assumptions in Box-Jenkins methodology; (i) Significance of parameters, (ii) Randomness of residuals, (iii) Normality of residuals, and (iv) Parameter redundancy was checked using "lmtest" package, Box-Ljung test, Shapiro-Wilk test, and AIC values respectively. To evaluate model performance, a subset of the data from March 2023 to February 2024 was selected. The MAPE and accuracy were then calculated by comparing the predicted values with the corresponding actual values. Finally, utilizing the

'forecast' package in R, monthly domestic water consumption for the subsequent year was predicted based on the best-fitted model.

4 RESULTS AND DISCUSSION

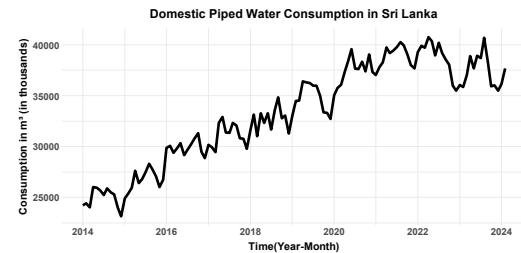


Figure 1: Monthly domestic piped water consumption in Sri Lanka

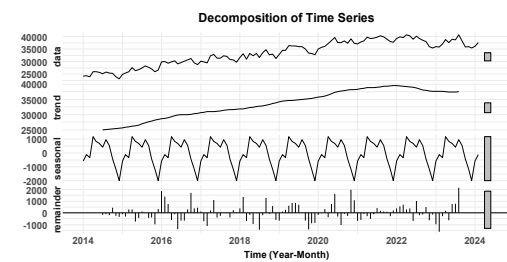


Figure 2: Decomposition plot

As depicted in Figure 1, time series plot indicates a clear upward trend with a general increase, and some noticeable seasonal fluctuations has occurred over the years, suggesting a seasonal component as in Figure 2. According to the ADF test ($p = 0.5839$), the original series is not stationary. Then, $SARIMA(0,1,2)(0,1,1)_{12}$ with lowest AIC value of 1814.16 was identified as the best fitted model. In line with diagnostic checking for model adequacy, the significance of parameters is primarily checked. As shown in **Table** , the coefficients for MA1 and SMA1 were found to be statistically significant at the 0.05 significance level, as indicated by p-values less than 0.05.

Table 1: Final estimates for parameters

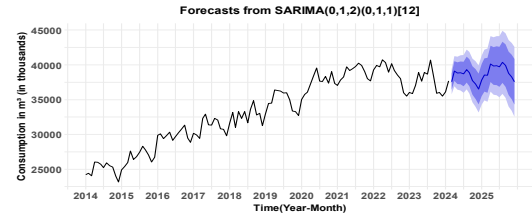
	Estimated coefficient	Pr(> z)
MA1	-0.3108	0.0013**
MA2	-0.1724	0.0779.
SMA1	-0.8540	1.539e-08***

The p-value for MA2 is 0.0779, which falls between the conventional significance thresholds of 0.05 and 0.10, suggesting marginal significance.

In the Box-Ljung test, yielded a p-value of 0.8723, indicating that the residuals are randomly distributed. Residuals were also normally distributed according to the Shapiro-Wilk test ($w = 0.9864$ and $p = 0.2616$). The selected model owed the lowest AIC value equals 1814.16, indicating that it avoids excessive parameters to overfitting. Therefore, the fitted model indicates that the parameter redundancy does not exist. Accordingly, the selected model satisfied key assumptions in model adequacy. The high accuracy (97.78%) and low MAPE (2.22%) of the SARIMA(0,1,2)(0,1,1)₁₂ model suggest its effectiveness in forecasting domestic water consumption in Sri Lanka. The model equation for forecasting is represented by,

$$X_t = X_{t-1} + X_{t-12} - X_{t-13} + Z_t - 0.3108Z_{t-1} - 0.1724Z_{t-2} - 0.854Z_{t-12} + 0.2654Z_{t-13} + 0.1472Z_{t-14} \quad (1)$$

As illustrated Figure 3, the forecast suggests a slight upward trend in domestic water consumption over the next two years. Also, there are distinct seasonal patterns, with higher consumption likely during certain months of the year possibly due to factors like agricultural seasons or climatic conditions.

**Figure 3:** Forecast plot on domestic water consumption**Table 2:** Forecast monthly domestic piped water consumption in Sri Lanka

	Point forecast	Lo 95	Hi 95
2024			
Mar	37589.23	35801.56	39376.90
Apr	39098.12	36926.97	41269.28
May	38809.71	36450.18	41169.24
Jun	38847.12	36313.17	41381.06
July	38702.08	36004.97	41399.18
Aug	39329.46	36478.52	42180.41
Sep	38870.30	35873.41	41867.19
Oct	37743.37	34607.32	40879.43
Nov	37244.89	33975.58	40514.19
Dec	36539.36	33141.85	39936.86
2025			
Jan	37828.78	34307.38	41350.19
Feb	38539.01	34898.83	42179.19
Mar	38518.08	34684.49	42351.68
Apr	40130.33	36137.86	44122.80
May	39841.92	35709.39	43974.45
Jun	39879.32	35611.33	44147.32
July	39734.28	35334.99	44133.57
Aug	40361.67	35834.89	44888.45
Sep	39902.50	35251.73	44553.28
Oct	38775.58	34004.03	43547.13
Nov	38277.09	33387.75	43166.44
Dec	37571.56	32566.87	42576.26

Table 2 represents the predicted domestic piped water consumption values in thousands, from March 2024 to December 2025.

5 CONCLUSION

As NWSDB plays a critical role in ensuring the provision of safe water on the island, they are always ready to supply and meet demand. Therefore, forecasting water consumption and water demand variations helps to identify the periods that may face future water storage, allowing early solutions such as invest new treatment plants, pipeline expansions, limiting water supply per period, and encouraging conservation practices. According to the purpose of this analysis, SARIMA(0,1,2)(0,1,1)₁₂ is the fitted model for domestic piped water consumption in Sri Lanka with 2.22% MAPE and 97.78% accuracy.

Further information about the dataset is provided by the coefficients of the error terms ($Z_t, Z_{t-1}, Z_{t-2}, Z_{t-12}, Z_{t-13}, Z_{t-14}$), which shows the impact of past errors on the current consumption. Sri Lanka's water consumption is predicted to peak in August 2025, reaching an estimated 40,361.67 thousand m³. This is followed by April 2025, with a forecast of 40,130.33 thousand m³. This coincides with both the typically hot temperatures of August and the festive season in April, which may lead to increased human consumption patterns during these months. In addition, the number of domestic water connections has increased from 1,577,266 to 2,793,030 by February 2024. Moreover, considering the years 2014 and 2024, the consumption per connection as of the end of February fluctuated from 15.346 m³ to 13.236 m³

accounting 13.75% decrement in nationally by 2024 compared to 2014.

Furthermore, as a future research work, this study will be further developed using the exogenous variables affecting on domestic piped water consumption.

REFERENCES

- Aponsu, L. (2024). *Forecasting Monthly Treated Water Production of Akuressa Area Forecasting Monthly Treated Water Production of Akuressa Area. September.*
- Bhatti, A. M., and Nasu, S. (2010). Domestic Water Demand Forecasting and Management Under Changing Socio-Economic Scenario. Society for Social Management Systems, v.
- Department of Census & Statistics. (2019). 2019 Household Income and Expenditure Survey - Final Report.
- Garza, F., Ihaka, R., Reid, D., and Shaub, D. (2024). Package 'forecast'
- Mohamed, M. M., and Al-Mualla, A. A. (2010). Water Demand Forecasting in Umm Al-Quwain (UAE) Using the IWR-MAIN Specify Forecasting Model. *Water Resources Management*, 24(14), 4093–4120.
- National Water Supply & Drainage Board. (2022). 2022 Annual Report.
- Ristow, D. C. M., Henning, E., Kalbusch, A., and Petersen, C. E. (2021). Models for forecasting water demand using time series analysis: A case study in southern brazil. *Journal of Water Sanitation and Hygiene for Development*, 11(2), 231–240.
- Tripathi, A., Kaur, S., Sankaranarayanan, S., Narayanan, L. K., and Tom, R. J. (2019). Water demand prediction for housing apartments using time series analysis. *International Journal of Intelligent Information Technologies*, 15(4), 57–75.
- Wen, Y., Huang, W., Wu, J., Chen, Y., and Song, J. (2013). Water consumption analysis system based on data mining. *Applied Mechanics and Materials*, 241–244, 1093–1097.



Forecasting Weekly Gasoline 92 World Market Price Using Time Series Analysis

Athukorala MK¹, Herath CHMAU¹, Dahanayaka SD¹

Department of Mathematical Sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka

amkumari1997@gmail.com

ABSTRACT

Fuel prices significantly impact global economies, influencing transportation costs, inflation, and policymaking. The volatile nature of gasoline prices presents a challenge for accurate forecasting, particularly in rapidly shifting markets. Despite existing studies on gasoline price predictions, a gap remains in developing robust, reliable models specifically for weekly price forecasting in highly volatile global oil markets. This research addresses this gap by analyzing and modeling weekly Gasoline 92 prices (USD/BBLS) from July 2021 to September 2024 using time series methods. The study employs a hybrid ARIMA-GARCH model to capture both the price trend and the volatility clustering often seen in financial time series data. The stationarity of the series was verified using the Augmented Dickey-Fuller test, and the ARIMA (0,1,1)-GARCH (1,1) model was identified as the best fit. The model achieved a Mean Absolute Percentage Error (MAPE) of 12.87%, demonstrating an 87.13% forecast accuracy. This innovative approach offers a dependable framework for predicting gasoline prices, which is instrumental for strategic decision-making in procurement, pricing, and inventory management at Ceylon Petroleum Corporation and beyond.

KEYWORDS: ARIMA, GARCH, Gasoline 92 Prices, MAPE

1 INTRODUCTION

Gasoline products have driven Sri Lanka's economic growth, powering transportation, industry, and agriculture. Gasoline 92 remains vital for daily commuting and commerce. While still essential, future reliance may shift toward cleaner energy. Infrastructure modernization and biofuel exploration will balance energy security with sustainability amid global renewable energy trends.

a. Background and Rationale for the Study

Gasoline 92 is crucial to Sri Lanka's economy, with price fluctuations affecting inflation, transportation, and living costs.

Accurate forecasting using time series models like ARIMA helps predict price trends amid global market volatility. This study's reliable fuel price predictions support better decision-making for policymakers, businesses, and consumers.

b. Objectives of the study

- To analyze the behavior of weekly gasoline 92 (UNL) prices over the past four years and to assess the variations in these prices relative to global market prices.
- To evaluate the forecasting performance of the developed model.

2 LITERATURE REVIEW

In past studies, few researchers have analyzed the prices of gasolines. They have proposed different modeling methods for forecasting gasoline 92 prices.

Xu et al. (2018) evaluated five time-series forecasting models ARIMA-GARCH, exponential smoothing, grey system, neural networks, and Support Vector Machines using monthly gasoline price data in China from 2006 to 2017. Their findings revealed that ARIMA performed best for short-term forecasts, while SVM and neural networks excelled in medium- and long-term predictions, emphasizing forecast horizon considerations.

Mardiana et al. (2020) examined demand forecasting for total gasoline and its three types of gasoline 88, 90, and 92 in Indonesia using 2017–2019 data. They found the Holt–Winters additive model more accurate than ARIMA and enhanced predictions by integrating Holt–Winters with a neural network. Results indicated rising total demand, with gasoline 92 and 88 decreasing and gasoline 90 increasing.

He, (2023) forecasted U.S. gasoline prices using both univariate and multivariate time series models to analyze the economic and managerial implications. By employing models such as exponential smoothing, ARIMA, and time series regression with variables like GDP, CPI, and crude oil prices, they found that the multivariate regression model with trend and seasonality performed the best. This research, used data from January 2002 to November 2022.

Most previous studies used monthly gasoline price data, which may

not capture short-term market fluctuations. This study uses weekly data, filling the gap by providing higher-frequency forecasting, which is crucial for real-time decision-making in volatile markets.

3 METHODOLOGY

This study utilized secondary data obtained from the Commercial Function of the Petroleum Corporation in Colombo. A dataset of 156 weekly average gasoline prices, covering the period from July 2021 to September 2024, was analyzed using time series methods to forecast gasoline prices for the corporation. The analysis was conducted with R software.

The Box-Jenkins methodology was applied to develop a suitable mean model. Initially, the stationarity of the series was tested using the Augmented Dickey-Fuller (ADF) test. The results indicated that the t-statistic exceeded the critical value at the 5% significance level, confirming that the series was non-stationary.

Subsequent to parameter estimation, the model's goodness of fit was evaluated. Residual diagnostics, including the Serial Correlation LM test for randomness and the Jarque-Bera test for normality, were employed to ensure the adequacy of the model.

3.1 GARCH Model

Bollerslev (1986) generalized Engle's model to make it more realistic, called GARCH model. The GARCH model is an extension of the ARCH model. It is a widely used statistical model in time series analysis and econometrics to model and forecast the volatility, or the time-varying variance, of financial returns or other time series data. The GARCH model was introduced to address some

limitations of the ARCH model by incorporating lagged conditional variances in the modeling process. GARCH model cannot capture the asymmetric performance.

4 RESULTS AND DISCUSSION

Table 1 summarizes the descriptive statistics for weekly Gasoline 92 prices. The maximum price recorded was \$151.55 per barrel in 2022, while the minimum price was \$56.62 per barrel in 2021. Fig 1 presents the time series plot, depicting weekly Gasoline 92 prices (USD/BBLs) over the past four years. An upward trend is evident until 2022, followed by a downward trend after June 2022. Overall, from 2021 to 2024, a relatively upward trend is observed.

As presented in Table 2, the results of the Augmented Dickey-Fuller (ADF) test indicate that the original time series is non-stationary, as evidenced by a P-value greater than 0.05. However, after applying first-order differencing, the ADF test confirms that the series has achieved stationarity, with a P-value falling below the 0.05 threshold. Figure 2 provides a visual representation of this transformation through the Auto-Correlation Function (ACF) and Partial Auto-Correlation Function (PACF) plots for the first-differenced series.

Table 1: Descriptive statistics of weekly Gasoline 92 prices USD/BBLs 2021-2024

Mean	SD	Max	Min
92.18	5.16	151.55	56.62

Table 2: Augmented Dickey-Fuller test

Original	Differenced
P-value	0.6105
	0.01

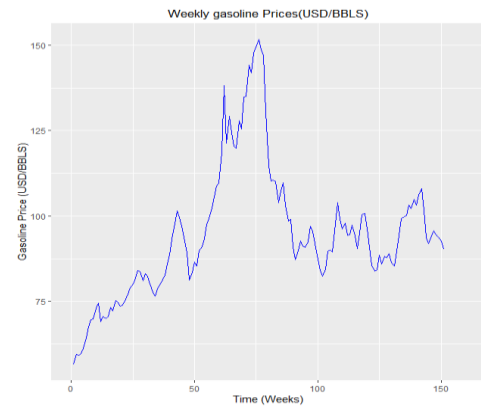


Figure 1: Time series plot

Fig 2 indicates that significant ACF and PACF values suggest $q=1$ and $p=0$, respectively. Based on AIC and BIC values, the ARIMA (0,1,1) model is the best fit for forecasting Gasoline 92 prices, with all parameters significant.

