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Age Invariant Face Recognition using Lightweight Deep Convolutional Neural Networks

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Abstract

Age Invariant Facial Recognition is a field of study that is constantly evolving and is applied in a variety of real-world settings. The majority of age-invariant facial recognition works that make use of Convolutional Neural Networks rely on heavyweight Convolutional Neural Networks. However, training and inferring with heavyweight networks is an extremely resource-consuming task. Lightweight models have a greater advantage over the heavyweight ones, as they have less computational and memory (in terms of the number of parameters) demands, and also are proven to perform well in face recognition tasks. But no previous comparison has been made on which Lightweight Architecture is best suited for the Age Invariant Face Recognition task. Hence, this research aims at achieving three objective 1) compare the performance of 5 pre-trained lightweight Deep Convolutional Neural Network Architectures/models for the task of Age Invariant Face Recognition. 2) conducting set of experiments with different techniques before or during classification to improve the recognition accuracy and, 3) compare the performance of lightweight models pre-trained only on ImageNet for the task of AIFR.

After conducting all experiments for objectives 1 and 2, the highest accuracies that are achieved by each of the models are 80.75% for MobileNetV1, 87.7% for MobileNetV2, 84.88% for EfficientNet, 80.65% for ShuffleNet, and 78.43% for SqueezeNet. This shows that the MobileNetV2 (pre-trained on a face dataset) is the best-suited architecture/model for the task of Age Invariant Face Recognition. The results of the experiments also show that combining the original embedding's of the classifiers training set with embedding's of Generative Adversarial Networks/FaceApp augmented images leads to an increase in classification accuracy given that (1) A Support vector machine classifier with a "Radial Basis Function" kernel is used and (2) Each embedding is represented individually (the highest accuracy is achieved when it is used along with gender guidance). Moreover it is also shows that fine-tuning leads to an increase in accuracy. The experiments conducted to achieve objective 3 show that shows that lightweight models pre-trained only on ImageNet

are not suitable for the task of AIFR.

Keywords: Lightweight CNN, Age Invariant Face Recognition, Pre-trained model, FaceApp, GAN, Support Vector Machine, ImageNet.

1. Introduction

Face Recognition is a technology that has shown tremendous advances in the past few years. Despite its advance, efficient face recognition still faces major challenges [1] caused by illumination, pose, expression, and aging [2, 3, 4, 5]. This research focuses on the problem of age variation in face recognition. The effect of aging causes significant intra-class variations [6, 7]; and hence images of the same identity will have lower similarities. Age-invariant facial recognition (AIFR) is one of the techniques used to tackle this problem. Various solutions have been proposed for Age Invariant Face Recognition; generative approach, use of handcrafted/engineered features such as Scale Invariant Feature Transform (SIFT), Local Binary Pattern (LBP) and its variants, etc. [6, 8], and use of deep Convolutional Neural Network (CNN) based features [1, 3, 4, 6, 8].

Deep CNNs have powerful feature-extracting capabilities, with high accuracy, and are reported as adequate frameworks in image classification and recognition tasks [6]. Moreover, various heavyweight and lightweight deep CNN architectures, depending on the number of configurable parameters and computational complexity, have been designed for the task of image recognition. Deep learning is extremely resource consuming (processor, memory, energy, etc.) [9], whereas the lightweight CNNs have less computational and memory (in terms of the number of parameters) demands. This research focuses on using pre-trained lightweight architectures for the task of AIFR.

The problems investigated in this research are 1) A thorough comparison of different well-known lightweight deep CNN architectures for the task of AIFR has not been carried out, hence it is not known which lightweight architecture is best suited for the task of AIFR. 2) The complexity of lightweight models is less when compared to heavyweight models, and theoretically, that leads to a lower accuracy of the lightweight models [10] unless the lightweight model's architecture is cleverly designed to avoid the reduction in accuracy, thus it is always necessary to investigate on additional techniques that can be applied to increase the recognition accuracy on AIFR tasks. 3) Although using ImageNet pre-trained models for various kinds of recognition tasks is common nowadays, not enough investigation has been done on the use of ImageNet pre-trained lightweight deep CNN models for the task of Age Invariant Face Recognition (AIFR).

The above concerns lead to the following research questions:

- Which of the well-known lightweight CNN architectures is well suited for age-invariant face recognition in terms of accuracy and computational complexity?

- What techniques could be applied before or during the classification stage in order to improve the recognition accuracy when lightweight models are used?
- Which of the well-known lightweight deep CNN architectures pre-trained only on ImageNet is well suited for the task of AIFR?

2. Related Work

In this section, the main works related to AIFR that make use of CNNs are presented.

In [6], Yousaf *et al.* compared the performance of nine diverse ImageNet pre-trained CNNs fine-tuned on the FG-NET-AD dataset. Their output shows that employing the Resnet-18 model for feature extraction and classification is found to be the most robust, time-efficient, and computationally effective model. In [2] Khiyari and Wechsler proposed a set-based matching approach where the probe and gallery templates are treated as collections of images rather than singletons; extracted features are grouped as sets to form the biometric templates of different subjects. The distance between subjects is the similarity distance between their respective sets. Better performance is reported in generalization due to transfer learning, and local processing due to the combined use of CNN and robust similarity distances for set images rather than singletons. Wen, Li and Qiao in [11] proposes a novel deep face recognition framework to learn age-invariant deep face features through a carefully designed CNN model. Extensive experiments are conducted on several public domain face aging datasets (MORPH Album 2, FGNET, and CACD-VS) to demonstrate the effectiveness of the proposed model over the state-of-the-art.

Wang *et al.* in [7] proposes a novel approach named, Orthogonal Embedding CNNs, to learn age-invariant deep face features. Extensive experiments conducted on three public domain face aging datasets (MORPH Album 2, CACD-VS, and FGNET) have shown the effectiveness of the proposed approach.

In [4] Bianco proposes a new deep CNN architecture having a feature injection layer that fuses external features with the activation of the deepest deep CNN layers. Experimental results on the Large Age-Gap (LAG) dataset show that the proposed approach outperforms the face verification methods in the state of the art considered.

Bodhe, Kapse and Singh in [12] proposes a ScatterNet Inception Hybrid Network (SIHN) for AIFR, it consists of a hand-crafted ScatterNet front-end and an Inception ResNet-v1 based backend. Experimental results evaluated over 27,000 frames show that the proposed method achieve state-of-art performance on both video datasets as well as the other widely used datasets for age-invariant face datasets such as CACD and FG-NET.

In summary, it has seen that various techniques have been applied to address the

problem of AIFR. Some of the drawbacks observed are, most of the researches use heavyweight CNN's [2, 4, 6, 12] as feature extractors, despite the fact that these architectures are resource-consuming by nature, very little work has been done in the use of Lightweight CNN [6] models for the task of AIFR. Additionally, it is also noted that enough investigation of Lightweight models only pre-trained on ImageNet for the task of AIFR has not been performed. Moreover [6] performs the evaluation of ImageNet pre-trained CNN models on the FGNET dataset, but the evaluation strategy used is the 80% train and 20% test split set, and that would not be a fair comparison with other researches, as most researches evaluating on FGNET use the Leave one out testing strategy, some other researches that use this evaluation technique are [13], [14], [15], [16], [17], and [18]. Hence based on the drawbacks mentioned above, this research sets out to compare the performance of 5 pre-trained lightweight deep CNN models that are suited for resource-constrained devices, for the task of AIFR, it also aims to determine the best technique that could be applied before or during classification stage in order to improve the recognition accuracy. The research is limited to 5 models due to computational constraints, and the selection of these models is based on the number of parameters, computational complexity, availability of an ImageNet pre-trained model and its accuracy.

3. Proposed Approach

3.1. Proposed Approach in the Case of CASIA-Webface pre-trained models

i. Proposed architecture when embedding's of GAN/FaceApp augmented images are used to enhance the classifiers train set.