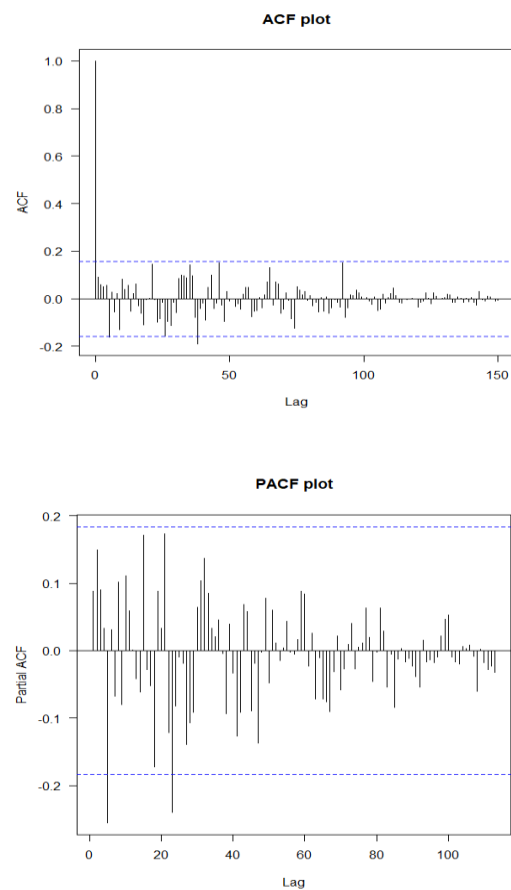


Figure 2: ACF and PACF plots

Table 3 summarizes residual diagnostic tests, revealing conditional heteroscedasticity through the ARCH LM test, indicating volatility clustering in residuals. A GARCH model is required to address this.

Here, Four GARCH models GARCH(1,1), GARCH(1,2), GARCH(2,1), and GARCH(2,2) were fitted, with Table 4 presenting the AIC, BIC, and HQC values for each. The ARIMA(0,1,1)-GARCH(1,1) model was selected as the best conditional variance model, minimizing all three criteria. Subsequently, the asymmetric effect was assessed using the sign bias test, with results shown in Table 5. A P-value > 0.05 indicates no asymmetric effect in the residuals.

Table 3: Residuals Diagnostic Tests on ARIMA(0,1,1) Model

Test	P-value	Conclusion
Serial correlation LM test	0.2239 > 0.05	Residuals are Random
Jarque-Bera test	0.3568 > 0.05	Residuals are normal
ARCH LM test	1.076e-05 > 0.05	Residuals have volatility

Table 4: GARCH(p,q) model related to ARIMA(0,1,1)

Model	AIC	BIC	HQC
GARCH(1,1)	5.7030	5.7914	5.7429
GARCH(1,2)	5.7128	5.8012	5.7447
GARCH(2,1)	5.7284	5.8265	5.7682
GARCH(2,2)	5.7159	5.8337	5.7638

Table 5: Sign Bias Test

P-value	
Sign Bias	0.1969
Negative Sign Bias	0.9453
Positive Sign Bias	0.1916

Table 6: Parameter Estimation of ARIMA(0,1,1)- GARCH(1,1)

	Estimate	Pr($> t $)
Ma1	0.25238	0.001660
Omega	0.69314	0.001374
Alpha1	0.29718	0.000089
Beta1	0.84044	0.000000
Gamma1	-0.31026	0.000275

Table 6 shows that all coefficients in the mean and variance equations have probabilities below 0.05, indicating significance at the 5% level. Based on the comparison, the ARIMA(0,1,1)-GARCH(1,1) model was selected as the best fit. Fig 3 presents the Normal Q-Q plot for the fitted ARIMA(0,1,1)-GARCH(1,1) model, indicating that residuals align closely with the straight line, confirming they are approximately normally distributed.

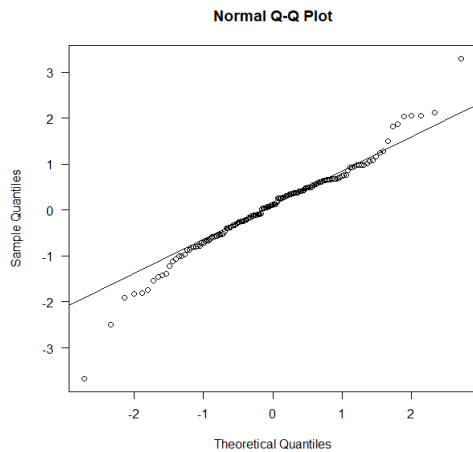


Figure 3: Normal Q-Q plot

Table 7: Forecasting Performance

Time period	12 weeks of 2024
MAPE (%)	12.87

Therefore, the normality of residuals is confirmed by the plot in Fig 3. After checking the adequacy of the model, it is established that the ARIMA(0,1,1)-GARCH(1,1) model is the best for modeling gasoline 92 price.

The forecast performance of the fitted ARIMA(0, 1, 1)-GARCH(1,1) model was measured by using MAPE, and the results are shown in Table 7 it is clear that all error values are very low indicating a higher accuracy of the identified model.

5 CONCLUSION

This study mainly analyzed and modeled the weekly gasoline 92 (USD/BBLS) price at the global oil market price. Overall, the analysis showed an upward trend in prices during the four-year period from 2021 to 2024. These fluctuations were accounted for by building a univariate model. In overall, a model shows upward trend pattern.

Due to the volatility in weekly oil prices, a symmetric GARCH model, denoted as

ARIMA (0, 1, 1)-GARCH (1,1), was fitted for forecasting gasoline 92 prices. It is capable of capturing volatility, time-varying conditional variance, and errors. The model's forecasting performance, with a MAPE of 12.87% and an accuracy of approximately 87.13%. These results show that ARIMA (0, 1, 1)-GARCH (1,1) is the best-fit model and can be used for modeling and forecasting weekly gasoline 92 world oil price at Ceylon Petroleum Corporation.

REFERENCES

- Bollerslev, T. (1986). Generalized autoregressive conditional heteroskedasticity. *Journal of Econometrics*, 31(3), 307-327.
- He, X. J. (2023). Forecasting gasoline price with time series models. *Communications of the IIMA*, 21(1).
- Mardiana, S., Saragih, F., and Huseini, M. (2020). Forecasting gasoline demand in Indonesia using time series. *International Journal of Energy Economics and Policy*, 10(6), 132-145.
- Xu, F., Sepehri, M., Hua, J., Ivanov, S., and Anyu, J. N. (2018). Time-series forecasting models for gasoline prices in China. *International Journal of Economics and Finance*, 10(12), 1-43.



Identification of the Upcoming and Outgoing Fabric Qualities Using the K-Means Algorithm

Weeraratne WLM¹, Dissanayake AAL¹, Dahanayaka SD¹

Department of Mathematical Sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka
madu.pabani1998@gmail.com

ABSTRACT

The textile industry relies heavily on understanding customer demand to remain competitive in global markets. With the increasing complexity and variety of fabric qualities, accurately predicting emerging and declining trends is crucial for optimizing production and meeting market demands. This study focuses on using the K-means clustering algorithm to identify fabric qualities that are either upcoming or outgoing in demand. By recognizing patterns in customer demand, this study provides actionable insights for aligning production strategies with market needs, improving efficiency, and reducing resource wastage. The ABC Company analyzed a dataset that included 1163 fabric characteristics from client order records. An unsupervised learning method of data mining approach was used since there is unlabeled data to uncover hidden patterns. Key steps included data preprocessing, normalization, clustering using K-means, and trend analysis using linear regression. The optimal number of clusters ($k=3$) was determined using the Elbow, Silhouette, and Gap statistic techniques. Internal cluster validation achieved a silhouette value of 0.83, indicating well-structured clusters. Results revealed 9 outgoing and 33 upcoming fabric qualities. By identifying the fabric qualities that are upcoming over time the company can meet the market demand well according to a plan and gain potential benefits such as reliable profits. By identifying the fabric qualities that are outgoing over time, the company can check whether they have any significant issues affecting those qualities other than decreasing market demand. This approach not only clusters the fabric qualities but also identifies the upcoming and outgoing clusters separately.

KEYWORDS: Data Mining, Data normalization, K-means, Machine Learning, Trend analysis

1 INTRODUCTION

The textile industry plays a vital role in Sri Lanka's economy, producing a wide range of fabric types, including Single Jersey, Rib, and Jacquard. Each fabric type is categorized into different fabric qualities based on fabric composition, raw material content, and production routes. Accordingly, they are assigned a unique quality reference. Thousands of unique fabric qualities are manufactured based on customer orders, but many are subject to fluctuating demand. Understanding which fabric qualities are emerging or declining is critical for aligning production strategies with market demands.

However, the company lacks a systematic approach to identifying these trends, leading to inefficiencies. Machine learning algorithms like K-means offer a robust solution for clustering and by aligning it with trend analysis, this gap can be addressed.

1.1 Research Objective

The primary objective of this study is to identify fabric qualities that are either upcoming (trending) or outgoing over time. Additionally, it aims to validate the clustering structure.

2 LITERATURE REVIEW

Prior studies have demonstrated the versatility of the K-means algorithm. Ayooob (2017) focused on the K-means methodology for breast cancer diagnosis with an accuracy of 96.4861%. A database consists of 699 real cases of patients. The database included nine symptoms as attributes and the value ranges of each were from 1 to 10 with class status and labels with who is either benign or malignant.

As performed by Sudirman et al. (2018) the k-means algorithm was used to identify the potential areas of food crops from 34 provinces in Indonesia. 3 clusters were used as high production, normal production, and low production using 3 attributes. The Davies-Boulding index was obtained as -0.392, which showed this as the best algorithm based on the attributes.

Gupta & Panda (2019) compared K-means with CLARA clustering, emphasizing the importance of internal validation metrics like Silhouette and Dunn indices. Gayathri and Napagoda (2022) describe the use of the K-means approach with the Lloyd algorithm on lung cancer data. The dataset included details on 1000 patients, with their demographic and diagnostic attributes. In the preprocessing step, the value of class label attributes changed into low:1, medium:2, and high:3. They suggested an approach with an accuracy of 75.8% with the help of the value of class label attributes in the dataset.

Danny et al. (2024) explained an application of the K Nearest Neighbor Machine Learning Algorithm to predict products that are best-selling and not selling at a company that produces tuners

in Indonesia. Based on the analysis results, prediction results were obtained with an accuracy level of 94.74% and an error rate of 5.26%.

3 METHODOLOGY

3.1 Introduction to the Dataset

In this research project, the Sales Order Details dataset for 2022 and 2023 was obtained from the sales department of the company. It included the details of the fabric orders incoming to the sales department from the customers. The monthly order quantities of each quality were taken for analysis.

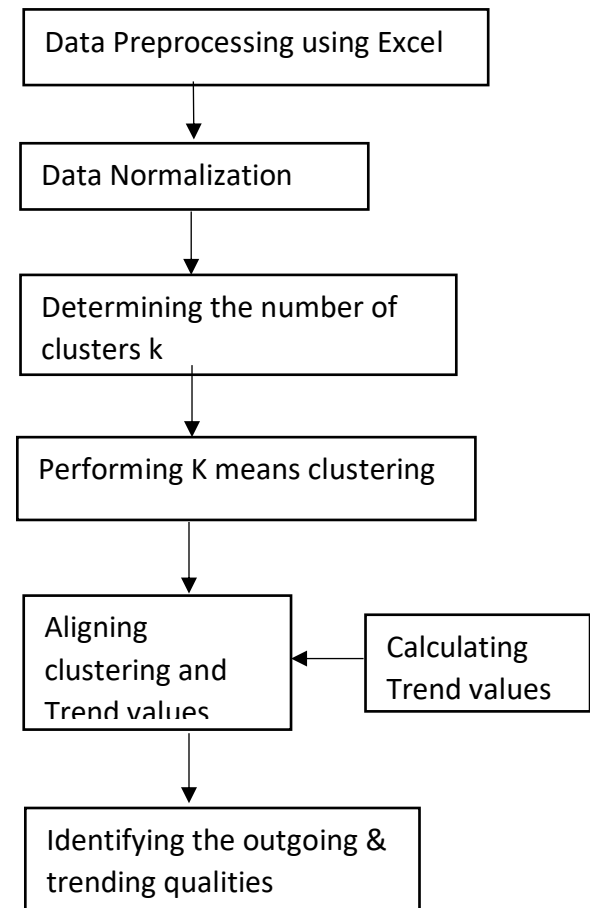


Figure 1: Research Methodology

3.2 Data Preprocessing

Excel was used for preprocessing purposes. The required data was selected and the order quantities were categorized into each month using the pivot table

option in Excel. After this step, it showed 1163 unique fabric qualities and monthly order quantities of each quality in 24 months. the dataset did not have labels.

R software was used to perform the analysis. The dataset was read to the software as the initial step. After checking for missing values, there were no missing values in the dataset.

3.3 Data Normalization

The data was normalized to ensure that all the values in each attribute equally contribute to clustering performance.

3.4 Determining the number of clusters k

After normalizing the data, before performing K-means clustering the number of clusters (k) should be identified. Using a comparison between the three methods; the Elbow method, the Average silhouette method and the Gap statistic method the most suitable k value can be identified (Kassambara, 2018).

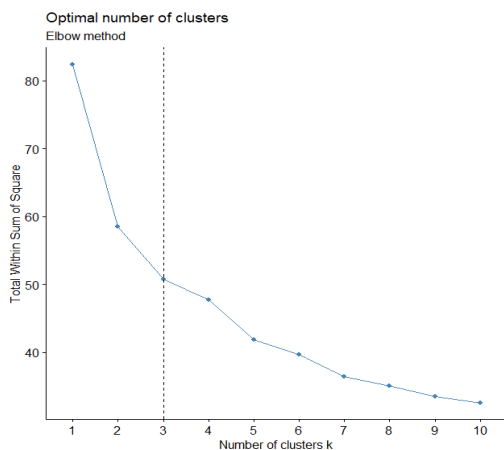


Figure 2: The optimal k value from the Elbow method

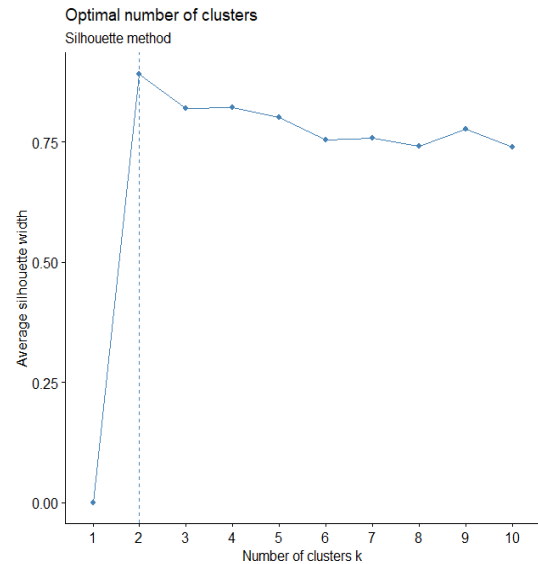


Figure 3: The optimal k value from the Average silhouette method

Using the Elbow method and the Gap statistic method, 3 clusters are suitable. Using the Average silhouette method, 2 clusters are suitable.

According to most observations above, the optimal number of clusters should be $k=3$. The average silhouette method suggested $k=2$, which is not meaningful according to the objective and the domain knowledge. Therefore, the next maximum average silhouette value can be observed as $k=3$ from Figure 3.

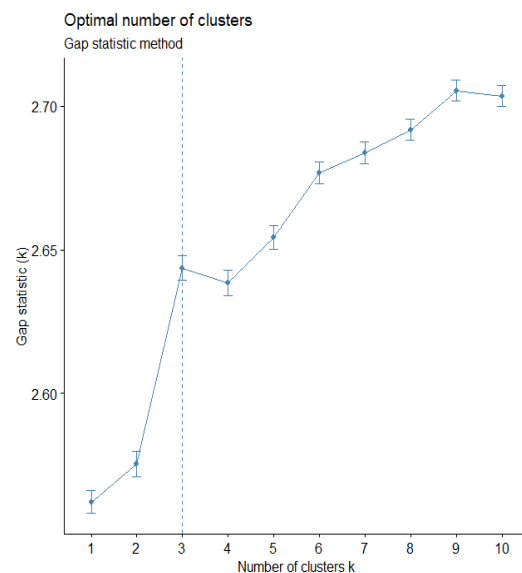


Figure 4: The optimal k value from the Gap statistic method

3.5 Performing k-means clustering

Using k=3 as the number of clusters, the k-means clustering was performed in R.

Table 1: Clustering Result

No	Quality	Cluster
1	LPSJ184703	2
2	LPSJ187108/A	2
3	LPSJ187108/G	2
4	LPDN094312	2
5	LPDN094312/A	2
.....		
575	LPSJ176904/L	3
576	LPSJ176904/LIN	2
577	LPSJ176904/LINP	2
578	LPSJ176904/LTOC	2
579	LPSJ176904/LTOCP	2
.....		
1159	LYSJ441619/BCIAS	2
1160	LYSJ441619/BCIFS	2
1161	LYSJ672214/GFS	2
1162	LYWR212116/FS	2
1163	LYWR335215/FS	2

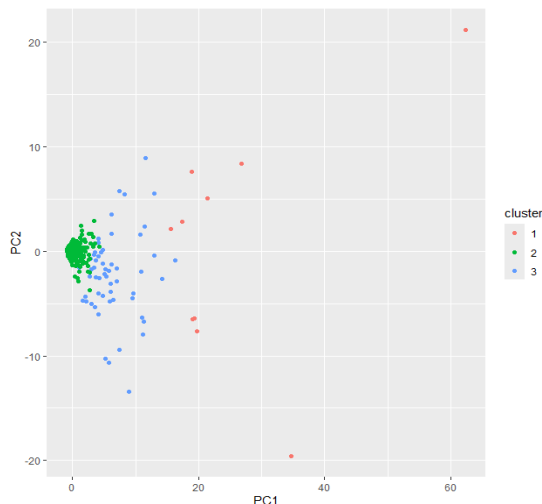


Figure 5: Visualization of clustering

3.6 Aligning Clustering and Trend Values Using an Excel Analysis

Trend analysis using linear regression was used to calculate the trend value (slope) for each fabric quality to

understand whether the qualities are upcoming, outgoing, or remaining stable. The output was sorted by trend value from the most positive to the most negative.

Using the conditional formatting, the 75th percentile which is the top 25% of values, and the 25th percentile which is the bottom 25% of values were highlighted.

Table 2: Result after sorting by trend value with highlighted percentiles

No	Quality	Trend	Cluster
395	LPSJ032398	5971.774	3
235	LPRB066499/B CI	4735.119	3
33	LPFL132122	3893.717	3
34	LPFL132122/B	3328.187	3
504	LPSJ115917	2844.581	3
581	LPSJ176904/T OC	2808.701	3
516	LPSJ118014/R	2350.388	3
...			...
997	LTSJ176904/LP	-1.83	2
527	LPSJ134022	-1.83696	2
310	LPRB293616	-1.85	2
322	LPRB324717	-1.85304	2
101 9	LTSJ213413	-1.9213	2
80	LPFT080117	-1.93696	2
...			...
735	LPSJ385008/A BCI	-2729.43	3
514	LPSJ118014	-2736.87	1
499	LPSJ115203/RE	-3829.93	1
38	LPFL138020	-5327.82	3
343	LPRB427009/C	-6303.69	1
721	LPSJ355018CF	-6540.26	1

Table 3: The Summary of the number of qualities in each cluster & its percentile position

Cluster	75th percentile (top 25%)	50th percentile (middle 50%)	25th percentile (bottom 25%)
1	1	0	9
2	217	620	260
3	33	2	21

Since almost all qualities in cluster 1 are in the 25th percentile which has the most negative trend values, it should be the outgoing cluster. Since most qualities in cluster 3 are in the 75th percentile with the most positive trend values, it should be the upcoming cluster. Since most of the qualities in cluster 2 are in the 50th percentile which has trend values close to 0, it should be the stable cluster.

4 RESULTS AND DISCUSSION

The algorithm identified 10 outgoing qualities, 56 upcoming qualities, and 1097 remaining stable qualities. After using the trend analysis, 9 outgoing qualities, 33 upcoming qualities, and 620 stable qualities were identified.

The internal cluster validation was used to check the goodness of the clustering structure. The average silhouette value was 0.83 which is closer to +1. This indicates the clustering was well-structured according to this analysis.

5 CONCLUSION

Recognizing emerging and declining fabric qualities has several benefits for the company. The company can focus more on the identified 33 upcoming qualities since they might have the market demand. They can allocate more production

capacity for these fabric qualities than others, not letting them be delayed which can dissatisfy the customers. The company should individually check the issues in the 9 outgoing qualities were identified correctly. That can make sure whether there is a decrease in the actual market or an internal quality issue that affects the order placements. Future work could incorporate additional variables and explore advanced clustering techniques for improved accuracy.

REFERENCES

- Ayoob, N. K. (2017, December). Breast Cancer Diagnosis Using K-means Methodology . *Journal of University of Babylon for Pure and Applied Sciences* . December 2017, 26, 9-16.
- Danny, M., Muhidin, A., and Jamal, A. (2024, May). Application of the K Nearest Neighbor Machine Learning Algorithm to Predict Sales of Best Selling Products. *Brilliance: Research of Artificial Intelligence*, 4(1), 255-264.
- Gayathri, Y., and Napagoda, N. (2022). Lung Cancer Diagnosis Using the Lloyd K-means Algorithm. *Proceedings of the 14th Symposium on Applied Science, Business & Industrial Research*, 172-176.
- Gupta, T., and Panda, S. P. (2019). Clustering Validation of CLARA and K-Means Using Silhouette & DUNN Measures on Iris Dataset. *International Conference on Machine Learning, Big Data, Cloud and Parallel Computing*, 10-13.
- Kassambara, A. (2018). *Determining The Optimal Number Of Clusters: 3 Must Know Methods*. Retrieved from Data Nova: <https://www.datanovia.com/en/lessons/determining-the-optimal-number-of-clusters-3-must-know-methods/>
- Sudirman, Windarto , A. P., and Wanto, A. (2018). Data mining tools | rapidminer:

K-means method on clustering of rice crops by province as efforts to stabilize food crops in Indonesia. *IOP Conference Series: Materials Science and Engineering*, 1-8.



Modeling and Forecasting Tourist Arrivals in Sri Lanka After COVID-19 Pandemic

Priyankara VBHD¹, Francisco GS¹

Department of Mathematical Sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka
hirunidevindi29@gmail.com

ABSTRACT

Currently, Sri Lanka becomes one of the largest economics of the world in which tourism have significantly contributed. This research is focused on finding a suitable forecasting model for the tourist arrivals in Sri Lanka using an asymmetric Generalized Auto Regressive Conditional Heteroscedasticity Model (GARCH) to investigate and model the volatility on the tourist arrivals after covid-19 pandemic. Weekly data was collected from January 2022 to September 2024. A mixed-methods approach was employed, including a boxplot to identify natural disaster-related outliers in the data set and an Augmented Dickey-Fuller (ADF) test to assess the stationary behavior of data and transformed differenced series is used to fit the model. The Akaike Information Criteria (AIC) was employed to select and compare models, based on the lowest AIC values, AR (4) was chosen as conditional mean models of weekly tourist arrivals in Sri Lanka. The Ljung-Box test was applied to detect the autoregressive conditional heteroscedasticity (ARCH) in the residuals of the conditional mean model. After checking residuals of the AR (4) model, conditional heteroscedasticity in residuals of fitted AR (4) model is detected using ARCH LM test. Under this effect, conditional variance model, GARCH (1, 1) model was built to forecast the weekly tourist arrivals in Sri Lanka. The asymmetric effect was checked using the sign bias test and AR (4)-EGARCH (1,1) is selected as the best for modeling tourist arrivals in Sri Lanka with the accuracy of 86%.

KEYWORDS: SLTDA, Time Series, Tourist Arrivals, Volatility

1 INTRODUCTION

Tourist arrivals refer to visitors coming from outside a region for leisure, business, or other activities. Tourism has become a global industry and an essential contributor to economic development. Sri Lanka, known as the "Pearl of the Indian Ocean," boasts a variety of tourist attractions, including cultural, natural, and adventure-based destinations, which are crucial to its economy. Despite its significant role in generating foreign exchange and supporting economic growth, Sri Lanka's tourism has faced challenges due to the COVID-19 pandemic, global events, and changing travel preferences. From 2021 to 2024, tourism experienced fluctuations due to

these factors, influencing the industry worldwide.

c. Significance of the Study

This study is significant in the post-pandemic context as it provides reliable forecasts of tourism arrivals in Sri Lanka, a key sector for the nation's economy. By identifying suitable forecasting models, providing valuable insights for effective planning, resource allocation, and sustainable growth. It helps policymakers and businesses optimize strategies and distribute tourism benefits more evenly. The research contributes to academic literature on tourism forecasting and supports Sri Lanka's long-term tourism growth and economic sustainability.

d. Objective of the Study

The objective of the study is to analyze the behavior of tourist arrivals weekly. The study aims to construct a suitable time series model to forecast weekly tourist arrivals in Sri Lanka and forecast the volatility of tourist arrivals for the tourism industry from October 2024 to December 2026, evaluating the forecasting performance of the model.

2 LITERATURE REVIEW

Tourist forecasting is crucial for strategic planning in the tourism industry. In Sri Lanka, while research exists, there are significant gaps in methodologies, data sources, and applications that address the country's unique tourism characteristics.

Nagendrakumar et al. (2021) used ARIMA and GARCH models to forecast tourist arrivals in Sri Lanka, applying the Box-Cox transformation to address variance and heteroscedasticity. While SARIMA handled seasonal patterns, GARCH models proved more effective for time-varying volatility. The study highlighted the importance of exploring multiple approaches, with ARCH (1) models using lags (2, 7, and 12) providing accurate forecasts.

Shanika and Jahufer (2021) analyzed the volatility of international tourist arrivals in Sri Lanka (1970–2019) using GARCH(1,1), GJR-GARCH(1,1), and EGARCH(1,1) models. The GARCH models effectively captured monthly volatility, while EGARCH was better for annual data. Results showed that a 0.164 decrease in tourist arrivals increased volatility, highlighting the models' importance in understanding and managing tourism trends.

Shameera et al. (2018) used SARIMA models to forecast Sri Lankan tourist arrivals (2000–2017), highlighting the impact of the Civil War. The SARIMA(3,1,2)(1,0,1)₁₂ model was best for long-term data, while SARIMA(2,1,3)(1,0,0)₁₂ excelled post-war, achieving higher accuracy. The study underscores SARIMA's effectiveness in capturing seasonal trends for tourism planning.

Kodituwakku et al. (2015) analyzed Sri Lanka's tourist arrivals from January 2010 to August 2014 post-civil war and found the Holt-Winters Multiplicative Seasonal Model to be the most accurate. It outperformed SARIMA, the Holt-Winters Additive Model, and NARX neural networks.

Konarasinghe (2020) emphasized the importance of forecasting for post-war tourism planning in Sri Lanka. The study found Winter's three-parameter multiplicative and additive models to be best for short-term forecasting, and recommended exploring advanced techniques like Decomposition, ARIMA, GARCH, and ARCH for better long-term accuracy.

3 METHODOLOGY

e. Data Collection

This study was undertaken by using weekly tourist arrivals in Sri Lanka. The secondary data of weekly tourist arrivals from January, 2022 to September, 2024 were collected from the Sri Lanka Tourism Development Authority (SLTDA) reports. The data were collected every year for 48 weeks. The analysis was done by using R software.

The Box-Jenkins method was employed to formulate a mean model. First, stationarity of the series was checked

by using ADF test. If the series is not stationary, it should be done trend or seasonal differencing accordingly. The ACF and PACF were used to identify mean model.

Following the assessment of parameter significance, it is imperative to evaluate the goodness of fit for the model. In order to check randomness and normality of residuals, serial Correlation LM test and Shapiro Wilk test can be employed.

.2 Garch Model

Bollerslev and Taylor (1986) generalized Engle's model to make it more realistic, called GARCH model. It is a widely used statistical model in time series analysis and econometrics to model and forecast the volatility, or the time-varying variance, of financial returns or other time series data. The GARCH model was introduced to address some limitations of the ARCH model by incorporating lagged conditional variances in the modeling process. GARCH model can capture the asymmetric performance.

The asymmetric effect was tested using the sign bias test, and several asymmetric GARCH models (IGARCH, EGARCH, GJRARCH, APARCH, and TGARCH) were considered. The best model for forecasting tourist arrivals was selected by comparing information criteria (AIC, BIC, and HQIC) and analyzing the model's parameters and residuals. The model's accuracy was evaluated using MAPE.

Table 1: Augmented Dickey-Fuller test

	Original	Differenced
P-value	0.0728	0.0143

4 RESULTS AND DISCUSSIONS

Table 1 depicts descriptive statistics of the weekly tourist arrivals in Sri Lanka over the period 2022 January to 2024 September. It shows the maximum and minimum arrivals are 82305 in 48th week in 2023 and 5600 in first week 2022, respectively.

According to Fig.1, weekly tourist arrivals in Sri Lanka have a trend of going upwards over the past three years starting in early 2022. A sharp rise occurred in early 2024, peaking above 80,000.

Fig.2 shows ACF plots for the original series. It shows the decreasing upward trend and the presence of the trend pattern indicate non-stationary data.

According to Table 2, ADF test confirms that original series is not stationary (P-value > 0.05). After the first order differencing, ADF test reveals that differenced data are stationary (P-value < 0.05).

Table 2: Descriptive statistics of weekly tourist arrivals in Sri Lanka 2022-2024

Mean	SD	Max	Min
27913	14590.14	82305	5600

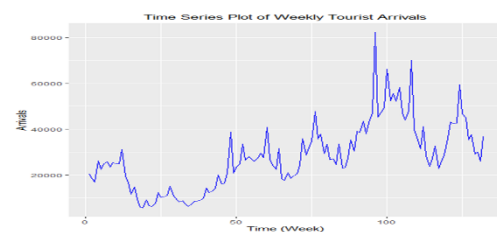


Figure 1: Time series plot

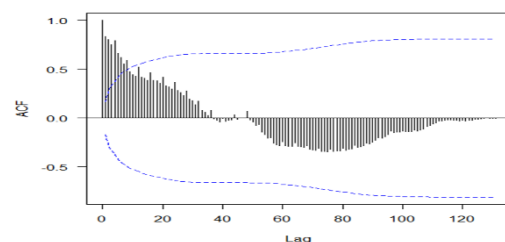


Figure 2: ACF plot

Based on the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) values, AR (4) is the most suitable model among the suspected models to forecast the tourist arrival volatility where all the parameters are significant at their respective significance levels.

Table 3 shows the results of residuals diagnostic tests. According to ARCH LM test result, conditional heteroscedastic behavior is present and there exist volatility clusters among residuals. The GARCH model must fit to remove this impact.