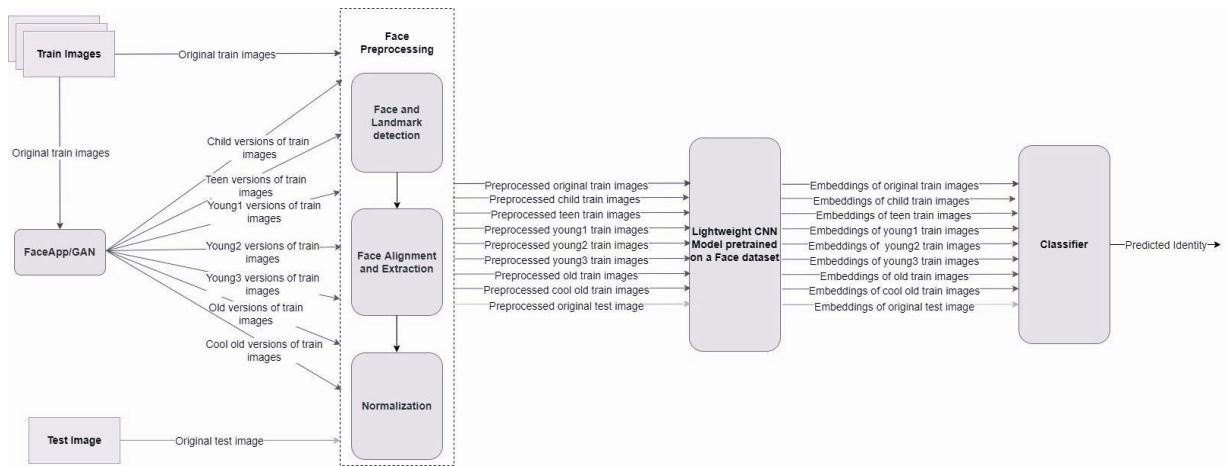


Figure 1. Proposed architecture when embedding's of GAN/FaceApp augmented images are used to enhance the classifiers train set

- ii. Proposed architecture when the CNN embedding's are concatenated with Principal Component Analysis (PCA) embedding's. (Experiments on embedding modifications before evaluation/classification is performed)

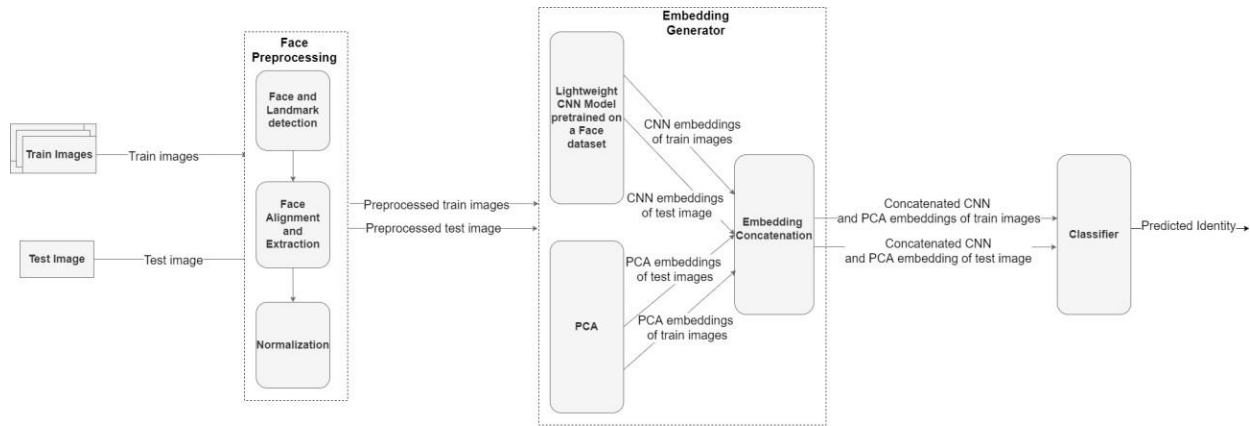
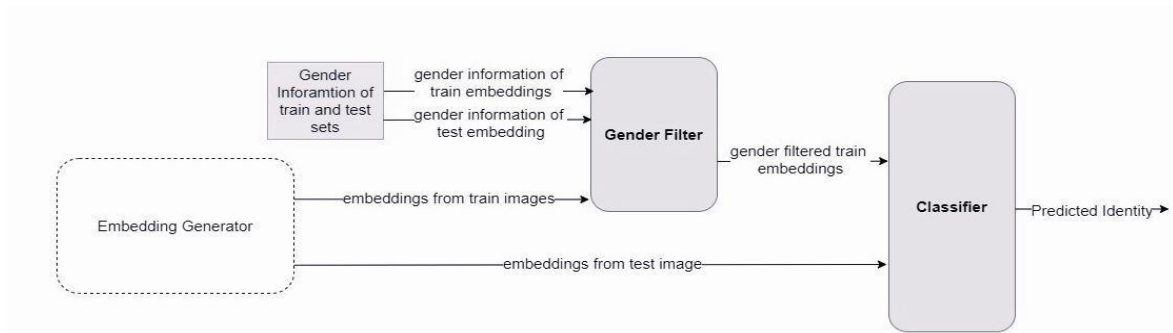


Figure 2. Proposed architecture when the CNN embedding's are concatenated with PCA embedding's

- iii. Proposed Architecture when gender guidance is used (Experiments on the evaluation process)

Gender guidance is introduced just before the classification stage, and it can be added to any of the above architectures, the diagram below shows the parts that will be added



- iv. Architecture for summing embedding's (Experiments on embedding representation before evaluation/classification is performed.)

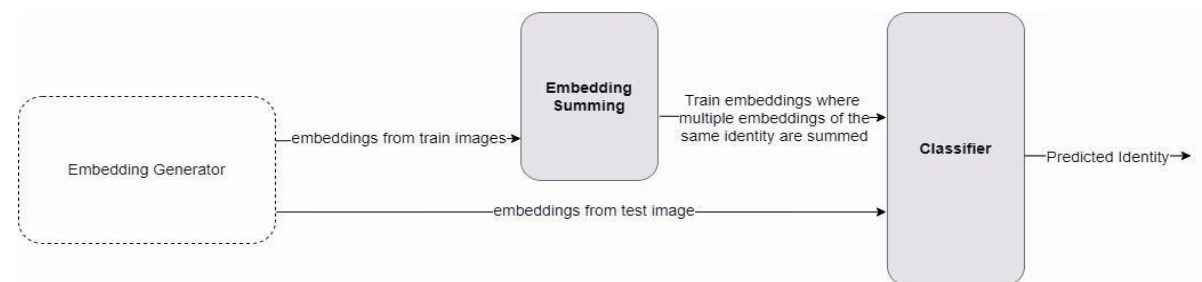


Figure 4. Architecture for summing embedding's

The embedding summer is introduced just before the classification stage, it sums multiple train embedding's of an individual. Any of the above architectures, including gender guidance, can incorporate it. This summing technique is observed in [19] and [20], but in this research it will be used in combination with the above architectures.

In order to perform the experiments, five well-known lightweight CNN models are selected; they are then prepared by removing their top layers and adding a few extra layers to the end of every model, which includes Global Depthwise Convolution (GDC) layers. These models are then pre-trained on a face dataset (CASIA-Webface) using the code and recommended hyper-parameters provided in [21] (with minor changes on embedding shape, output layer setup, and batch_size; 256, GDC, and 512 were chosen respectively). In addition, the selected loss functions are ArcFace, for MobileNet, MobileNetV2, EfficientNet, ShuffleNet, and Categorical Cross-entropy for SqueezeNet. Evaluation is then done using the LFW dataset using the evaluation script of Leondgarse [21]. The obtained LFW accuracies are 97.98% for MobileNet, 98.48% for MobileNetV2, 98.28% for EfficientNetB0, 96.28% for SqueezeNet-v1.1 and 97.52% for ShuffleNet.

Using the leave-one-out testing strategy with an embedding size of 256, the pre-trained models are then evaluated on the FGNET dataset for the task of age-invariant face recognition (the trainability of all layers is set to false during evaluation, except for the fine-tuning experiments). Moreover, the FGNET dataset is preprocessed (face alignment, extraction, and normalization) before performing the evaluation; the extracted faces used for the CASIA Webface models have a size of 112x112 before normalization is performed).

Various experiments/evaluations are performed to test the performance of each of the pre-trained models on the FGNET dataset. The performed experiments are listed below.

- Experiments on enhancing the classifiers train set with embedding's of Generative Adversarial Network (GAN)/FaceApp generated images.
 - Images generated by GANs are selected because they are capable of producing life like images [22] that realistically mimic the training set, and FaceApp is a popular photo-editing program that is renowned for producing incredibly life like changes to human faces in images. Many sources assert that the technology behind FaceApp is GAN's [23, 24, 25, 26].
 - In this experiment seven FaceApp aging filters (Child, Teen, Young1, Young2, Young3, Old, and Cool Old) are used to generate the images, and their embeddings are used to enhance the classifiers train set.
 - Experiments on embedding modifications before evaluation/classification is

performed.

- Experiments on embedding representation before evaluation/classification is performed.
- Experiments on the evaluation process (Gender Guidance).
- Experiments on the classifiers (K-Nearest Neighbors (KNN), Support Vector Machine (SVM), and Fully Connected Layers)
- Experiments on the models (Fine Tuning)

The above experiments are performed by introducing different modifications. The modifications introduced are shown in Figures 1, 2, 3 and 4.

The experiments listed above, excluding the fine-tuning experiment, are combined in different ways in order to know which modification strategy gives the best accuracy. A total of 37 experiments are performed for a single model, hence there are a total of 185 experiments for the five models. All the evaluation is done using the leave-one-out evaluation strategy, moreover, the embedding's used for experimentation are extracted from the second-to-last layer, which has a size of 256.

Once the best-performing model and strategy are selected, the model is further fine-tuned to see if that causes an increase in accuracy. This is done by setting the trainability of selected layers to true. To have a fair comparison with literature, the model that performed best in the non-gender- guided case is also fine-tuned.