Table 3: Residuals Diagnostic Tests on AR (4) Model

Test	P-value	Conclusion
Serial Correlation LM Test	0.5703 > 0.05	Residuals are random
Shapiro Wilk Test	0.06214 > 0.05	Residuals are normal
ARCH LM test	0.02279 < 0.05	Residuals have volatility

Table 4: GARCH(p,q) model related to AR(4)

Model	AIC	BIC	HQIC
GARCH (1,1)	2.0271	2.1807	2.0895
GARCH (1,2)	2.0423	2.2179	2.1137
GARCH (2,1)	2.0423	2.2179	2.1137
GARCH (2,2)	2.0576	2.2551	2.1379

Here, four GARCH models were fitted as GARCH (1,1), GARCH (1,2), GARCH (2,1) and GARCH (2,2). Table 4 depicts

the values of AIC, BIC, and Hannan-Quinn Criterion (HQC) for the above GARCH models. Hence, AR (4) – GARCH (1,1) was selected as the best conditional variance model which has the minimum value for all three-information criterion.

Thereafter, asymmetric effect on this model was examined via a sign bias test and results are shown in Table 5. P - value of sign bias test does not exceed 0.05. This result is leading to the conclusion that there are asymmetric effects in residuals.

Table 5: Sign Bias Test

	P - value
Sign Bias	0.008069
Negative Sign Bias	0.008686
Positive Sign bias	0.008109

Table 6: Asymmetric GARCH model with AR (4)

Model	AIC	BIC	HQIC
EGARCH (1,1)	1.8101	1.9857	1.8814
IGARCH (1,1)	2.0118	2.1435	2.0653
GJRGARCH (1,1)	1.9697	2.1452	2.0410
TGARCH (1,1)	1.9697	2.1452	2.0410
APARCH (1,1)	1.9016	2.0772	1.9729

As indicated in Table 6, the probabilities associated with the coefficients in both the mean equation and the parameters of the variance equation are all below 0.05.

Therefore, all the parameters are significant at 5% level of significant in the

fitted model. By comparing the results, AR (4) - EGARCH (1, 1) is selected as the most preferable model.

According to the Table 8 since all residuals have p values greater than 0.05. It can be concluded there is no serial correlation among standardized residuals. Hence, residuals behave as white noise.

According to the Table 9, all p values are greater than 0.05. Hence, there is no evidence of serial correlation among squared residuals. It can be concluded that residuals behave as a white noise process.

Normal Q-Q plot and density plot of the fitted AR (4)-EGARCH (1,1) are shown in Fig. 3. Normal Q-Q plot reveals that residuals are well fitted with the straight line. And density plot visualizes distribution of the residuals remarkably close to bell shape, which means residuals are normally distributed.

Table 7: Parameter Estimation of AR (4)- EGARCH (1,1)

	Estimates	Pr(> t)
ar 1	- 0.112838	0.000364
ar 2	-0.028407	0.022915
ar 3	-0.097608	0.029474
ar 4	0.467213	0.000000
omega	-1.758795	0.000000
alpha1	0.315163	0.015136
beta 1	-0.535806	0.000000
gamma1	0.719521	0.000155

Table 8: Weighted Ljung-Box test results on standardized residuals

	statistic	p-value
Lag [1]	0.246	0.61990
Lag [2*(p + q) + (p + q)-1][11]	6.985	0.05647
Lag [4*(p + q) + (p+ q)-1][19]	14.586	0.03866

Table 9: Weighted Ljung-Box test results on standardized squared residuals

	statistic	p-value
Lag [1]	0.2215	0.6379
Lag [2*(p +q) + (p +q)-1][5]	1.1694	0.8203
Lag [4*(p +q) + (p + q)-1][9]	1.7378	0.9339

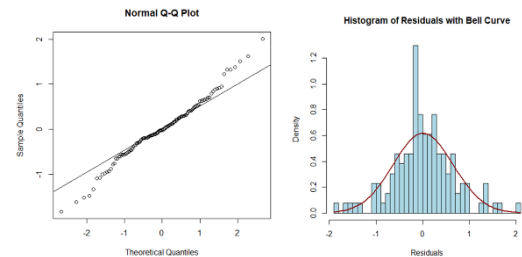


Figure 3: Normal Q-Q Plot and Density Plot of Residuals

Table 10: Forecasting Performance

Performance Metrics	Result
MAPE (%)	14.2963
MPE	14.41288
MAE	0.4698446

Therefore, normality of residuals is confirmed by both plots in Fig.3. checking the adequacy of the model is proved that the AR (4)- EGARCH (1,1) model is the best for modeling weekly tourist arrival volatility.

Forecast performance of the fitted AR (4)-EGARCH (1,1) model was measured by using MAPE, MPE and MAE and the results are shown in Table 10 and all error values are extremely low indicating a higher accuracy of the identified model.

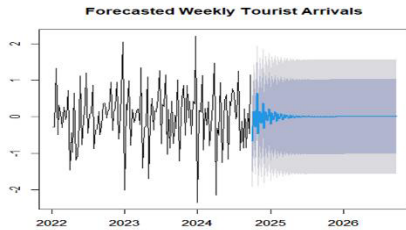


Figure 4: Forecasting Performance of Variance Model

Fig.4 shows the forecasted weekly tourist arrivals from October 2024 to December 2026 using the AR (4)-EGARCH (1,1) model. The AR (4) component captures recent trends, while the EGARCH (1,1) model accounts for volatility and asymmetries in the data. The mean forecast indicates expected arrivals, and the shaded prediction intervals represent the associated uncertainty.

5 CONCLUSION

This study analyzed weekly tourist arrivals in Sri Lanka, revealing a steady increase from 2022 to 2024. After a slow start in 2022 due to COVID-19 and travel restrictions, arrivals began recovering mid-year. In 2023, there were fluctuations, with peaks over 60,000, and by early 2024, arrivals surged past 80,000 before declining. These fluctuations were influenced by global economic conditions, seasonal demand, and natural events, which are important for developing a forecasting model.

Due to the volatility in weekly tourist arrivals in Sri Lanka, a nonlinear parametric model was used for

forecasting. Various univariate nonlinear models were evaluated, and the AR (4)-EGARCH (1,1) model was chosen as the best fit. This model effectively captures volatility, time-varying conditional variance, and errors. The AR (4)-EGARCH (1,1) model demonstrated an accuracy of about 86%, indicating it is a good fit for forecasting tourist arrivals.

REFERENCES

- Kodituwakku, W. H., Wijesundara, W. M. D. M., & Hettiarachchi, C. (2015). *Modelling and Forecasting Tourism Demand for Sri Lanka*.
- Konarasinghe, K. M. U. B. (2020). Forecasting Tourist Arrivals to Sri Lanka: Post-War Period. *International Journal of Novel Research in Physics Chemistry & Mathematics*, 3(June), 57–63.
- Nagendrakumar, N., Lokeshwara, A. A., Gunawardana, S. A. D. C. K., Kodikara, U. P., Rajapaksha, R. W. N. H., & Rathnayake, K. R. M. C. S. (2021). Modelling and Forecasting Tourist Arrivals in Sri Lanka. *SLIIT Business Review*, 01(02), 95–120.
- Shameera, F., Wahid, A., Nadhira, F., Kuddoos, A., & Shafrana, F. (2018). Forecasting Sri Lankan tourist arrivals: a comparative study of Holt- Winter's method versus ARIMA model. 1320–1327.
- Shanika, A. G. S., & Jahufer, A. (2021). Volatility analysis of international tourist arrivals to Sri Lanka using GARCH models. 3, 111–115.



Modeling XAU/USD Gold Price Using Time Series Techniques

De Silva DSM¹, Herath CHMAU¹

Department of Mathematical Sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka
shakyamadhuhani@gmail.com

ABSTRACT

Globally, gold remains a critical financial asset, widely regarded as a safe-haven investment during periods of economic uncertainty, currency fluctuation, and geopolitical tensions. This study was conducted to analyze and model the monthly XAU/USD gold price based on time series analysis. In this study, a symmetric Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model was employed to assess and model the monthly XAU/USD gold price. In the beginning, stationarity of the data was assessed by using the Augmented Dickey-Fuller (ADF) test. Following this, a conditional mean model, ARIMA (0,1,1) was applied to the differenced series. After checking residuals of the ARIMA (0,1,1) model, conditional heteroscedasticity in residuals of fitted ARIMA (0,1,1) model was detected using Autoregressive Conditional Heteroskedasticity Lagrange Multiplier (ARCH LM) test. In response to these findings, a conditional variance model, GARCH (1,1) was developed for forecasting LKR/USD exchange rate volatility. Finally, the ARIMA (0,1,1) -GARCH (1,1) was selected as the best model for volatility forecasting. The accuracy of the model was measured by using Mean Absolute Percentage Error (MAPE), Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) which results resulted in 12.15%, 5.3231 and 3.5475 respectively. However, uncontrollable circumstances like inflation and conflict may cause gold values to change. As a result, traders and investors should also take the previously listed considerations into account.

KEYWORDS: ARIMA, GARCH, MAE, MAPE, RMSE

1 INTRODUCTION

Since gold is regarded as one of the most widely used financial instruments, it serves as an essential indication for investors. Investor expectations and global economic trends are reflected in the price of gold. Therefore, analyzing the closing price of gold is crucial for reducing risk and making wise investing.

f. Significance of the study

Analyzing XAU/USD gold price in global financial markets provides gold's behavior in response to macroeconomic factors such as inflation, interest rates, and geopolitical events. And also, it helps investors, traders and economic

understand its value as a hedge and diversification tool.

g. Objective of the study

The objective of the study is to analyze the behavior of gold price to construct a more appropriate time series model for monthly XAU/USD gold price and evaluate the forecasting performance of the model.

2 LITERATURE REVIEW

In past studies, few researchers have analyzed the gold price and importance of the modeling gold's behavior. They have proposed different modeling methods for forecasting XAU/USD gold prices.

Yean and Maizah (2014) demonstrated the significant causal relationship between gold prices and the USD foreign

exchange rate, by applying a multivariate GARCH model to daily data from 2000 to 2014. This study had shown that incorporating exchange rate fluctuation into gold price models enhances forecasting accuracy.

Lidija et al. (2023) analyzed global gold price trends and volatility using ARCH, GARCH, and E-GARCH models, highlighting the lasting impact of negative shocks on gold yield volatility and the importance of cautious investment strategies in uncertain economies.

Ronald and Neli (2024) found the decomposition-ARIMA (2,1,2) model more accurate than ARCH-GARCH for forecasting gold prices in Indonesia, revealing an upward trend and offering key insights for investors in emerging markets.

The research was done (conducted by) integrating ARIMA-based forecasting into an interactive dashboard, bypassing ARCH/GARCH models due to the absence of ARCH effects in the dataset by Korakot et al. (2023). It also demonstrates the effectiveness of the ARIMA (1,1,1) model for gold price prediction in Thailand.

3 METHODOLOGY

For this study, secondary data of the XAU/USD gold closing price was captured across monthly intervals that were collected from the Internet portal of octafx.com over ten years, from May 2004 to September 2024. The analysis was done by using R software.

A mean model was developed using the Box-Jenkins technique, and the ADF test was employed to confirm the series' stationarity. The ADF test results indicate that the series is not stationary as its t-statistics exceed the crucial value at the

5% significance level. The difference approach is employed to create a trend or seasonally adjusted time series from monthly data, identifying the mean model using ACF and PACF lags. MA terms(q) and AR terms (p) are suggested by significant ACF and PACF lags respectively.

After assessing parameter significance, the model's goodness of fit is evaluated using the Serial Correlation LM test for residual randomness and the Jarque-Bera test for normality.

h. GARCH Model

Bollerslev (1986) developed the GARCH model as a generalization of Engle's ARCH model to better capture time-varying variance in financial data by incorporating lagged conditional variances, though it does not account for asymmetric performance.

The GARCH(p,q) model is defined by,

$$\gamma_t = \mu_t + \varepsilon_t \quad (1)$$

$$\varepsilon_t = z_t \sigma_t \quad (2)$$

$$\sigma_t^2 = w + \sum_{j=1}^p \beta_j \sigma_{t-j}^2 + \sum_{i=1}^q \alpha_i \varepsilon_{t-i}^2 \quad (3)$$

$$z_t \sim (0,1), \varepsilon_t \sim N(0, \sigma_t^2)$$

Where, γ_t is return,

$$w > 0, \alpha_i \geq 0, i = 1, \dots, q, \beta_j \geq 0, j = 1, \dots, p$$

$$\sum_{j=1}^p \beta_j \sigma_{t-j}^2 + \sum_{i=1}^q \alpha_i \varepsilon_{t-i}^2 \quad i < 1 \text{ for ensuring}$$

4 RESULTS AND DISCUSSION

Table 1 depicts descriptive statistics of the monthly gold close price. It shows the maximum and minimum prices are

2592.29 USD and 390.50 USD respectively.

Table 1: Descriptive Statistics of Monthly Gold Price 2004-2024

Mean	SD	Max	Min
1298.12	477.12	2592.29	390.50

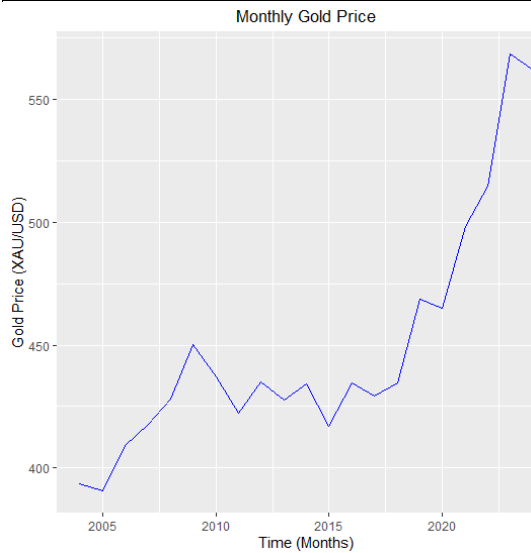


Figure 1: Time series plot

The time series plot, which is displayed in Fig 1, reveals that the monthly gold price series is trending upward. And also, it illustrates that data are not stationary. Within this period, there is a large growth in the gold price seen after January 2020. Numerous domestic and foreign economic, political, and environmental factors contribute to these oscillations.

According to Table 2, the ADF test confirms that the original series is not stationary ($P\text{-value} > 0.05$). After the first order differencing, ADF test reveals that differenced data are stationary ($P\text{-value} < 0.05$). Fig 2 shows ACF and PACF plots for the first differenced series.

Table 2: Augmented Dickey-Fuller test

	Original	Differenced
P-value	0.99	0.01

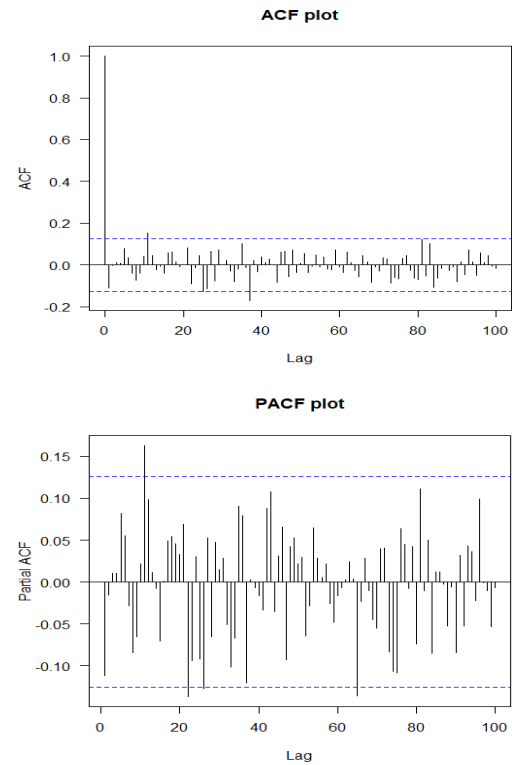


Figure 2: ACF and PACF plots

Fig 2 indicates that $q = 1$ and $p = 0$ are suggested by Significant ACF and PACF, respectively. Based on the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values, ARIMA (0,1,1) is the best model among the suspected models to predict the monthly gold price when all the parameters are significant at their respective significance levels.