3.2. Proposed Approach in the Case of ImageNet pre-trained models

ImageNet pre-trained models are downloaded for each of the 5 architectures, their accuracies are 70.4% for MobileNet [27], 71.3% for MobileNetV2 [27], 77.10% for EfficientNetB0 [27], 52.28% for ShuffleNet (Groups = 3) [28], and 57.5% for SqueezeNet-v1.1 [29] (Approximate value taken from the official SqueezeNet paper, as the exact accuracy is not stated).

The top layers of these models are removed and a Global average pooling (GAP) layer is added to the end of every model. After setting the trainability of all layers to false, the performance of these models is evaluated on the FGNET dataset.

Three of the experiments listed in section 3.1 are performed in order to test the performance of ImageNet-only pre-trained models on the FGNET dataset (for the task of AIFR). These are experiments on embedding representation before evaluation/classification is performed, experiments on the evaluation/classification process, and experiments on the classifiers. They are combined in different ways in order to know which modification strategy gives the best accuracy. Thirteen experiments are

performed for a single model, hence a total of 65 experiments are done for the 5 models. The model that performs best is then further fine-tuned. The preprocessed FGNET images used for the ImageNet pre-trained models have a final size of 224x224 before normalization is performed.

4. Discussion

4.1. Number of Parameters and Computational Complexity

Table 1. Total Number of Parameters and FLOPs of CASIA-Webface and ImageNet pre-trained models

Model	Total Number of Parameters		Computational Complexity (Floating Point Operations, FLOPs)	
	CASIA-Webface Pre-trained Models	ImageNet Pre-trained Models	CASIA-Webface Pre-trained Models	ImageNet Pre-trained Models
MobileNet	3,505,344	3,228,864	0.277G	1.15 G
MobileNetV2	2,612,288	2,257,984	0.166G	0.613 G
Efficient	4,403,875	4,049,571	0.221G	0.8 G
ShuffleNet	1,203,736	937,752	0.0782G	0.295 G
SqueezeNet-v1.1	875,072	722,496	0.121G	0.531 G

From the results shown in Table 1, we can observe that SqueezeNet-v1.1 is the lightest model in terms of the number of parameters; it is followed by ShuffleNet, MobileNetV2, MobileNet, and EfficientNet. From the same table, we can observe that the ShuffleNet model performs the least amount of computations. It is followed by SqueezeNet-v1.1, MobileNetV2, EfficientNet, and MobileNet. Therefore we can claim that ShuffleNet is the lightest in terms of computational complexity.

4.2. Accuracy Results

4.2.1. Accuracy Results for CASIA-Webface Pre-trained Models

The highest accuracies achieved for each of the models are shown in Figure 5. From Figure 5, we can observe that the MobileNetV2 architecture provides the maximum accuracy in two embedding cases: original embedding's combined with the embedding's of GAN/ FaceApp augmented images and original embedding's alone. Moreover, in both cases, the EfficientNetB0 architecture gives the second-highest accuracy. In the third case when the original embedding's are concatenated with the PCA embedding's, the SqueezeNet-v1.1 model gives the highest accuracy followed by the MobileNetV2 model.

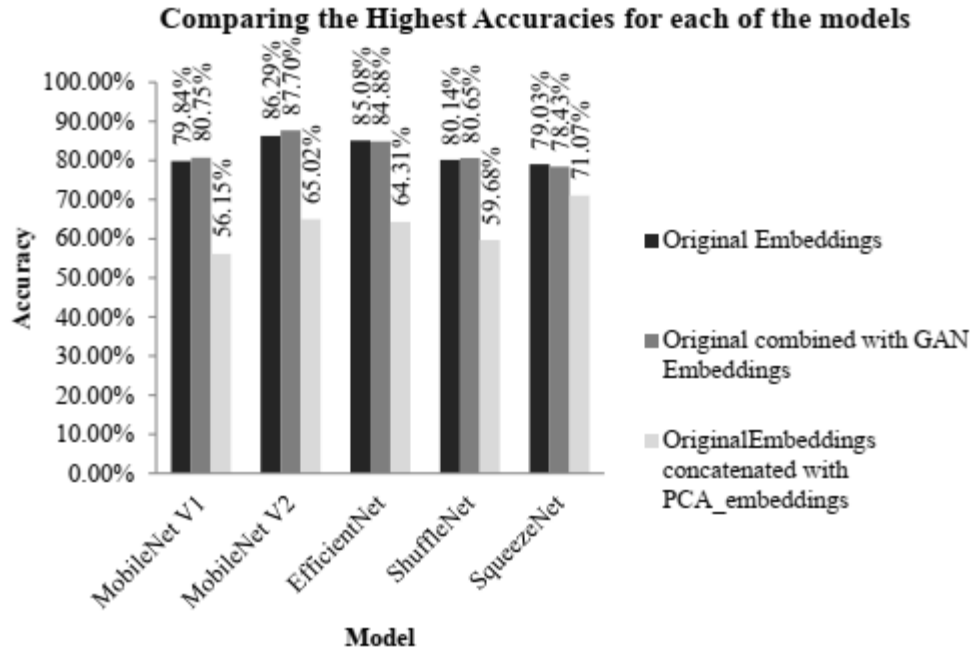


Figure 5. Comparing the highest accuracy in each of the models

Comparing all three cases, original embeddings only, original embeddings combined with GAN embeddings, and original embeddings concatenated with PCA embeddings, the highest accuracy, 87.7%, is achieved when the original embedding's are combined with the embedding's of GAN/ FaceApp augmented images, using the MobileNetV2 architecture. This accuracy is achieved using the following setup, (1) Combining the original embeddings of the classifiers train set with their corresponding GAN/FaceApp embeddings (embeddings of the corresponding GAN/FaceApp images), (2) Using an SVM classifier with an rbf kernel, (3) Each embedding is represented individually during classification/recognition (Embeddings of the same Identity are not summed) and (4) Gender guidance is introduced during the evaluation process

Other observations made are,

- In all models when the original embeddings are combined with the embeddings of GAN/FaceApp generated images the gender-guided version of the SVM classifier with an rbf kernel always has the best performance. But this is the case when embeddings are represented individually.
- In all models when only the original embeddings are used, the gender-guided version of the SVM classifier with a linear kernel always has the best performance. But this is the case when embedding's are represented individually. This is also true when the original embedding's are concatenated with the PCA embedding's.

- Using gender guidance during classification/recognition always leads to an increase in accuracy.
- Directly concatenating the original embedding's and the PCA embedding's leads to a significant decrease in accuracy compared to using the original embedding's only.
- Except in a few instances, expressing each embedding individually improves accuracy compared to summing all the embedding's of an identity.

Due to high computational requirements, the fine-tuning experiment is performed on the model that performed best using the original embedding setup, which has an accuracy of 86.29% (The setup used in this case is similar to the best-performing model with the only difference being that the SVM classifier with the linear kernel gave a higher accuracy instead of the rbf kernel). The accuracy before fine-tuning is 86.29%, and after fine-tuning this increased to 88.21%. The results from the fine-tuning experiments can be seen in Figure 6.

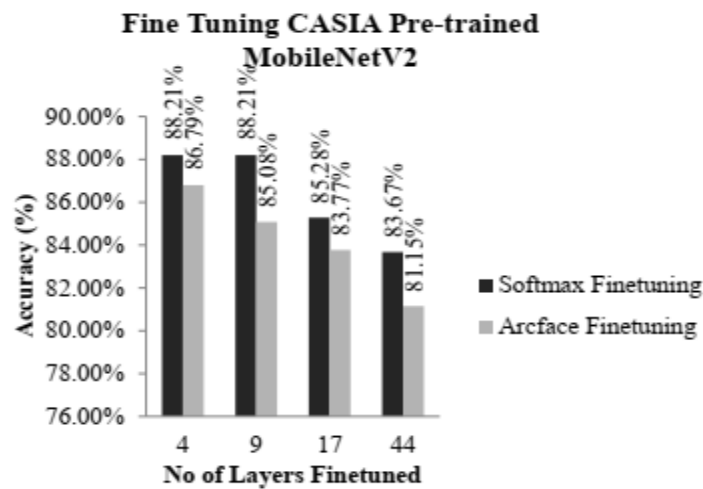


Figure 6. Accuracy results of fine-tuning the MobileNetV2 model

Moreover, from the Fine Tuning results it can be observed that the highest increase in accuracy is achieved when 4 or 9 numbers of layers are fine-tuned using categorical cross entropy as loss. We can also observe that, as the number of fine-tuned layers increases the accuracy starts to decrease, and using categorical cross-entropy as loss during fine-tuning leads to a higher accuracy. In relation to results reported on the FGNET dataset using the leave one out testing strategy, this accuracy of 88.21% shows good performance. The results reported in Literature are 93.20% by [13], 88.10% by [11], 86.50% by [14], 76.2% by [15], 69% by [16], 47.5% by [17], and 37.4% by [18]. For further comparison with literature, the non-gender guided version of the model that performed best using the original embedding setup is also fine-tuned. This is done so that we can know how well the model compares with the literature in cases it is not provided with gender information.

Originally it had an accuracy of 82.86%, after fine-tuning, the highest accuracy achieved is 86.09%, comparing it to the results of literature listed above, it can be seen that the accuracy achieved could be considered very good.

4.2.2. Accuracy Results for ImageNet Pre-trained Models

The accuracy achieved using ImageNet-only pre-trained models is very low; the highest accuracy achieved is 36.9% by the MobileNet model. The experimental setup used to obtain this accuracy is, (1) SVM classifier with Linear Kernel, (2) Use of gender guidance, and (3) Representing embedding's individually. Using the same setup, the model is further fine-tuned to see if an increase in accuracy is achieved, but the highest accuracy that could be achieved is 38.51%. This leads to the conclusion that models pre-trained only on ImageNet have poor performance for the task of Age Invariant Face Recognition.

5. Conclusion

This work focused on evaluating the performance of 5 pre-trained lightweight CNN models for the task of AIFR. The comparison was also done using different experimental setups in order to determine a setup/technique that could lead to higher classification accuracy. The results show that MobileNetV2 pre-trained with the CASIA-Webface dataset has the highest accuracy (87.7%). From the experimental setup that is used to achieve this accuracy, we can conclude that combining the original embedding's of the classifiers train set with the corresponding embedding's of GAN/FaceApp augmented Images, along with using an SVM classifier with rbf kernel, and representing the embedding of each individual separately leads to an increase in accuracy and the highest accuracy is achieved when gender guidance is used.

Due to high computational requirements, the fine-tuning experiment is performed on the model that performed best using the original embedding setup, MobileNetV2 with 86.29% accuracy. Upon fine-tuning 4 or 9 layers of this model using categorical cross entropy as loss, its accuracy increased from 86.29% to 88.21%. Other conclusions that can be made from this research are; models pre-trained only on ImageNet are not suitable for the task of AIFR, concatenating the original embedding's directly with PCA embedding's leads to significant decrease in accuracy, compared to the other classifiers SVM classifier with an rbf kernel has the best accuracy when original embedding's are combined with the embedding's of GAN/FaceApp augmented images, but this is the case when embedding's are represented individually and the best performance is seen by the gender guided version, compared to other classifiers SVM classifier with a linear kernel always has the best accuracy when only the original embedding's are used, but this is the case when embedding's are represented individually and the best performance is seen by the gender guided version, using gender guidance always leads to an increase in accuracy, and except in a few cases representing the embedding's individually leads to higher accuracy instead of summing them.

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An improved Campus Student Management System Architecture based on User Satisfaction for Ethiopian Private Higher Education Institutions

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Abstract

This study aims to bridge the gap between the services offered by the Student Management System (SMS), which have not been thoroughly evaluated by investigating the factors that influence user satisfaction, identifying existing issues, and exploring alternative mechanisms and tools, this research aims to enhance the system's performance and align it with the requirements of registrar offices in private Higher Education Institutions (HEIs) in Ethiopia. The methodology employed in this study involves survey and case study methods. A survey was conducted using a self-administered data collection system to gather data from 385 users of the SMS who had previous experience using the system. User satisfaction was evaluated by examining three key areas: system quality, information quality, and service quality. Additionally, a case study was conducted using a Scenario-based approach to the System Architecture Analysis Method (SAAM) in two selected private HEIs. The findings indicated that the overall user satisfaction with the campus SMS was moderate, highlighting the need to identify and address gaps and improve the architecture of the campus Student Management System. Overall, this study provides valuable insights into user satisfaction with the campus SMS in private HEIs in Ethiopia and contributes practical improvements to the system architecture.

Keywords: Student Management System, User Satisfaction, System Architecture

1. Introduction

Ethiopia's Higher Education (HE) and Technical and Vocational Education and Training (TVET) system has played a major role in the development of the nation and economy, and will have an even more critical role to play in the coming decades as Ethiopia seeks to rebuild an innovative, knowledge-based economy that provides sustainable employment opportunities and achieves middle-income status in the near future. Tertiary education

plays a fundamental role in enabling every citizen to realize their full potential and in generating new ideas through research and community service, forming the foundation for wider developments in the country. Ethiopian tertiary education has seen exceptional development in recent years, with the number of institutions growing from less than ten to hundreds. The scale of investment in the system has expanded considerably; however, the quality and relevance of its outcomes still fall short of expectations. [1]

ICTs play an enabling role in achieving the goals of the education sector. Teaching and learning in the digital age has become increasingly flexible, interactive, and student-centered. Neither Higher Education (HE) nor Technical and Vocational Education and Training (TVET) can afford to ignore the potential of online and blended learning design to transform the way their staff teaches and their students learn, now and in the future. Research collaboration is now unthinkable without the use of ICT. [1]

The use of technology is changing the way things are done, including work in higher education institutions where the teaching and learning processes require significant improvement. Recognizing that automation systems are essential tools for facilitating academic activities and saving time and manpower, owners of private higher education institutions in Ethiopia have invested heavily in establishing internet services in their schools. The internet services provided have had a major impact on the university context, organization, and teaching and learning methods. Today, the situation demands digital transformation for all industries, and education is the most important sector seeking digital transformation. Automation in education has various benefits for management, administrative staff, administration, and students. Automation is a method or technique of operating and controlling a single or different process, with its core focus being to minimize manual work in repetitive tasks. It helps teachers, faculties, and administrators to focus more on proper teaching and learning processes for students. Many higher education institutions face challenges in bringing together various concerned bodies of institutions to fulfill the teaching and learning process in controlled and manageable ways. To manage every task and activity of the institution, a technology-enabled transformed automation tool like a student management system is necessary. This system has the requirements and capabilities to easily control and manage student management services, course management services, attendance management services, administration management services, document management services, and employee management services [2], [3]. In all private and public higher education institutions, registrar offices are the backbone of the teaching and learning process. The college registrar's office provides services for students, faculty, and staff of the college or university. During student applications for admission, the registrar officer collects all necessary documents, registers them in a specific department, provides timely and accurate course listings or registration slips, students' academic records, academic performance, student statistics, and attrition data [3], [4].

Higher education institutions' registrar offices use a Student Management System to accurately perform and manage their tasks. This computer system is one of the most fundamental requirements and provides complete information about students' courses, grades, faculty, and the educational institution. As a registrar and data analyst with several years of experience in both public and private higher institutes, I have observed that while the system design is fully automated, there are difficulties in using it, particularly in private higher education institutions. Therefore, my motivation is to conduct research that identifies, evaluates, and explores gaps in the system's architecture and contributes to its improvement, specifically in a private higher education institution.

2 Literature Review

In accordance with [5], both private and public higher education institutions are increasingly adopting automated systems to streamline administrative tasks and enhance the teaching and learning process. This modernization involves the use of cloud, mobile, and digital technologies to improve operational efficiency and overall institution management, aligning with the institution's mission and objectives.

Incorporating technology in academic institutions, as suggested in [6], improves registration and course management through online forms, notifications, adaptable curricula, and Course Management Systems. It enhances teaching and learning, aids instructor evaluation, and helps students track progress efficiently.

To prevent communication gaps in academic institutions, [7] suggests implementing a web-based management system for seamless communication among students, administrators, staff, and teachers through various channels. This system also automates student record management, including attendance and discipline, easing the workload on instructors and enhancing operational efficiency. Additionally, it assists in tracking financial activities, such as fee collections, for improved financial management. As per [9] and [10], User Information Satisfaction (UIS) relates to user beliefs about system expectations. [8] revised the User Information Satisfaction Model, emphasizing user and organizational characteristics as fundamental factors influencing expectations. The model incorporates user, organizational, and system characteristics, which, when aligned or disconfirmed, determine user satisfaction or dissatisfaction. The EUCS model, as described in [11], gauges end-user computing satisfaction by considering factors like content accuracy, format, ease of use, timeliness, precision, reliability, currency, completeness, and format across various computer applications.

Three key software architecture evaluation methods are discussed: SAAM, ATAM, and CBAM [12], [13]. SAAM focuses on quality attributes like Modifiability and has six evaluation steps. It involves External Stakeholders, Internal Stakeholders, and the evaluation team. ATAM comprehensively assesses quality attributes like Performance and

has nine steps, involving similar stakeholder roles. CBAM emphasizes economic aspects, considering costs and benefits in its six-step process and involving the same stakeholder roles. Additionally, ALMA assesses modifiability with a five-step process and similar stakeholder roles [12], [13]. The chosen method for this study is SAAM, which evaluates scenario-based software architecture.