The residual diagnostic test results are displayed in Table 3. The results of the ARCH LM test indicate the presence of conditional heteroscedastic behavior and volatility clusters among the residuals. To eliminate this effect, the GARCH model needs to be fitted.

Table 3: Residuals Diagnostic Tests on ARIMA(0,1,1) Model

Test	P-value	Conclusion
Serial correlation LM test	0.1574 > 0.05	Residuals are random
Jarque-Bera test	0.3651 > 0.05	Residuals are normal
ARCH LM test	0.0030 < 0.05	Residuals have volatility

Four GARCH models, GARCH (1,1), GARCH (1,2), GARCH (2,1), and GARCH (2,2) were fitted in this instance. The AIC and BIC values for the aforementioned GARCH models are shown in Table 4. Because it has the lowest value for each of the three information criteria, ARIMA (0,1,1) – GARCH (1,1) was chosen as the best conditional variance model.

. A sign bias test was then used to investigate the asymmetric influence on this model, and the findings are displayed in Table 5. The sign bias test's P-value is more than 0.05. This finding supports the idea that the residuals do not have an asymmetric influence.

Table 4: GARCH(p, q) model related to ARIMA(0,1,1)

Model	AIC	BIC
GARCH(1,1)	11.02908	11.0868
GARCH(1,2)	11.04270	11.11458
GARCH(2,1)	11.03615	11.10802
GARCH(2,2)	11.04438	11.13063

Table 5: Sign Bias Test

	P-value
Sign Bias	0.4227186
Negative Sign Bias	0.4841210
Positive Sign Bias	0.9914034

Table 6: Parameter Estimation of ARIMA(0,1,1)- GARCH(1,1)

	Estimate	Pr(> t)
ma1	-0.024149	0.040978
omega	98.288128	0.011085
alpha1	0.196183	0.007024
beta1	0.832625	0.000000
Gamma1	-0.082874	0.029005

The coefficient probabilities in the mean equation and the variance equation's parameters are all less than 0.05, as shown in Table 6. As a result, every parameter in the fitted model is significant at the 5% level. ARIMA(0,1,1)-GARCH(1,1) was determined to be the best most desirable model by comparing the outcomes.

Normal Q-Q plots of the fitted ARIMA(0,1,1)-GARCH(1,1) are shown in Fig 3. Normal Q-Q plot reveals that residuals are well fitted with the straight line. And also, density plot visualizes the distribution of the residuals very close to bell shape, which means residuals are normally distributed.

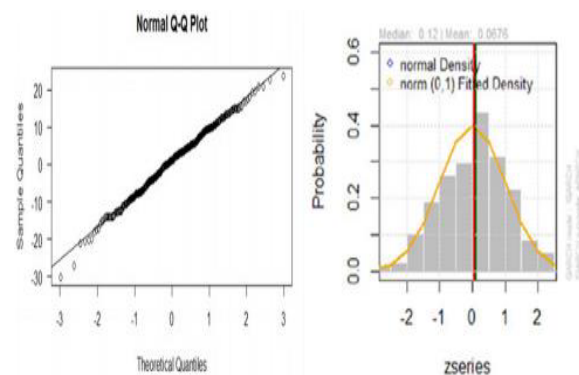
**Figure 3:** Normal Q-Q Plot and Density Plot of Residuals

Table 7: Forecasting Performance

Performance Metrics	Result
MAPE(%)	12.15
RMSE	5.3231
MAE	3.5475

Therefore, the normality of residuals is confirmed by both plots in fig 3. After checking the adequacy of the model, it is proved that the ARIMA(0,1,1)-GARCH(1,1) model is the best for modeling XAU/USD gold price.

The forecast performance of the ARIMA(0,1,1)-GARCH(1,1) model was evaluated using MAPE, RMSE, and MAE, as presented in Table 7. The results indicate very low error values, demonstrating the high accuracy of the identified model for predicting the monthly XAU/USD gold price.

5 CONCLUSION

This study focused on analyzing and modeling the monthly XAU/USD gold price, highlighting a discernible price increase over the ten-year from 2004 to 2024, accompanied by various rising and downward trend patterns. These variations served as the foundation for developing a univariate model to capture the complexities of gold price movements. The study's novelty lies in identifying how inter-market dependencies evolve over time, offering insights into the relationships between gold prices (XAU/USD) and other asset classes, such as cryptocurrencies, oil prices, and equity indexes.

The ARIMA(0,1,1)-GARCH(1,1) model was selected as the most suitable approach for forecasting the monthly XAU/USD gold price due to its ability to capture shifting conditional variance and errors

over time. The model's forecasting performance was validated using MAPE, RMSE, and MAE, yielding values of 12.15%, 5.3231, and 3.5475, respectively. These results confirm that the ARIMA(0,1,1)-GARCH(1,1) model is the best fit for predicting and analyzing the monthly XAU/USD gold price.

REFERENCES

- Ahmad, Maizah and Pung. (2014). Modelling world gold prices and USD foreign exchange relationship using multivariate GARCH model. *AIP Conference Proceedings*. 1635. 849-853. 10.1063/1.4903682.
- Bollerslev, T. (1986). Generalized autoregressive conditional heteroskedasticity. *Journal of Econometrics*, 31(3), 307-327.
- Borjana, M., Dušica, K., and Lidija, M. (2023). Modelling the volatility of the global gold price by applying the ARCH/GARCH models. *Ekonomika*. 69. 23-34. 10.5937/ekonomika2302023M.
- Chidchanok, C., Korakot, J., and Sureena, M. (2023). Utilization of various time series models forecasting gold prices in Thailand. *Science, Engineering and Health Studies*. 17. 23020007.10.69598/sehs.17.23020007.
- Ronald, H., and Neli, A. (2024). A Comparative Analysis of ARCH/GARCH and Decomposition-ARIMA Models for Gold Price Forecasting in Indonesia. *InPrime: Indonesian Journal of Pure and Applied Mathematics*. 6. 158-171. 10.15408/inprime.v6i2.40249.



Regression-Based Imputation on Missing Values in Annual Survey of Industries Data

Dhanushika MS¹, Panahatipola PMOP¹

Department of Mathematical Sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka
sawanid42@gmail.com

ABSTRACT

Missing data is invertible in surveys, and it is crucial to handle them appropriately for accurate statistical findings. Particularly in surveys, when data are missing for specific subgroups, the findings may not be generalizable to the entire population. Missing values are also invertible in the Annual Survey of Industries (ASI) because survey mode (e.g. e-mail, telephone), misplacement of manual data records, answering only a few questions, and etc. To address imputation, the post-stratification, substitution, and hot-deck imputation along with mean and median imputation are some of the imputation techniques in statistical analysis. However, unlike aforementioned methods, the regression-based imputation addresses the relationship between the missing variable and the other independent variables to provide accurate imputations. Accordingly, the production moved out in ASI also depends on some other variables within the dataset. Therefore, based on the data availability for performing regression analysis, regression models with logarithmic transformation for two important economic activities in the Manufacture industry; ISIC 105 - Manufacture of Dairy Products, and ISIC 131 - Spinning Weaving and Finishing of Textiles has developed using ASI data for 2019, with 5 and 4 independent variables respectively, serving the production moving out as the dependent variable. The obtained models from stepwise regression suggests 79.99% and 52.65% of the variability of logarithmic production moved out in ISIC 105 and ISIC 131 respectively. Performing the paired t-test resulted in the reliability of the regression-based imputed values.

KEYWORDS: Imputation, Missing Values, Regression, Survey, Transformation

1 INTRODUCTION

Annual Survey of Industries (ASI) is one of the most important and oldest surveys conducted by the Department of Census and Statistics (DCS), Sri Lanka since 1979, covering a sample of industrial establishments which engage five or more persons throughout the country. The indicators of the industrial sector, including value-added, output, intermediate consumption, and employment, are calculated through ASI (Department of Census & Statistics, 2019). This is an indicative of the present economic state of the country, since it is providing indicators on the performance and the structure of the industrial sector,

and updating the existing list of industrial establishments classified under the (i) manufacturing, (ii) mining and quarrying, (iii) electricity, gas, steam and air conditioning supply, and (iv) water supply, sewerage, waste management and remediation activities. The results in ASI report are presented under the International Standard Industrial Classification (ISIC) 2-digit code level and 3-digit code level.

However, Missing data is inevitable in surveys, and it is crucial to handle them appropriately for accurate statistical findings (Hu & Salvucci, 2001). In ASI, missing data poses a significant challenge, particularly with variables like total

production moved out of the establishment, the value of own accounts fixed assets, and total salary and wages, which frequently have missing values due to the fact that not having data records in some industries, misplacement of manual data records, answering only a few questions, not giving accurate and correct values due to taxes, difficulties in contacting industries, and survey mode (e.g e-mail, telephone).

DCS currently uses post-stratification, substitution, and hot-deck imputation methods to address this issue. However, production moved out is one of the variables depend on some other factors within the dataset, and fails to provide more accurate and reflective values from the aforementioned imputation methods. Accordingly, regression imputation would be an effective imputation method for addressing this gap, since it addresses the relationship between other factors also. However, the DCS has not yet implemented a regression based imputation, and therefore, the main objective of this study was to develop regression models for impute missing values on total production moved out of the establishment in ASI within the economic activities Spinning weaving and finishing of textiles, and Manufacture of dairy products, to have a more accurate and reflective value for missing variable, and to determine the reliability of this method for other missing variables in remaining categories. While answering the main objective, to determine the reliability of the regression imputed data came across as another objective.

2 LITERATURE REVIEW

Kromrey and Hines (1994) examined the best imputation method using the deletion method (both listwise and pairwise), deterministic imputation (based on the sample mean, simple regression and multiple regression), stochastic imputation (mean, simple regression and multiple regression), maximum likelihood estimation and multiple imputation. Stochastic multiple regression imputation has been concluded as the most effective imputation method.

Fetter (2001) has concluded that the Regression with Empirical Residual method provides better accuracy for estimates than the Markov Chain Monte Carlo Multiple Imputation method according to the evaluation of a dataset with 60% of missing data.

West et al. (2001) have employed imputation methods including Mean, Hot-Deck (Random Selection and Nearest Neighbor), Regression, Bayesian, Multiple, and their imputation method called ES-202, on three SIC groups and three sample designs based on employment class size of Employment Statistics Survey of establishments. The regression imputation method has been concluded superior to other methods compared with Mean Error (ME) and Mean Absolute Error (MAE).

Annas et al. (2021) has explored the importance of minimizing missing values in datasets for accuracy by employing two scenarios of the amount of missing values: 10% and 15% within the same dataset. The findings conclude that, when the percentage of missing values are increasing increases, the degrading model performance by decreasing R^2 and increasing MSE value.

Bernaards and Farmer (2021) has focused imputation on a cancer screening survey and endorsed the application of either of two multiple imputation methods: a combination of hot deck and regression imputation, or multivariate normal multiple imputation is satisfactory, since these both appear to give similar results.

Mirzaei et al. (2022) discussed the three categories of missing data according to the degree of randomness: Missing at Random (MAR) is when the missing data depends on another observed data and not unobserved data, Missing Completely at Random (MCAR) or ignorable missingness is when a missing value has no relationship between any other value in the dataset, and Missing Not at Random (MNAR) or non-ignorable missingness is satisfied when an unobservable factor directly affecting a data point is missing.

3 METHODOLOGY

3.1 Data Collection

Secondary data of ASI 2020, based on the reference year 2019, was collected from, DCS, Battaramulla, Sri Lanka. Two ISIC categories in ASI; (i) ISIC 105 - Manufacture of Dairy Products, and (ii) ISIC 131 - Spinning Weaving and Finishing of Textiles were used for the analysis, Production Moved out (PMO) serving as the dependent variable, since it depends on some other variables within the dataset and it is one of the most important variable for major calculations. Independent variables were selected based on their availability, which were measured by Sri Lankan Rupee, LKR, except PE. The available data for each category was 32 and 65, respectively. The cost of electricity (ELCC), cost of raw materials (RMC), cost of packing

materials (PMC), transport cost (TRC), and total number of persons engaged (PE) are serving as the independent variables in ISIC 105, while ELCC, RMC, PE, and value of machine depreciation during the year (MDP) were used in ISIC 131.

3.2 Data Analysis

The multiple regression analysis was used as the primary statistical technique using R 4.3.1, and adopted significance level for this study was 5%. As the first step, the z-score scaling (or standardization) has done on independent variables in both categories to bring them all to a the same scale. The stepwise regression was done in order to obtain the best fitted model based on the lowest AIC values. However, since the residuals fail to satisfy the normality assumptions, the logarithmic transformation has done only on the dependent variable and rechecked the regression assumptions; (i) normality of residuals, (ii) randomness of residuals, (iii) homogeneity of residual variance, (iv) serial correlation of residuals, and (v) no multi-collinearity, to obtain the best fitted model. As the last step, the paired t test done on 30% proportion of each sample to determine the significance difference between actual and regression based imputed values. By validating these models through diagnostic checks and paired t-test, this imputation technique can be suggested for other missing variables in the remaining categories in ASI.

4 RESULTS AND DISCUSSION

According to the initial stepwise regression on ISIC 105, the model $PMO \sim RMC + TRC + PMC + PE + ELCC$ has remained with the lowest AIC of 1151.27, while the model $PMO \sim RMC + PE + ELCC$ has remained for ISIC 131.

However, the logarithmic transformation has done on the dependent variable in both categories since the residuals were not normally distributed according to the Shapiro-wilk test (p-value for ISIC 105 = 6.657e-05 and p-value for ISIC 131 = 3.251e-11).

Table 1: Coefficients of logarithmic transformed model of ISIC 105

Data	Estimated coefficient	p-value
(Intercept)	17.8184	<2e-16***
PE	1.0737	0.0004***
RMC	0.7127	0.0033**
PMC	0.4766	0.0711.

Table 2: Coefficients of logarithmic transformed model of ISIC 131

Data	Estimated coefficient	p-value
(Intercept)	17.0417	<2e-16***
PE	2.5789	6.69e-07***
MDP	-1.7428	0.0005**
ELCC	0.8025	0.0349*

Primarily, significance of coefficients of logarithmic transformation model has been checked. P-value of intercept, PE and RMC in **Table 1**, and all p-values in **Table 2** are less than 0.05. Therefore, it can be concluded that those parameters are statistically significant. P-value of PMC in **Table 1**, lies between 0.1 and 0.05, indicating that it is marginally significant.

The obtained p-value for the model for ISIC 105 is < 2.924e-10, and for ISIC 131 is 5.82e-10. Therefore, both models were statistically significant.

The residuals indicates a normal distribution in Shapiro-wilk test for both ISIC 105 and ISIC 131 (p = 0.7556 and p = 0.1408, respectively), and residuals are

randomly distributed according to the runs test for both ISIC 105 and ISIC 131 (p = 1.0000 and p = 0.6143, respectively). The Breusch-Pagan test with p = 0.6336 and p = 0.0893 for ISIC 105 and ISIC 131, respectively indicates the residuals are assumed to have constant variance.

Table 3: VIF values for ISIC 105

Parameter	PE	RMC	PMC
VIF value	2.2198	1.5143	1.9759

Table 4: VIF values for ISIC 131

Parameter	PE	MDP	ELCC
VIF value	4.0722	4.2828	2.6027

The models for both categories show no evidence that residuals are linearly auto-correlated, according to the Durbin Watson test with D-W statistics = 2.0770, p = 0.8760, and D-W statistics = 2.0297, p = 0.9340 for ISIC 105 and ISIC 131, respectively. To identify potential multicollinearity issues, Variance Inflation Factor (VIF) values were computed for all independent variables as shown in **Table 3** and **Table 4**. Therefore, it can be concluded that, there is no high multi-collinearity exists in models, since the VIF values of variables in both models are between 1 and 5. The results from the statistical tests for assumptions confirmed that all are satisfied.

In comparison with the actual values and predicted values, the paired t test confirmed that there is no significant difference between the actual value and predicted value resulting p = 0.4901 and p = 0.3271 for ISIC 105 and ISIC 131 respectively in 95% confidence interval.

5 CONCLUSION

All the independent variables are in terms of standard deviation from the mean according to the z-score scaling.

The estimated regression model equation for ISIC 105 is given by,

$$\log(\text{PMO}) = 17.8184 + 1.0737 \times \text{PE}_{\text{Scaled}} + 0.7127 \times \text{RMC}_{\text{Scaled}} + 0.4766 \times \text{PMC}_{\text{Scaled}} \quad (1)$$

This logarithmic transformation resulted in a better fit to the data, with R^2 value of 0.7999 suggesting 79.99% of variability of logarithmic production moved out in manufacture of dairy products category is explained by the above regression model. The coefficient of $\text{PE}_{\text{Scaled}}$ represents, a one standard deviation increase in PE, the PMO would increase by a factor of $e^{1.0737}$, holding other independent variables constant. Here, the standard deviation of PE is 86.14. Therefore, if PE increases by 86 units, the PMO would increase by a factor of $e^{1.0737}$ or approximately 2.923 times, holding other variables constant.

The estimated regression model for the ISIC 131 is as follows, with R^2 value of 0.5265 suggesting 52.65% of variability of logarithmic production moved out in manufacture of spinning weaving and finishing of textiles category is explained by the following model,

$$\log(\text{PMO}) = 17.0417 + 2.5789 \times \text{PE}_{\text{Scaled}} - 1.7428 \times \text{MDP}_{\text{Scaled}} + 0.8025 \times \text{ELCC}_{\text{Scaled}} \quad (2)$$

In addition, the paired t-test on both categories suggested that there is no significant difference between the actual and regression predicted values in both categories. Therefore, this regression based imputation is an effective approach to addressing the missing values in production moved out in ISIC 105 and ISIC 131 categories. Typically, other ISIC 3-digit categories consist of a small number of data for each within ASI dataset. Therefore, regression imputation

would be an effective method for imputing PMO as well as other variables in other economic categories in ASI. Moreover, it maintains the correlation of the variable, addressing the common challenges like complexity and loss of variability. Also, it can streamline the process, saving time.

Furthermore, to conclude the best imputation method, the comparison of regression imputation with currently using used methods in DCS will be carried out as future research works.

REFERENCES

- Annas, S., Kartikasari, P., and Arisandi, R. (2021). Handling Incomplete Data with Regression Imputation. *Journal of Physics: Conference Series*, 1752(1).
- Bernaards, C. A., and Farmer, M. M. (2021). Comparison of Two Multiple Imputation Procedures in a Cancer Screening Survey. *Journal of Data Science*, 1(3), 293-312.
- Department of Census & Statistics. (2019). 2019 Annual Survey of Industries.
- Fetter, M. (2001). Mass Imputation of Agricultural Economic Data Missing by Design A Simulation Study of Two Regression Based Techniques.
- Hu, M., and Salvucci, S. (2001). A Study of Imputation Algorithms. *Working Paper 2001-17*.
- Kromrey, J. D., and Hines, C. V. (1994). Nonrandomly missing data in multiple regression: An empirical comparison of common missing-data treatments. *Educational and Psychological Measurement*, 54(3), 573-593.
- Mirzaei, A., Carter, S. R., Patanwala, A. E., and Schneider, C. R. (2022). Missing data in surveys: Key concepts, approaches, and applications. *Research in Social and Administrative Pharmacy*, 18(2), 2308-2316.
- West, S., Butani, S., Witt, M., and Adlans, C. (2001). Alternative Imputation Methods for Employment Data. In *Proceedings of the American Statistical Association, Section on Survey Research Methods*, (pp. 227-232).



Risk Scoring for Loan Default Probability Using Gradient Boosting Machines Techniques

Tharushika DDH¹, Napagoda NADN¹

Department of Mathematical Sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka
tharushikadampahala71@gmail.com

ABSTRACT

Risk scoring is considered as an important feature of financial organizations, particularly in loan management, because it enables institutions to predict the risk of loan default. Our research focuses on forecasting loan risk scores based on borrowers' personal and financial attributes. The dataset, consisting of 17 variables and over 2,000 observations, is provided by a financial organization in Sri Lanka that is regulated by the Central Bank of Sri Lanka. An accurate risk scoring prediction model is created using Gradient Boosting approaches including eXtreme Gradient Boosting (XGBoost), Light Gradient Boosting (LightGBM), and CatBoost. The models are evaluated using Root Mean Squared Error (RMSE) and R-Squared (R^2 score). The LightGBM model outperformed others, identifying key factors influencing loan risk scores, including interest rate, total assets, credit score, debt-to-income ratio, and credit card utilization. Default risks can be reduced by financial institutions through the implementation of real-time forecasts that allow for proactive decision-making, risk-based pricing strategies that match interest rates to borrower risk profiles, and comprehensive borrower education programs that improve financial literacy and responsible borrowing behavior. Possible defaulters can also be detected and timely assistance can be provided through targeted mitigation techniques, such as early involvement programs, personalized repayment plans, and improved credit monitoring. Default rates can be effectively minimized, possible losses can be mitigated, and overall case stability can be increased by combining these techniques, all while long-term customer relationships are refined.

KEYWORDS: CatBoost, eXtreme Gradient Boosting, Light Gradient Boosting, Risk Score

1 INTRODUCTION

Loan scoring is a method used to determine a borrower's reliability by characteristics such as financial history, income, credit behavior, debt-to-income ratio, and employment status. This score provides a measurable indicator of the borrower's ability and willingness to repay the loan, enabling better decisions to be made by financial institutions regarding loan approvals, interest rates, and repayment schedules.

A significant amount of data is needed to generate a risk score, involving the use of big data analytical techniques. The use of data mining is required for identifying relationships between borrower-related

information and the risk score, leading to more accurate risk valuations and informed decision-making.

The impact of borrower-related features, including Age, Annual Income, Credit Score, Employment Status, Loan Amount, Loan Duration, Marital Status, Monthly Debt Payments, Credit Card Utilization Rate, Loan Purpose, Savings Account Balance, Total Assets, Total Liabilities, Monthly Income, Interest Rate, Monthly Loan Payment, and Total Debt To Income Ratio, is examined in the analysis of risk score prediction, using over 2,000 observations. An accurate understanding of how these variables affect the forecast of a borrower's risk

score is enabled by our comprehensive approach.

The risk score is forecasted using Gradient Boosting Machine (GBM) approaches since complicated, nonlinear relationships in data are excelled at handling by GBMs. A comparison is made amongst GBM approaches, including eXtreme Gradient Boosting (XGBoost), Light Gradient Boosting (LightGBM), and CatBoost, to determine which has the most accuracy and performance for predicting risk ratings. These models are recognized for their dependability, efficiency, and ability to improve forecast accuracy through continuous learning.

Considerable insights are provided by this study into the most important borrower-related factors influencing risk score prediction, allowing financial institutions to make better decisions. Financial institutions can be assisted in optimizing their lending strategies, reducing the risk of default, and ensuring better loan terms for borrowers based on their unique features.

2 LITERATURE REVIEW

This section discusses many previous studies on forecasting risk scores and loan defaults. The use of a variety of techniques, from traditional statistical methods to more modern machine learning algorithms, is explored to forecast loan defaults and risk scores.

Coşer et al. (2019) created prediction models for loan default risk utilizing Light Gradient Boosting, eXtreme Gradient Boosting, Logistic Regression, and Random Forest. The Random Forest model performed better than others, with an Area under the Curve

(AUC) of 0.89. According to the findings, customers at risk of default had higher interest rates and lower incomes.

Odegua (2018) used the XGBoost algorithm to predict loan defaults, using data from a major bank. The findings identified client geography and age as important factors of loan default. The study emphasized the need for robust predictive algorithms to handle increasing loan defaults.

Carmona et al. (2019) employed eXtreme Gradient Boosting to predict bank failures in the United States banking industry. Significant indicators including retained earnings, pretax returned on assets, and risk-based capital ratio had been shown to foreshadow bank difficulty. The XGBoost model achieved 95% prediction accuracy, surpassing Logistic Regression and Random Forest. Limitations included the exclusion of state banks and the possibility of expanding the study to include European banks for further insights.

Madaan et al. (2021) compared Decision Trees to Random Forest models for loan default prediction. Researchers discovered that Random Forests outperformed choice trees, with 80% accuracy. One constraint was the minimal number of loan defaults in the sample.

Xu et al. (2021) employed machine learned methods Random Forest, Neural Networks, and Gradient Boosting methods to forecast loan defaults in China's peer-to-peer lending sector. Researchers discovered that borrower verification criteria such as mobile phone, video, and income influenced repayment behavior, with Random Forest performing the best.

Our study uses a combination of eXtreme Gradient Boosting (XGBoost), Light Gradient Boosting (LightGBM), and CatBoost to improve the accuracy and robustness of loan default risk prediction models, unlike previous studies. By adding a number of variables, the study aims to enhance model accuracy and provide valuable findings for better risk assessment solutions that are more accurate and accessible.

3 METHODOLOGY

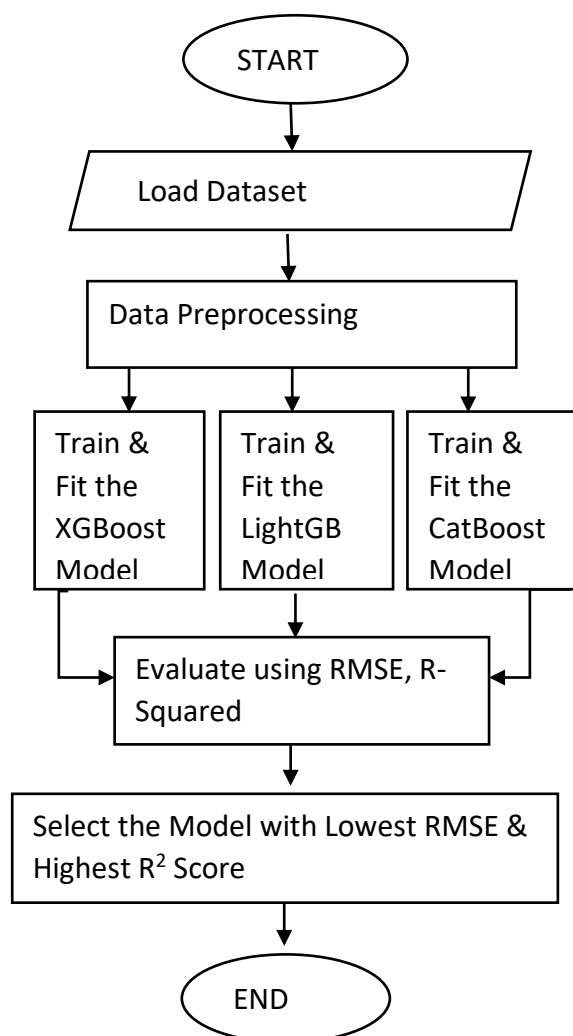


Figure 1: A flow diagram of the methodology

The dataset, consisting of 17 variables and over 2,000 observations, is provided by a financial organization in Sri Lanka

that is regulated by the Central Bank of Sri Lanka. A flow diagram of the methodology is shown by the Fig 1. The research is initiated with data preprocessing, which involved the conversion of categorical variables to numerical formats, standardization of features using the Standard Scaler methodology, handling missing values, and addressing outliers with the Interquartile Range (IQR) method.

Three advanced Gradient Boosting models, are trained and fitted. XGBoost is chosen due to its efficiency, capacity to manage missing values, and robust performance on big datasets. LightGBM enabled faster training and lower memory utilization, whilst CatBoost excelled at handling categorical features and minimizing overfitting. Hyperparameters are tuned and model performance is improved using Grid Search Cross-Validation (GridSearchCV).

Root Mean Squared Error (RMSE) and R-Squared (R^2 scores) are used for models evaluation. A feature importance analysis is used to determine the most significant variables that are influenced by loan risk.

4 RESULTS AND DISCUSSION

The risk score for loans is aimed at being predicted by a dataset comprising 17 independent variables. This includes 14 numerical variables: Age, Annual Income, Credit Score, Loan Amount, Loan Duration, Monthly Debt Payments, Credit Card Utilization Rate, Savings Account Balance, Total Assets, Total Liabilities, Monthly Income, Interest Rate, Monthly Loan Payment, and Total Debt-to-Income Ratio. Additionally, there are 3 categorical variables: Employment

Status, Loan Purpose, and Marital Status. A total of 2,191 instances are contained within the dataset.

As an initial step, the category variables employment status, loan purpose, and marital status are transformed to numerical form. The data is standardized with StandardScaler, and outliers identified using the Inter Quartile Range method. After the removal of outliers, the dataset is reduced to 1,154 occurrences. Finally, the dataset is divided into training and testing sets using 0.2 ratio.

The XGB model is fitted using the optimal parameters. The average prediction error between expected and actual values is 5.309. The model explanations for 88.05% of the variation in the data, denoted by the R-squared value of 0.8805. In Fig 2, a feature importance plot indicates that monthly income, total debt to income ratio, interest rate, credit score, and annual income are identified as the most significant variables for predicting loan risk.

The LightGB model is trained, and the optimal parameters are found using GridSearchCV. A relatively low average prediction error between expected and actual data is indicated by the RMSE score of 0.2873. The model's ability to explain 96.58% of the total variation is demonstrated by the R-squared. In Fig 3, the feature importance plot showed that the most significant variables for forecasting loan risk are interest rate, total assets, credit score, total debt to income ratio, and credit card utilization ratio.

The CatBoost model is trained and the optimal parameters are discovered using GridSearchCV. The model is fitted using

the optimal parameters. The RMSE score of 5.409 shows an average prediction error between the expected and actual values. The R-squared of 0.7568 indicates that 75.68% of the variance in the data is explained by the model. It is shown in Fig 4, the feature importance plot, that the most important variables for predicting loan risk are total debt to income ratio, interest rate, monthly income, total assets, and credit score.

Table 1: Summary of the three models

Model	RMSE	R-Squared (%)
XGB	5.309	88.05
LightGB	0.2873	96.58
CatBoost	5.409	75.68

Table 1 summarizes the results of the three models. According to the findings, the best accurate forecasts for the risk score are delivered by the Light Gradient Boosting model, which has the lowest RMSE and the greatest R-squared score. Therefore, the most significant variables for forecasting loan risk are concluded to be interest rate, total assets, credit score, total debt to income ratio, and credit card utilization ratio.