3 Related Work

According to research [3], the computerized registration system proves to be highly significant in higher education institutions by facilitating efficient data retrieval and management. This system effectively controls the student registration process, reducing redundancy and minimizing time wastage. Notably, it simplifies registration for students compared to manual methods, though it incurs a high initial setup cost. Importantly, both staff and students found the computerized system user-friendly, expressing a positive preference for it. However, the study pointed out a potential issue with the receipt system. Overall, this research underscores the benefits of tailored computer systems for student registration in higher education, shedding light on their potential to streamline and improve the overall registration experience.

Research [4] conducted at the University of Ibadan, Nigeria, focuses on the user satisfaction of a web-portal system for postgraduate students. The study employs statistical analysis to assess how system quality, information quality, service quality, technological and infrastructural aspects, and IT self-efficacy influence user satisfaction. The proposed system addresses existing limitations and offers numerous advantages, including accurate tracking of student attendance and assessment marks, elimination of redundancy, centralized information access, real-time data retrieval, and SMS notifications to parents regarding student absences. Moreover, it facilitates various administrative tasks, streamlines course management, and provides distinct user roles for administrators, faculty, and students. This research serves as a valuable foundation for understanding student management systems, their efficiency, and their implications within an educational context, shaping subsequent investigations in this field.

In a study focused on assessing users' perspectives regarding a student information management system [14], various aspects such as accessibility, user interface, reliability, timeliness, convenience, and privacy/security measures were examined. The research utilized a descriptive survey method with a sample size of 370 participants selected through random sampling techniques. The collected data underwent analysis using statistical measures like average weighted mean, frequency, and ranking. The study's results overwhelmingly indicated high user satisfaction with the student information management system, with positive evaluations across all assessed dimensions. This suggests that the system effectively met user needs and expectations. The study

recommended a follow-up assessment to delve deeper into user perspectives and identify areas for potential system enhancements. Overall, the findings underscore the system's success in satisfying users and advocate for further research to continuously improve the system and gather ongoing user feedback.

4 Existing Architecture

For this study the researcher is select two private higher institutions were selected which is one of them used student management system and other school use the Integrated Student Management information system. The existing system architecture, identifying strengths and weaknesses through scenario analysis, user feedback, and stakeholder interviews. Two private higher institutions are chosen: one using a Student Management System and the other an Integrated Student Management Information System.

The Student Management System comprises these modules:

- User Authentication
- Registration Management
- Course Management
- Attendance Management
- Grade Management
- Report Generation
- Data Backup and Recovery.



Figure 1: Modules for Integrated Student Management Information System (ISMIS)

5 Research Methodology

This study focuses on Campus Student Management System user satisfaction and system architecture improvement in private Higher Education institutions. The research methodology employs both survey and case study methods to gain a comprehensive understanding. Private Higher Education institutions are chosen due to their role in producing graduates, with the researcher's experience as a registrar in a medical college in Addis Ababa informing the focus. The study follows a mixed-methods approach, combining qualitative and quantitative research methods to gain deeper insights. The case study provides qualitative analysis, while the survey gathers quantitative data from a broader sample.

The data collection and analysis techniques include:

Questionnaire: A Likert scale-based questionnaire assesses user perceptions of current system practices, focusing on information quality, system quality, and system services provided by the student management system. It aims to gauge user satisfaction with the system. The Likert scale measures attitudes from (5) strongly satisfied to (1) strongly dissatisfied. The questionnaire gathers user opinions and attitudes about the system's effectiveness from their perspectives.

Interviews: Interviews are conducted to verify information gathered from the questionnaire. They help fill gaps and gather insights not covered in the survey. Separate interview guides are prepared for staff members of the registrar's office to explore their views on system management and decision-making.

Observation: The observation technique is used during visits to the registrar's office to assess the status of the student management system and observe user interactions. It involves two types: user interaction observations and workflow observations.

Case Study: Two private higher education institutions, chosen for their effective and long-term use of a student management system, are studied. The researcher's experience provides valuable data for the study.

Reliability and Validity:

Reliability: The study uses Cronbach's alpha to assess reliability. A value of 0.91 indicates strong internal consistency and reliability.

Convergent Validity: The Average Variance Extracted (AVE) is used to establish convergent validity, which ranges from 0.568 to 0.710, suggesting good validity.

Sample Design: Clustered sampling is employed. Private Higher Education Institutions in Addis Ababa are classified into three clusters (University, University College, and College), and two institutions are selected from each cluster. The sample size is 381.

Data Analysis: Data is analyzed using SPSS, and the architecture improvement process includes various steps such as requirements gathering, goal setting, analysis and validation, gap analysis, documentation, technology selection, design decisions, and iterative updates.

6 Data Analysis and Findings

6.1 Demographic Characteristics of the Sample

A total of 381 questionnaires were distributed from which 371 were returned which accounts to a 98% response rate. However, 10 questionnaires (2% of the total questionnaire distributed) were rejected due to high missing values.

The purpose of respondents was asked to state their gender to ensure that both gender groups were covered by the study. Out of 371 total number of respondents using Student managements system in private higher education, 181 (48.8%) of total respondents were male and 190 (51.2%) were female.

6.2 Level of User satisfaction of Student Management system

In this study, we conducted a comprehensive evaluation of a student management system in higher education institutions, seeking to gauge user satisfaction across three key dimensions: system quality, information quality, and service quality. Through surveys targeting both respondents and direct system users, we aimed to assess the system's effectiveness in facilitating teaching and learning, as well as streamlining administrative processes. Utilizing descriptive analysis, we examined each variable and overall user satisfaction to determine whether the system met the expectations and needs of stakeholders, including school registrars, administrators, students, and staff.

Based on the survey for Overall mean for system quality is 3.7746 which indicate that this variable is acceptable and the respondents are positive and agree with the quality of the system is satisfied. Overall mean for information quality is 3.7533 which indicate that this variable is acceptable and the respondents are positive with the information quality of the system is satisfied. Overall mean for service quality is 3.6443 which indicate that this variable is acceptable and the respondents are positive and agree with the service quality of the student management system is satisfied.

According to Figure 2, The research findings highlight low mean values in areas such as Student Management System accessibility, timeliness of information provision, and user satisfaction during interactions. These findings signify specific areas of user dissatisfaction and unmet expectations. To address these issues, the researcher will investigate the underlying causes through methods like reviewing existing studies, conducting user interviews or focus groups, and observing real-world interactions. This information will

guide efforts to enhance

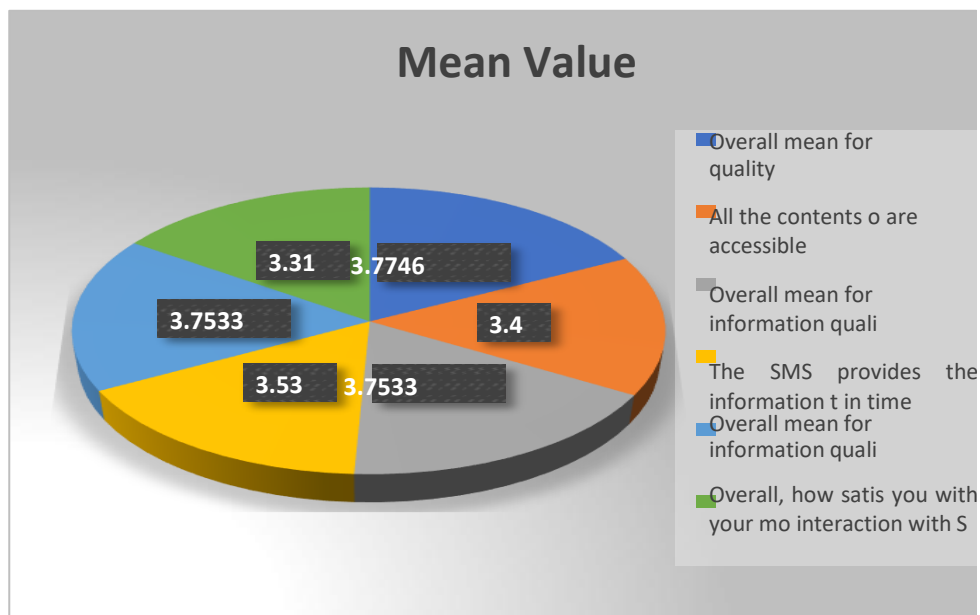


Figure 2: Overall mean values

6.3 Scenarios for Architecture of Campus Student Management System

Scenario 1: Adding a new student to the system

On the activities to add new students to the Campus Student Management System by the Registrar or Assistance registrar taking time and sometimes it makes Data entry errors: The process of adding new students to a student management system involves entering a lot of data, including personal information like Name, Date of birth, academic history, and other details. This data entry process can be prone to errors, which can cause problems. So, allow the system to fetch data from forms filled by students for this reason a modification on the architecture of a system will be done by adding new database tables or modifying existing tables to store student information, or adding new forms and user interfaces to allow students to input their information directly into the system.

Scenario 2: Integrations

To enhance the functionality and adaptability of the student management system within colleges, it is imperative that it seamlessly integrates with system accessibility, improve information timeliness, and address user satisfaction concerns, ultimately leading to a more effective Student Management System. Other vital software systems like the library management system (KOHA) and the financial management system. This integration necessitates a forward-thinking architectural approach, prioritizing design elements that facilitate such interoperability. Techniques such as web services and APIs should be employed to enable efficient data exchange and compatibility between systems.

Furthermore, adopting a modular architecture ensures flexibility, allowing for the effortless incorporation of new integrations as the evolving needs of the institution require, thereby creating a more cohesive and efficient digital ecosystem.

Scenario 3: Adoption of Cloud-Based Solutions

The adoption of cloud-based solutions among Private Higher Education Institutions in Ethiopia is driven by several key factors. Firstly, cloud solutions prove cost-effective, eliminating the need for substantial hardware investments, making them accessible to institutions with budget constraints. Additionally, their accessibility from anywhere with an internet connection enhances convenience for students, teachers, and administrators. Cloud systems offer scalability, allowing easy adjustments to match organizational needs without extensive hardware upgrades. They also provide robust data security measures, safeguarding against cyber threats more effectively than local installations. Moreover, cloud service providers typically offer high reliability and uptime, reducing downtime. Nevertheless, challenges like limited internet connectivity in certain regions and concerns regarding data privacy and security persist. As Ethiopia's internet infrastructure improves, the adoption of cloud-based solutions, including Integrated Student Information Management Systems (ISIMS), is poised for continued growth.

Scenario 4: Remove unnecessary modules from the system

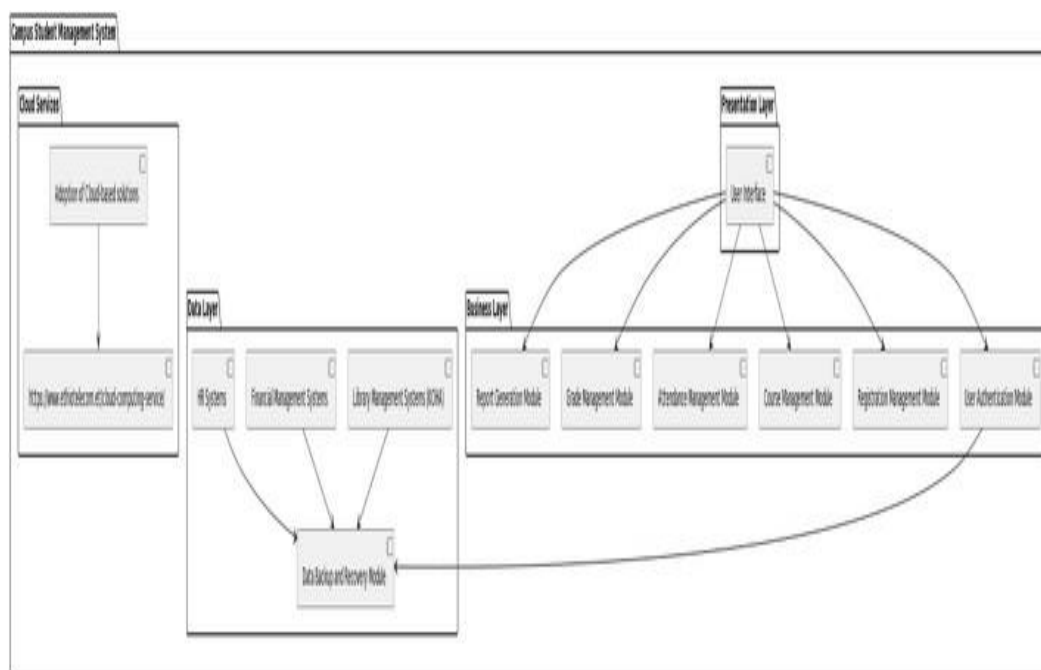
Organizations often grapple with the challenge of managing information systems that have accrued unnecessary modules over time, negatively affecting system performance and cost-effectiveness. To tackle this issue effectively, a comprehensive analysis was conducted, delving into system usage patterns, module interdependencies, and their potential impact on the overall system. This analysis aimed to identify and eliminate any redundant modules, a strategy supported by previous studies [15], [16], which have demonstrated that such removal can lead to substantial enhancements in performance, cost savings, and improved usability. Factors contributing to the accumulation of unnecessary modules often stem from inadequate planning, communication gaps between stakeholders, and a focus on short-term gains rather than long-term sustainability. To address these challenges, organizations can implement a systematic approach to system planning and development, foster collaboration among stakeholders, and prioritize sustainable development practices.

In this specific scenario, the system modules, and based on insights gained from the researcher's experience and interviews with system users, the Department Placement module and its sub-modules were identified, including Student Application and Record Management, Placement Decision Making, and Placement Notification and Acceptance. These functionalities enable administrators to establish placement criteria for students in specific departments or programs, communicate placement decisions to students, and

monitor student progress while generating related reports. However, it was observed that these functionalities hold greater significance for Ethiopian Public Universities rather than Private Higher Education Institutions in Ethiopia. By evaluating component dependencies, it became evident that the Department Placement module relied on the Admission Management module, but its utility within the campus was limited. Therefore, the recommendation is to remove the Department Placement module from the system to enhance performance and reduce complexity, especially in the context of Admission processes in Ethiopian Private Higher Education Institutions, which typically adhere to specific Admission Criteria set by the Ministry of Education (MoE) or the FDRE Education and Training Authority, allowing students to directly join specific departments based on fulfilling the criteria and institutional acceptance rates.

7. Improved Architecture and Discussions

According to those scenarios the architecture of the campus Student Management System has been improved in a way that is shown in the figure 3 below, which also presents the scenarios mentioned above with their explanations.



User Authentication Module - This module is responsible for authenticating users who want to access the system. It provides a secure login interface that allows users to enter their username and password to gain access to the system.

Registration Management Module - This module manages the registration process for

students. It allows students to register for classes, add and drop classes, and view their schedules.

Course Management Module - This module manages the courses offered by the institution. It allows administrators to add new courses, modify existing courses, and delete courses that are no longer offered.

Attendance Management Module - This module manages student attendance records for each class. It allows instructors to take attendance, view attendance records, and generate reports.

Grade Management Module - This module manages student grades for each class. It allows instructors to enter grades, view student records, and generate reports.

Report Generation Module - This module generates various reports related to student data, such as attendance reports, grade reports, and registration reports.

Data Backup and Recovery Module - This module is responsible for backing up student data to ensure that it is not lost in case of system failure. It also allows for the recovery of lost data if needed.

New Forms and User Interfaces - This includes new user interfaces and forms that allow students to input their information directly into the system, such as online registration forms.

Integrated Systems - This refers to the integration of external systems, such as Library Management Systems like KOHA and Financial Management systems and HR systems. This allows for seamless data exchange and better management of resources.

Cloud-based Solutions - This involves the adoption of cloud-based technologies to store and manage student data [17]. This allows for easy accessibility, scalability, and cost-effectiveness.

7.1 Validation of Improved Architecture

The validation of the improved system architecture involves confirming its alignment with user needs and defined requirements. This process incorporates requirements verification by assessing whether the architecture fulfills both functional and non-functional requirements. User feedback, obtained through interviews, plays a crucial role in validation, helping identify areas for improvement. One notable enhancement is the implementation of a user-friendly interface and data entry form, reducing errors and enhancing efficiency within the Campus Student Management System. Another improvement involves addressing slow performance during peak usage periods through hardware and software optimizations rather than costly load balancing. Lastly, the

integration of library management system KOHA and financial management systems offers benefits like improved efficiency, data accuracy, and streamlined processes, though considerations like data security, user training, and ongoing maintenance are essential to successful implementation.

The fourth improvement implemented is the adoption of cloud computing, recognized as a crucial step in meeting business requirements efficiently and a key component of digital transformation. With major public cloud providers like AWS, Azure, and Google Cloud experiencing substantial growth, cloud computing offers various models and deployment options to enhance the Campus Student Management System's architecture, aligning it with industry standards and user needs.

The fifth enhancement focuses on removing unnecessary system modules to create a more streamlined and efficient system, which, after gathering feedback from users, has proven to be a productive exercise. This effort emphasizes the significance of system performance, highlighting how eliminating redundant modules can lead to increased efficiency, benefiting both the registrar office and students.

Additionally, it addresses the adverse impact of unnecessary modules on system responsiveness and complexity while underlining the advantages of simplifying the system for improved user experience. Careful planning, including impact analysis, necessary modifications, and thorough testing, is crucial when removing modules. Furthermore, user feedback remains vital throughout these changes, ensuring that adjustments align with user expectations and enhance system performance.

7.2 Discussions

Through interviews with staff members from private higher education institutions, the strengths and weaknesses of the current Campus Student Management System were evaluated. While the system offers essential tools like user authentication, student enrollment, course management, grade management, and reporting tools, it also exhibits weaknesses, including usability issues, limited customization options, technical infrastructure challenges, and integration difficulties. User feedback highlighted problems such as slow performance, interface comprehension difficulties, and inadequate user training and support. Achievements of the system include improved administrative efficiency, enhanced data accuracy, streamlined processes, and increased user satisfaction. Cost-effectiveness was considered, encompassing implementation, maintenance, and training costs, as well as long-term benefits such as reduced administrative overhead. Future improvements involve continuous user research, enhanced user experience, ongoing support, and addressing customization limitations, infrastructure issues, and integration challenges.