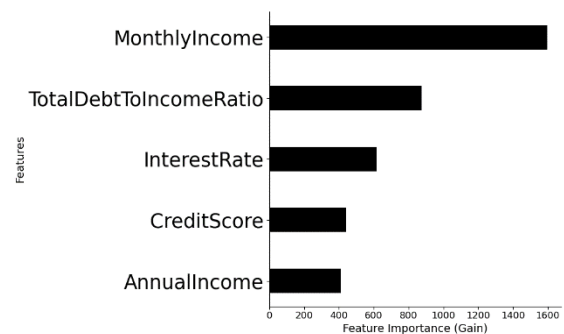


Figure 2: Feature importance plot of XGB model

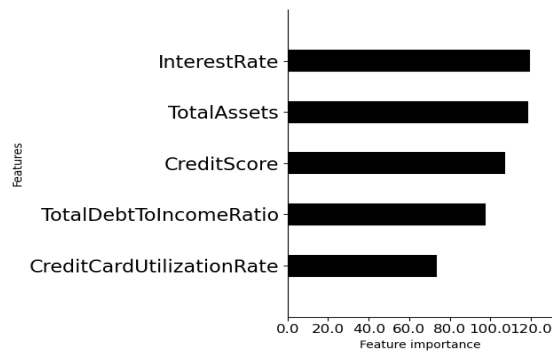


Figure 3: Feature importance plot of LightGB model

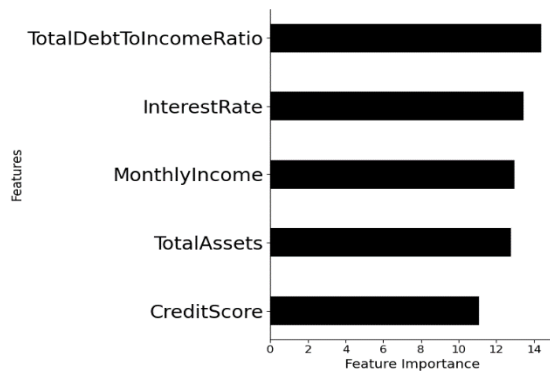


Figure 4: Feature importance plot of CatBoosting model

5 CONCLUSION

The prediction of loan risk scores using borrower-related variables from a dataset provided by a Sri Lankan financial organization is the focus of the study. Prediction models are created using three distinct Gradient Boosting approaches, with findings indicating that Light Gradient Boosting is found to be more accurate than eXtreme Gradient Boosting and CatBoosting. The most significant factors affecting the loan risk score are identified as the interest rate, total assets, credit score, total debt-to-income ratio, and credit card utilization ratio. Financial institutions should focus on key variables: interest rate, credit score, and debt-to-income ratio for accurate loan risk assessment. Using advanced models like

LightGBM, along with strategies like risk-based pricing and borrower education, can help reduce default risks and improve operational efficiency. Regular model updates and regulatory alignment will further enhance decision-making.

REFERENCES

- Carmona, P., Climent, F., and Momparler, A. (2019). Predicting failure in the US banking sector: An extreme gradient boosting approach. *International Review of Economics & Finance*, 61, 304-323.
- Coşer, A., Maer-Matei, M. M., and Albu, C. (2019). Predictive models for loan default risk assessment. *Economic Computation & Economic Cybernetics Studies & Research*, 53(2).
- Madaan, M., Kumar, A., Keshri, C., Jain, R., and Nagrath, P. (2021). Loan default prediction using decision trees and random forest: A comparative study. In *IOP conference series: materials science and engineering*.
- Odegua, R. (2020). Predicting bank loan default with extreme gradient boosting. *arXiv preprint arXiv:2002.02011*.
- Xu, J., Lu, Z., and Xie, Y. (2021). Loan default prediction of Chinese P2P market: a machine learning methodology. *Scientific Reports*, 11(1), 18759.



The Best Approach to Identifying the Factors Affecting Load Cell Quality Scores: A Case Study

Srimali KS¹, Appuhamy PADAN¹

Department of Mathematical Sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka
sitharasrimali28@gmail.com

ABSTRACT

A load cell is a device that measures force by converting mechanical force into an electrical signal, making it essential for accurate force and weight measurements in industries such as aerospace, agriculture, oil and gas, and biotechnology. However, challenges in the production process result in failure to meet quality standards, leading to high failure rates, rework, and increased costs. This study focuses on identifying the factors influencing the quality scores of load cells manufactured for the oil drilling industry. Data were collected from ABC (Pvt) Ltd on load cells produced between January and June 2024. The dataset included quality scores and variables such as process temperature, process pressure, oven tests, product elasticity, metal type, and product volume. Two modeling approaches, Multiple Linear Regression (MLR) and Random Forest (RF), were evaluated to identify the key factors influencing quality. Residual analysis evaluated the adequacy of the MLR model, while a grid search optimized the RF model's hyperparameters. The models were compared using Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), Root Mean Squared Error (RMSE), and R^2 value to select the best. Results revealed that nearly 50% of the load cells produced during this period did not meet the expected quality standards. The RF model outperformed MLR, achieving an MAE of 4.12, a MAPE of 5.23, an RMSE of 6.00, and an R^2 of 85.55%. Process temperature was identified as the most significant factor affecting load cell quality, followed by process pressure. These insights provide valuable guidance for improving production quality.

KEYWORDS: Efficiency, Load Cell, Measurement, Standard Quality.

1 INTRODUCTION

A load cell is a transducer designed to measure force or load by converting mechanical forces, such as weight or pressure, into an electrical signal that can be quantified and recorded. The success of the load cell industry heavily depends on the quality of its production, which impacts an organization's reputation and efficiency. ABC LoadCell Manufacturing Company is a reputable commercial entity in Sri Lanka that distributes its products to over 11 countries worldwide. They produce load cells for a diverse range of industries, including aerospace, industrial

automation, oil drilling, and biotechnology. Although ABC is known for its high-quality products, it is currently facing a critical issue related to specific load cell type failing to meet the accuracy standards of the company. This leads to quality deviations, resulting in rejections and costly rework. Identifying the key factors influencing load cell quality scores is essential to address these production challenges and help mitigate the problem by controlling these factors. The primary objective of the study is to identify the key factors influencing load cell quality scores at the maximum load applied, with a specific focus on developing Statistical

and Machine Learning (ML) models using production variables and selecting the best-performing model to highlight the most significant factors affecting load cell quality.

2 LITERATURE REVIEW

This section summarized the literature related to the load cell industry and models established, using various techniques in the manufacturing industry. Smith et al. (2020) examined the factors affecting load cell performance through theoretical analysis and experimental investigations, utilizing finite element analysis (FEA) to model load cell behavior under various loading and environmental conditions. Their findings suggested key design improvements to enhance load cell accuracy and reliability. Kamble et al. (2020) offer a detailed review of load cells, focusing on their various types and applications. They analyzed existing literature and conducted experiments on different load cell types, including strain gauge, hydraulic, and pneumatic load cells. Their study specifically tested strain gauge load cells under varying load conditions to evaluate their accuracy and reliability in real-world use. Moreover, John et al. (2020) investigated return-to-zero error in resistance strain load cells and its effect on measurement accuracy. Through experimental testing and data analysis, they identified hysteresis as the main cause of the error. The study suggested using better materials and refining manufacturing processes to minimize this error and improve accuracy.

Although there are no ML models for load cell quality, researchers have created ML models to predict the quality of other

different products. Tebrizcik et al. (2023) analyzed the production process of surgical masks, employing various ML techniques, including Random Forest and AdaBoost M1, to predict defect rates. Feature selection analysis improved model performance, with the Ibk algorithm achieving the highest accuracy of 92.3%. Similarly, Şanlıtürk applied Random Forest, Naive Bayes, SVM, and K-Nearest Neighbor methods to predict defects during the powder coating phase of washing machine production, finding that Random Forest performed best after scaling (2018). Zhang et al. (2020) developed a model to predict defect counts in steel production, using Partial Dependency Analysis and identified that the operator experience as a key factor. The study found that Random Forest provided the most accurate predictions, outperforming other models like SVM and Poisson Regression.

Although several experimental studies on load cells and their accuracy are available in the literature, there is a lack of research applying statistical and machine learning models to identify the production variables that significantly impact the quality score of a load cell at maximum load applied. This study seeks to address this gap and provide insights to help mitigate the company's challenges.

3 METHODOLOGY

a. Data Description

The secondary data was collected from ABC (Pvt) Ltd over six-month period, from January to June 2024. All the data collected by the company, consisted of six independent variables viz. Process Temperature (°C), Process Pressure (kPa), number of oven tests, Product Elasticity

(mV/V), Metal Type (steel or aluminum), and Product Volume (cm³) along with a dependent variable, the Quality Score of a specific load cell, measured as the percentage of accuracy at the maximum applied load, were used.

b. Data Analysis

The main objective of this research was to identify the factors that contribute most to the quality score of this specific type of load cell when the maximum load is applied. Initially, descriptive statistics of the quality score were obtained to observe variations and provide a description of product failures during the study period. The Pearson correlation coefficient was calculated to assess the linear relationship between the dependent variable and each independent variable.

Multiple Linear Regression (MLR) and Random Forest (RF) models were developed to identify the best-performing model for determining the contributing factors. As the first step in constructing the MLR model, the data was divided into two subsets: 80% for training and 20% for testing purposes. The stepwise regression technique was applied, and the significance of the parameters was tested at the 5% level. Subsequently, residual analysis was performed to validate the model assumptions, including the normality, homogeneity, and independence of residuals. Additionally, Variance Inflation Factor (VIF) values were calculated to check for multicollinearity among the independent variables. A log transformation of the quality score was applied when at least one of the assumptions mentioned was not met. The Random Forest (RF) model was developed as the second approach to capture complex non-linear relationships

between the independent variables and the quality score. This model was implemented using Google Colaboratory within the TensorFlow environment. Pre-processing steps included Standardization and one-hot encoding for categorical variables.. Similar to the MLR model, the dataset was split into two subsets: 80% for training and same 20% of data for testing. During training, grid search and cross-validation techniques were employed to fine-tune the RF model for optimal performance. The feature importance of the best-performing RF model was also done. To evaluate the performance of both models, metrics such as Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), Root Mean Squared Error (RMSE), and the Coefficient of Determination (R²) were calculated. These metrics were compared to select the best performing model and to identify the critical factors influencing the quality score based on the best selected model.

4 RESULTS AND DISCUSSION

The analysis of descriptive statistics showed that out of 3,238 load cells, 1,595 fell below the expected quality score, with some requiring rework and others being rejected. This means that nearly 50% of the load cells produced during the study period failed to meet the desired quality standards. Pearson correlation analysis showed a moderate negative linear relationship between the quality score and both process temperature (-0.53) and process pressure (-0.47). In contrast, a moderate positive linear relationship was observed between the quality score and product elasticity (0.45).

Due to violations of the normality and constant variance assumptions in the residuals of the MLR model, a log

transformation of the quality score was applied for modeling. The summary of the regression model with the lowest AIC value fitted to the log-transformed data is provided in Table 1 below. According to Table 1, it can be seen that process temperature, product elasticity, process pressure, metal type, and the number of oven tests are significant at the 5% level, as their p-values are less than 0.05.

This indicates that these independent variables significantly affect the quality score of the load cells. Moreover, process temperature, the number of oven tests, and process pressure are negatively related to the quality score of the load cells, while product elasticity and metal type (aluminum) have a positive impact on the quality score. The R^2 value of the model was 0.4963, meaning that around 50% of the variations in the quality score of the load cells can be explained by this linear regression model.

Fig. 1 presents residual plots used to assess the model assumptions. The Q-Q plot of the residuals in Fig. 1 shows that the points closely align with the diagonal line, suggesting that the residuals follow a normal distribution. Additionally, the residual vs. fitted plot demonstrates constant variance, with the residuals scattered around zero without any discernible trend or pattern. The Durbin-Watson test yielded a p-value of 0.7766, which is greater than 0.05, indicating no significant autocorrelation, thus confirming that the residuals are independent. Finally, based on the VIF values, it was concluded that there is no multicollinearity, as the VIF for each predictor variable was below 5. The results above suggest that the model meets

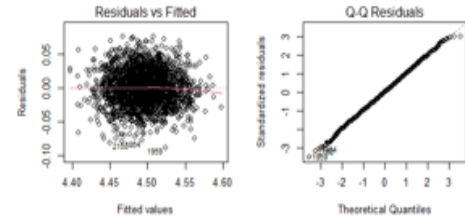


Figure 1: Residual plots of MRL model

all the assumptions and can be regarded as an adequate linear model for the quality score of the load cells, explaining the variations in the quality score moderately, represented by the following equation (1).

$$\begin{aligned} \text{Log } Y = & 5.058 - 0.008 \text{ p.tepm} - 0.006 \text{ oven test} \\ & + 0.024 \text{ elasticity} - 0.002 \text{ p.pressure} \\ & + 0.009 \text{ metal type} \end{aligned} \quad (1)$$

The results of the RF model showed that the model possesses a high R-squared value (relative to the MLR) of 0.8555. This means the model explains around 85% of the variation in the quality score of the load cells. The feature importance analysis indicated that process temperature is the most significant factor, with a feature importance score of 0.5771, followed by process pressure and product elasticity.

Table 1: The summary of the Multiple Linear Regression model

Variable name	Estimate	Std. Error	P value
(Intercept)	5.058	0.138	< 2e-16
P. temp	-0.008	0.000	< 2e-16
Oven test Count	-0.006	0.001	0.000
Elasticity	0.024	0.002	< 2e-16
P. pressure	-0.002	0.000	0.000
Metal Type	0.009	0.003	0.001

Table 2: Comparison of model performance

	Log-Transformed MLR	RF
R ²	49.63%	85.55%
MAE	6.45	4.12
RMSE	6.567	6.00
MAPE	6.31%	5.23%

Finally, both the log-transformed MLR and RF models were compared based on their predictive performance using the testing data. The results are shown in the above Table 2. According to the Table 2, the RF model had lower error statistics than that of the MLR model. Additionally, the high R-squared value for the RF model highlights its capability to capture underlying patterns in the data, including potential nonlinearities, in contrast to the MLR model. Therefore, it can be concluded that the RF model outperforms the log-transformed MLR model and is better suited for identifying the factors that influence the quality score of the load cells produced by this company.

5 CONCLUSION

Load cells play a crucial role in industrial applications by providing accurate weight and force measurements. High-quality load cells are essential for minimizing errors, ensuring reliable operation, avoiding safety risks, additional expenses, and inefficiencies. Identifying the factors that influence load cell quality is key to achieving consistent quality standards. The study revealed that nearly half of the load cells produced during the period failed to meet these standards. Among the models evaluated, the Random Forest model outperformed the Multiple Linear Regression model, accounting for 85% of the variations in

quality scores of load cells. Process temperature, which ranged from 51.3°C to 172.9°C during the study, emerged as the most significant factor affecting quality, followed by process pressure and elasticity. Strict monitoring and control of these variables could improve the quality of this specific load cell produced by this company, and future research should investigate the impact of human factors, such as worker experience and their process knowledge, on this quality issue.

REFERENCES

- Alemayehu, H., Wogaso, D., and Dadi, F. (2024). Prediction of surface roughness of tempered steel AISI 1060 under effective cooling using super learner machine learning. *Research Square*.
- Şanlıtürk, E. (2018). *Prediction of defective product with machine learning algorithms* (Master's thesis, Istanbul Technical University, Istanbul, Turkey).
- Smith, S., and Dawson, D. (2020). Critical assessment of load cells modified for harsh environments. *Engineering Applications*, 22(2), 19-32.
- Tebrizcik, S., Ersöz, S., and Aktepe, A. (2023). Improvement of quality performance in mask production by feature selection and machine learning methods and an application. *Savunma Bilimleri Dergisi*.
- Yan, W., and Shao, H. (2002). Application of support vector machine nonlinear classifier to fault diagnoses. In *Proceedings of the 4th World Congress on Intelligent Control and Automation*. Shanghai, China.
- Zhang, X., Kano, M., Tani, M., Mori, J., Ise, S., and Harada, K. (2020). Prediction and causal analysis of defects in steel products: Handling nonnegative and highly over dispersed count data. *Control Engineering Practice*, 95, 1-8.



The Best Model for Forecasting Renewable Energy's Share in Sri Lanka's Monthly Electricity Demand

Srimali KS¹, Appuhamy PADAN¹

Department of Mathematical Sciences, Faculty of Applied Sciences, Wayamba University of Sri Lanka
sitharasrimali28@gmail.com

ABSTRACT

Global electricity demand has surged due to population growth, industrialization, and technological progress, met by both renewable and non-renewable energy sources. Sri Lanka, like many developing countries, relies on non-renewable energy for its cost-effectiveness. However, the environmental impacts and finite nature of non-renewable resources have prompted a shift toward renewable energy, with Sri Lanka aiming for 100% renewable electricity generation by 2050. The objective of this study was to identify the optimal model for predicting renewable energy's share in Sri Lanka's monthly electricity needs. Monthly electricity demand and renewable energy production from January 2003 to December 2023 were used in this study. The share of monthly renewable energy was modelled using time series analysis and various Recurrent Neural Network (RNN) architectures, namely Simple RNN, Long Short-Term Memory (LSTM), and Gated Recurrent Unit (GRU). The performance of the models was evaluated and compared using Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and Mean Absolute Percentage Error (MAPE). The study found that renewable energy contribution varied between 10% and 100% of monthly electricity demand, highlighting the potential to fully meet demand in certain months. Moreover, it was found that the SARIMA (1, 0, 1) (1, 0, 1)₁₂ model outperformed the others, achieving the lowest RMSE (7.92) and MAE (5.97). Among the RNN models, the GRU proved to be the most accurate; however, its performance was inferior to that of the traditional model. This information helps authorities plan strategies for the transition to renewables by 2050.

KEYWORDS: Demand, Electricity, Prediction, Renewable Energy

1 INTRODUCTION

Around the globe, non-renewable energy sources have been widely used for electricity generation due to their cost-effectiveness, but they have significant negative impacts on humans and the environment and are depleting over time. In contrast, renewable energy sources like solar, wind, biomass, and hydropower are sustainable, environmentally friendly, and naturally replenished, though the initial establishment cost is high. Recognizing these benefits, many countries, including Sri Lanka, have increasingly focused on renewable energy for electricity generation in recent decades. At the 22nd

UNFCCC Conference held in Morocco in November 2016, Sri Lanka committed to transitioning to 100% renewable energy for electricity generation by 2050 (Ranathunga, 2023). To reach this target, over the past decade, the country has been investing in solar power projects, including rooftop installations, developing wind power plants in coastal areas, and exploring small-scale biomass production. Despite Sri Lanka's commitment to transitioning to 100% renewable energy for electricity generation by 2050, progress has been slow due to challenges such as delays in policy implementation, shortage of skilled experts, and insufficient

investment for developing new power plants. These issues might hinder the progress of the transition to a fully renewable energy power grid in the future. Therefore, this study aimed to model the renewable energy contribution to monthly electricity demand in Sri Lanka using both suitable conventional and machine learning techniques and identifies the best model to predict future contributions, helping authorities evaluate current progress and plan for future production to meet the goal.

2 LITERATURE REVIEW

Accurate energy forecasting is vital for planning and optimizing production amid increasing demand for renewable sources. Despite significant global research on renewable energy, studies focusing on Sri Lanka remain lacking.

Panklib et al. (2015) developed an Artificial Neural Network (ANN) and Multiple Linear Regression (MLR) model to predict long-term electricity consumption in Thailand, with the ANN model showing superior performance. Similarly, Kandananond compared various forecasting methods, including ARIMA, ANN, and MLR and found that the ANN model outperformed ARIMA and MLR based on error metrics (2011). In contrast, Salman et al. (2024) introduced hybrid deep learning models for solar power forecasting in France, revealing that the CNN-LSTM-TF hybrid model outperformed the individual CNN, LSTM, and Transformer models.

In the Sri Lankan context, Dissanayake and Perera applied an ARIMA model to forecast domestic electricity demand using quarterly data from 1997 to 2013 (2013). Rathnayake and Senevirathne compared the ARMA

and Grey models for predicting monthly electricity production and consumption, concluding that the Grey model was more effective (2014). Madushani and Kumari forecasted monthly electricity consumption using ARIMA and Holt-Winters exponential smoothing (2019).

In addition, Wickramasinghe et al. (2022) developed several models, including the Feed Forward Backpropagation Neural Network, to predict wind energy production with outstanding performance at the Nala Danavi wind farm. Moreover, Peiris et al. (2021) used ANN, MLR, and power regression techniques to forecast wind power generation based on climatic conditions at the Pawan Danawi wind farm in Sri Lanka, observing that the ANN model was the most accurate. This study bridges the gap between renewable energy production and electricity demand, predicting its monthly contribution and addressing a previously overlooked aspect in Sri Lankan studies.

3 METHODOLOGY

Monthly data on Sri Lanka's gross electricity demand and electricity generation from renewable sources, including purchases from the private sector, were collected from the Ceylon Electricity Board (CEB) for the period from January 2003 to December 2023.

In this study, the t^{th} monthly share of renewable energy to total monthly power demand, the variable of interest, is denoted by Y_t , defined as in Eq. (1).

$$Y_t = \left(\frac{a_t}{b_t} \right) \times 100 \quad (1)$$

where, $a_t = t^{\text{th}}$ monthly electricity generation from renewable energy sources and $b_t = t^{\text{th}}$ monthly total electricity demand in Sri Lanka.

Since the data for Y_t is sequential, both the Box-Jenkins approach of time series analysis (conventional) and recurrent neural network (deep learning) techniques were used for modeling. The Box-Jenkins method began by testing the stationarity of the original Y_t series using the Augmented Dickey-Fuller (ADF) test along with Auto-Correlation Function (ACF) and Partial Auto-Correlation Function (PACF) plots. The null hypothesis (H_0) of ADF is as follows.

H_0 : Time series has a unit root

If the series is non-stationary, regular differencing, seasonal differencing, or both are applied. Tentative models were then selected based on the ACF and PACF of the stationary series, with parameter significance tested. Diagnostic tests on the residuals were conducted for randomness and normal distribution. The best model was chosen based on the lowest Mean Absolute Percentage Error (MAPE), Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and Akaike Information Criterion (AIC) value and which was then used for forecasting the future share of monthly renewable energy to the power grid. Under deep learning approach, three types of recurrent neural networks viz. Simple Recurrent Neural Network (RNN), Long Short-Term Memory (LSTM), and Gated Recurrent Units (GRU) were applied, as these models are more suitable for sequential data. Under data pre-processing, the Min-Max Scaler from the scikit-learn library was used to normalize the data. The dataset was split into three subsets: 70% for training, 10% for validation and 20% for testing. The Y_t data served as the output for these networks, while the monthly gross electricity demand in Sri

Lanka was used as the input. The models were trained on the training data, with hyper parameters tuned and performance evaluated using the validation set to achieve optimal results. The test data was used to calculate RMSE, MAPE, and MAE to select the best RNN model. Finally, the predictive performance of the best conventional and RNN model were compared to select the optimal model for forecasting renewable energy's share in Sri Lanka's electricity demand.

4 RESULTS AND DISCUSSION

Descriptive statistics revealed that Y_t had a slight positive skew and an average of 48.9%, meaning that, on average, 50% of Sri Lanka's electricity demand was met by renewable energy. Fig. 1 below shows the time series plot of the Y_t series during the study period. It demonstrates the seasonal contribution of renewable energy to the power grid without a noticeable trend. Moreover, the share of renewable energy in Sri Lanka's monthly electricity demand fluctuates widely between 9.2% and 101.3% over the study period. In some months, renewable energy covered the country's entire electricity demand with a surplus, while in a few other months, its contribution was minimal. The ADF test p-value of 0.01(<0.05), rejects the null hypothesis, indicating the original series is stationary. Also, ACF and PACF plots of Y_t confirmed stationarity at seasonal lags. Further analyzing the ACF and PACF of the stationary time series

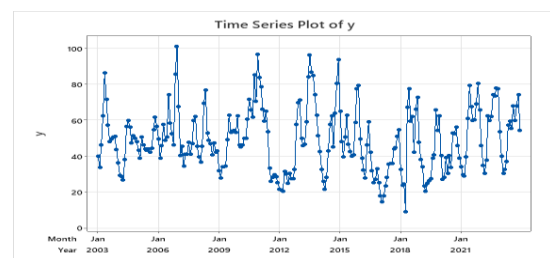


Figure 1: Time series plot of Y_t

(Y_t), Model 1-SARIMA (1,0,1)(1,0,1)₁₂ and Model 2-SARIMA (1,0,0)(1,0,1)₁₂ were chosen as tentative models, and their parameters were significant at the 5% level. The adequacy of the models was then tested using the residuals of the fitted models. Residual analysis showed no significant spikes in the ACF and PACF plots, confirming the randomness of the residuals for both models. Furthermore, the normal probability plots of the residuals for both models closely followed a straight line, indicating that the residuals were approximately normally distributed. Finally, both adequate time series models were compared based on their forecast error statistics, as summarized in Table 1. It is clear from Table 1 that the Model 1 has the lowest RMSE, MAPE, MAE, and AIC value. Therefore, the SARIMA (1, 0, 1)(1,0,1)₁₂ model was selected as the best time series model for forecasting the future monthly share of renewable energy in Sri Lanka's electricity demand. On the other hand, three RNN models viz. RNN, LSTM, and GRU were developed to predict the monthly Y_t based on historical data on electricity demand and monthly renewable energy production. The performance of these models was evaluated using several key metrics, as summarized in Table 2. According to Table 2, the predictive performance of all three models was comparatively low. The GRU model outperforms both the RNN and LSTM models across all evaluation metrics, as well as in terms of the R-squared value. The LSTM model shows the weakest performance, with higher error rates and a lower R-squared value.

Table 1: Comparison of predictive performance of the time series models

	Model 1	Model 2
RMSE	7.92	8.16
MAPE	10.03%	10.29%
MAE	5.97	6.41
AIC	1904	1919

Table 2: Comparison of predictive performance of the three RNN Models

	RNN	LSTM	GRU
RMSE	11.03	12.02	9.41
MAE	8.836	10.158	8.528
MAPE	17.9%	22.1%	16.1%
R-Squared	0.552	0.325	0.6256

This is likely due to its complexity, the potential for overfitting, and difficulty in capturing specific temporal patterns, especially given the limited data available for the study. Further, the simple RNN model performs moderately, outperforming the LSTM but slightly lagging behind the GRU in prediction accuracy. Finally, the best models from both the conventional approach (Model 1) and the deep learning approach (GRU) were compared based on RMSE, MAE and MAPE to identify the optimal model for forecasting the future contribution of renewable energy to Sri Lanka's power grid. According to the Tables 1 and 2, the predictive performance of the SARIMA (1, 0, 1)(1, 0, 1)₁₂ model was higher than that of the GRU.

Fig. 2 below shows the comparison between the actual (testing) data and the

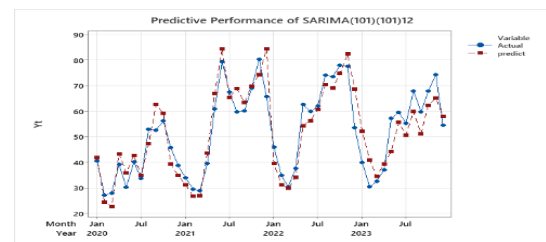


Figure 2: Predictive performance of the SARIMA (1, 0, 1)(1, 0, 1)₁₂ model

predicted values obtained from the SARIMA(1,0,1)(1,0,1)₁₂ model. It demonstrates that this conventional model effectively captures the actual data pattern with minimal error. Therefore, the SARIMA(1,0,1)(1,0,1)₁₂ model provided the best fit for the Y_t series, yielding the highest predictive performance.

This finding contrasts with Abbasimehr et al. (2020), which found that deep learning models like LSTM outperformed traditional models, possibly due to the limited data in this study, as renewable energy records in Sri Lanka only began in 2003.

5 CONCLUSION

Sri Lanka has considerable potential to develop renewable energy sources such as solar, wind, and hydro. However, challenges such as financial constraints, and a lack of technical expertise have hindered progress toward Sri Lanka's goal of transitioning to 100% renewable energy by 2050. To achieve this target, it is crucial for authorities to gain accurate insights into the current state of renewable energy production and reliable future projections to effectively plan the necessary development. The study revealed that the share of renewable energy in Sri Lanka's monthly electricity demand ranged from 9.2% to 101.3% during the study period, showing that renewable energy could fully meet demand in certain months. However, in half of the months analyzed, renewable energy contribution fell below 47%. The study concluded that the SARIMA (1,0,1)(1,0,1)₁₂ model was the most accurate in describing the share of renewable energy in Sri Lanka's monthly electricity demand. In contrast, the deep learning models showed weak

performance, making them inappropriate for prediction.

REFERENCES

- Dissanayake, D. M. S. E., and Perera, S. S. N. (2015). An empirical study of domestic electricity demand in Sri Lanka. In *Proceedings of the International Postgraduate Research Conference 2015* (pp., 160). University of Kelaniya.
- Kandanand, K. (2011). Forecasting electricity demand in Thailand with an artificial neural network approach. *Energies*, 4(8), 1246-1257.
- Madushani, L. S., and Kumari, K. D. N. (2019). Statistical modelling of electricity consumption in Sri Lanka. In *Proceedings of the 12th International Research Conference 2019, KDU* (p. 609).
- Panklib, T., Prakasvudhisarn, C., and Khummongkol, D. (2015). Electricity consumption forecasting in Thailand using an artificial neural network and multiple linear regression. *Energy Sources, Part B: Economics, Planning, and Policy*, 10, 427-434.
- Peiris, A. T., Jayasinghe, J., and Rathnayake, U. (2021). Forecasting wind power generation using artificial neural network: "Pawan Danawi"—A case study from Sri Lanka. *Journal of Electrical and Computer Engineering*, 2021, Article 5525063.
- Ranathunga, R.G.S.A. (2023). Potential Renewable Energy Sources in Sri Lanka. *Journal of Research Technology & Engineering*, 4(2), 111-124.
- Rathnayaka, R. M. K. (2018). Time series modelling approach for forecasting electricity demand in Sri Lanka. In *Proceedings of the KDU-IRC 2017*. General Sir John Kotelawala Defence University, Sri Lanka.
- Salman, D., Direkoglu, C., Kusaf, M., and Fahrioglu, M. (2024). Hybrid deep learning models for time series forecasting of solar power. *Neural Computing and Applications*, 36, 2113-2130.
- Wickramasinghe, L., Ekanayake, P., and Jayasinghe, J. (2022). Machine learning and statistical techniques for daily wind energy prediction. *Journal of Science*, 36, 411-424.

Faculty of Applied Sciences
Wayamba University of Sri Lanka
Kuliyapitiya