The observational study of the Campus Student Management System identified user roles and tasks, including administrators managing admissions and records, faculty members handling grades and course materials, and students enrolling and accessing grades. Interface design varied among user roles, affecting navigation. Data entry and retrieval processes were observed for tasks such as student information input and grade retrieval, while system responsiveness was monitored, with response times noted. Error handling and recovery processes were observed when users encountered system errors. Overall user satisfaction was assessed, with administrators expressing high satisfaction, faculty members being moderately satisfied, and students finding the system straightforward. User feedback included suggestions for improved search functionalities, mobile accessibility, and interface customization options, providing valuable input for future enhancements to the system.

8. Conclusion, Recommendation and Future Work

A student management system is essential for private higher education institutions to provide efficient learning environments and services, aligning with government policies emphasizing education quality. However, challenges persist in ensuring that these institutions utilize modern technology effectively while upholding educational standards. Improper digital technology use significantly impacts information management. This study focused on two private higher education institutions, identifying gaps and making modest improvements in their campus student management system architecture. The Registrar office and staff members cited challenges such as inconsistent guidelines and budget allocation for system upgrades, and a lack of technology transfer from government institutions. Consequently, system updates and improvements vary among institutions, hindering uniform progress and efficiency.

In today's educational landscape, the role of digital technology cannot be overstated, particularly in the efficient management and monitoring of educational systems. Timely and accurate information delivery is crucial for ensuring quality education and effective training, enabling educational institutions to attract students and remain competitive. To achieve these goals, institutions often rely on software and IT companies offering systems like Student Management Systems (SMS) and Student Information Management Systems (SIMS) for streamlined communication and administration. However, there exists a prevalent lack of awareness and proficiency in utilizing modern technology for information management, particularly among private higher education institutions. To bridge this gap, it is imperative for software development companies to raise awareness and offer affordable solutions to institution owners and top-level managers, allowing them to harness the full potential of digital technology in education. Addressing challenges and ensuring efficient system monitoring is essential to fully unlock the benefits of digital technology in

the educational sector, facilitating seamless communication with education authorities such as the ETA and MoE.

Future research directions can encompass several key areas. First, a comparative study should investigate the variance in digital technology adoption for student management systems between private and government higher education institutions. This research can delve into the underlying reasons for any disparities, assess their impact on service delivery and educational quality, and uncover best practices that could be shared across both sectors. Strategies for efficient technology transfer between these sectors should also be explored, with a focus on overcoming challenges and barriers, and the development of frameworks or guidelines to facilitate consistent and equitable technology adoption.

Secondly, cost-effectiveness analysis is paramount to understand the financial implications of implementing and sustaining student management systems in private institutions. This analysis should encompass initial investments, operational expenses, and strategies to enhance affordability and sustainability for institutions with limited budgets. Additionally, research should delve into the training and capacity-building needs of staff responsible for system management, identifying knowledge and skill gaps and proposing comprehensive training programs to bolster staff proficiency and optimize digital system utilization. Lastly, research should examine the long-term sustainability of student management systems in private institutions. This includes addressing challenges related to system upgrades and maintenance while proposing strategies and guidelines for consistent resource allocation and budget management to support ongoing technological advancements.

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The Existence of Healthcare Software and Factor Associated with Healthcare Software Adoption in Public and Private Hospitals: the Case of Addis Ababa

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Abstract

In the last decade, the field of health informatics has grown worldwide. Information communication technology has been integrated into health systems and services since 2000 G.C. Information technology is an essential tool to improve healthcare costs, safety, and the quality and equity of care. The health system faces different challenges, lack of supportive legislation, lack of budget, lack of relational collaboration and well-trained personnel is one of the factors. This study is assessed software adoption and factors affecting software adoption in public and private hospitals in Addis Ababa. The study conducted in Addis Ababa Hospitals. Both quantitative and qualitative research were done. Twenty percent of Addis Ababa's hospitals were sampled for the study using multistage and probability sampling techniques. The final sample of the study is 8 hospitals 5 public and 3 private hospitals. The quantitative data were analyzed using frequency, percentage and mean and range and the qualitative data were analyzed thematic analyses technique using open-coding. From the study, 8 hospitals 5 general and 3 specialized hospitals are identified. Only one private hospital uses an online patient appointment scheduling system, while all public hospitals use health information management systems and almost all public and private hospitals employ medical recording systems and all. Four contexts are identified as the factor of affecting health care software upgrade or implementation; Organizational context: that include expensiveness, complexity of system, and organizational culture and knowledge; Technical context: includes lack of cloud and weak internet, system complexity, incompatibility and lack of integration, and security and privacy issue; Environmental context: poor government support and internal developer, and Human context: Poor organization IT knowledge and capability.

Keywords: Software, Adoption, Adoption Factors, Hospital, Healthcare.

1. Introduction

In the last decade, the field of health informatics (HI) has grown worldwide. Information communication technology (ICT) has integrated into health systems and services since 2000 G.C [1]. The Institute of Medicine in the United States has declared that information technology (IT) is an essential tool to improve healthcare costs, patient safety and the quality and equity of care [2, 3].

Health systems globally are facing increasing demands for highly sophisticated services, yet they have limited resources and current and projected shortages of health professionals. In Australia, for example, health is already one of the most expensive sectors of the economy, at 9.3% of GDP. Global expenditure on ICT across all sectors exceeds \$US3.5 trillion. It driven by the desire for improvements in productivity, work practices and service outcomes. Studies have shown that the use of ICT in the health sector is capable of increasing efficiency, reducing errors, supporting more team-based care [4, 5 ,6, 7].

According to [8, 9] Africa has the greatest healthcare challenges in the world: life expectancy is 60 years, substantially lower than the global average of 72 years; maternal mortality ratio is 547 per 100,000, but 13 in high-income countries and 216 globally; under five mortality is 76 per 1000, but 5 in high-income countries and 39 globally. Africa lags in the capacity for health technology innovations, while it bears 23% of the global disease burden and 16% of the world population, with the continent expected to double its population by 2050, from 1 billion to nearly 2.4 billion. Without urgent technological, industrial, intellectual, and research-oriented health interventions, Africa cannot tackle the needs and demands of its population. If health technology innovations needed to transform health system gaps in Africa, it is important to generate country-specific evidence to identify challenges and opportunities in the region as potential resources for further interventions. In Ethiopia, ICT development has become one of the priorities and key drivers of the government for socio- economic growth and transformation in the last decade (Report from Ethiopian Ministry of science). Transform health system gaps in Africa, it is important to generate country- specific evidence to identify challenges and opportunities in the region as potential resources for further interventions [8, 9].

The adoption of the EHR, electronic patient records or digital medical records has a significant role in patient care and cost saving. Studies estimate the adoption of the EHR could save more than \$813 billion annually, prevent 200,000 adverse drug events and enhance doctor patient relationships through increased communication. This benefit may not see immediately during technology adoption. Rather, it takes a fortune during adoption, the benefit only seen at long run [10, 11].

The primary goal of the study is to determine how public and private hospitals in Addis

Ababa Ethiopia's utilize healthcare IT software across a variety of settings. The study's objectives include identifying the different categories of information technology software the health sector used, factors affecting the adoption of healthcare software, the use of AI software, mobile health systems in healthcare and propose a framework that enhance software adoption in health care.

To assess the objective of the study, the study uses quantitative research to understand a type of software for healthcare the hospital use and a quantitative thematic analysis method is used to identify factor affecting software adoption. Categorical data summarized using frequency and percentage, and mean and the standard deviation is used to summarize continuous variables. For semi- structured qualitative data, the organizational level is important therefore the CEO, the medical director, and senior IT staff response is used for the analysis to get a top-down understanding of health care software adoption. The data from the interviews were analyzed by using the methodology thematic analysis of open coding technique is used for systematically identify, organize and analyze qualitative data sets to receive patterns and themes (Braun & Clarke, 2012). Thematic analysis is chosen due to the flexibility and accessibility the methodology provides according to the authors to systematically analyze the data and receive wider conceptual themes and issues. The thematic analysis is conducted by with five phases: phase 1 familiarizing ourselves with the data, phase 2 generating initial codes, phase 3 searching for themes, phase 4 reviewing potential themes, and finally phase 5 defining and naming the themes.

2. Literature Review and Related Work

The medical record is a multifunctional document that used to communicate and document critical information about patients' medical care among health care professionals. Even if the medical records system is very important for effective and efficient management of medical information in the health sector, much more important in developing countries, it has never given priority and has usually been undermined, miss-handled, and even implemented in the private health sector in Ethiopia. It is very important that the healthcare facilities of Ethiopia accomplish only 45.7% of the medical information [12].

Japan's health sector use of software reviles that since in 1990s Japan's hospital begin a project of exchanging patient data (laboratory result, imaging and patient history) across different hospital initially using diskette. Japan widely use Electronic medical record (EMR) around 80% of health care are use it and other health information system (HIS) medical billing computer, picture archiving and communication system(PACS), medical appointment register system, cloud-based electronic medical records, online patient care system (Telehealth), communication app for medical staff, cloud-base PACS, Electronic patient interviewing system, home-visit medical care support system, cloud-base remote

image diagnostic and other AI software [13, 14].

Three dimensions are identified by the recently established framework (TOE) as having an impact on the adoption of innovation. These dimensions are; organizational dimensions: such as organizational scale, organizational structure, and communication process, technology dimensions: include accessibility and technological qualities, as well as an external task environment: that takes into account a country's culture, environmental factors, and legal requirements (see Figure 2.1). Similar to how TOE has three main aspects, another well-known framework (Hot-fit) outlines three dimensions that drive the acceptance of innovation. Organizational and technological dimensions are similar to TOE, but there is a single human dimension that is specific to user involvement (see Figure 2.2).

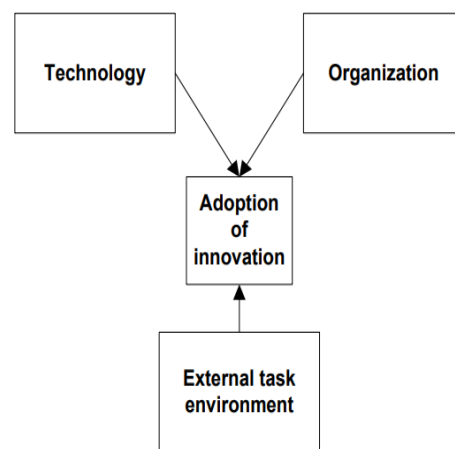


Figure 2.1. TOE framework (Tornatzky and Fleischer, 1990) factor that influence in ICT adoption [15].

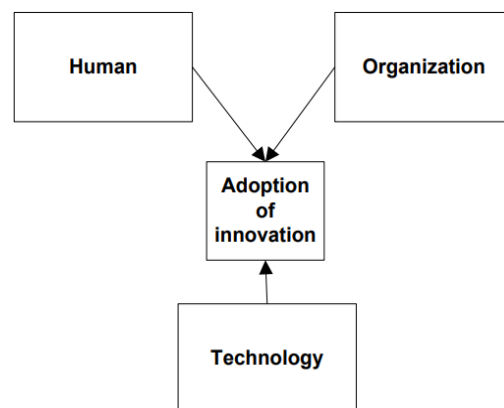


Figure 1.2: Hot-fit framework factor that influence in ICT adoption [16].

The well-known framework the TOE and HOT-fit are not covering all factors that influence adoption of innovation. Considering the two framework and combining together the following framework is constructed therefore the healthcare software adoption can be

influenced by Human context, organizational context, technological context, and environmental context (see Figure 2.3) and this need to be proofed.

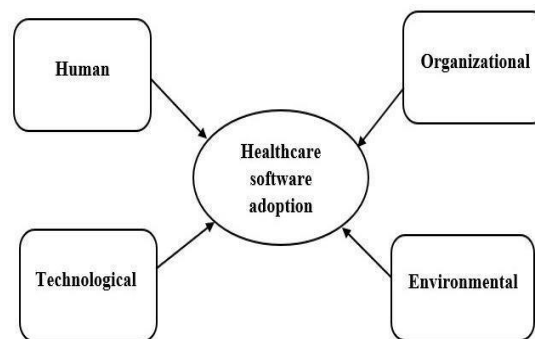


Figure 2.3 Factor that influence healthcare software adoption framework adopted from TOE and HOT-fit framework.

A systematic literature review study in PubMed, EBSCO host, and Google Scholar on factors associated with adoption of health information technology (HIT) system of three modes of HIT: Electronic health record (EHR), Electronic medical record (EMR), and computerized provider order entry (CPOE) system. This study identifies internal organizational and external organizational factors associated with the adoption of HIT [17].

According to studies in Sweden, Germany, and United States surgical centers on adoption and implementation of hospital IT systems (HIT) in ambulatory surgical care, six barriers in the adoption and implementation phase were identified under three categories: Organization barriers (expressive and complex implementation); Human barriers (two factors: internal resistance to change and lack of internal IT knowledge and capability); and Technical barriers (lack of system integration, complexity of HIT system, and privacy and security issues). The eight enablers in the adoption and implementation of HIT system in ambulatory surgical care fall under four categories: Organizational enabler (context includes computation and management support, change management and incentive, and business case); Human enabler (which includes internal IT education and training); Technical enablers (use of tailored and customizable system, and user-friendly system); and Environmental enablers (which includes external implementation support, government policy and regulation [55]).

3. Qualitative & Thematic Analysis

This study tries to understand the existence of software adoption in 5 private and 3 public hospitals in Addis Ababa. 5 of them are general hospitals; the rest 3 are specialized hospitals. This hospital has a maximum of more than 120 years and a minimum 12 years.

history of establishment (1902-2011GC). In Ethiopian year 2014 or September 11/2022 up to September 12/2023 These three public hospitals give service to 2,880,000 up to 6,200,000 or average 4,826,667 patient and the five-private hospital to 49,900 up to 234,000 or average for 152,380 patients.

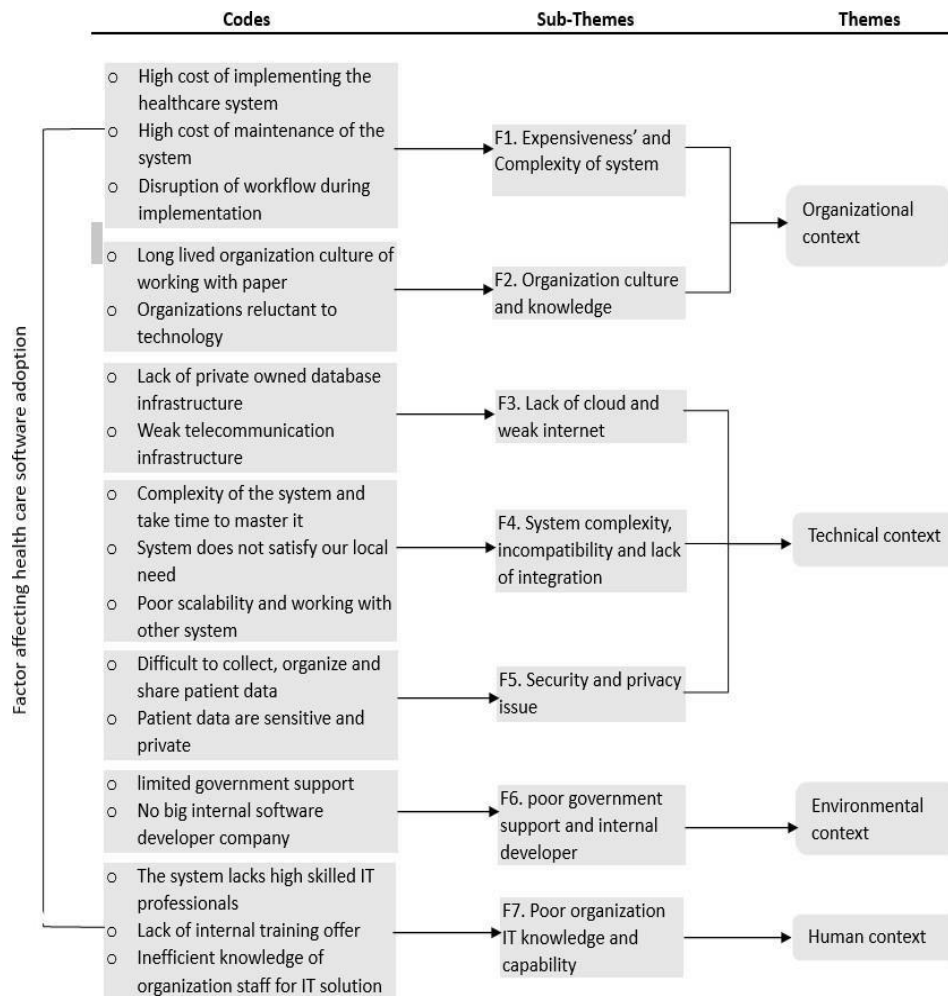


Figure 3.1: Thematic map of identifying factor affecting healthcare software adoption in public and private hospital Addis Ababa.

This study found that public and private hospitals use software differently; the public hospital invests in the Health Management Information system (HMIS), whereas the private hospital does not. On the other hand, a few private hospitals use an online system for booking patient appointments. In both public and commercial hospitals, automation is required for services including referral linkage systems, diagnostic and treatment plan systems, online patient registration systems, and home care systems that are now performed manually. The study pointed out that there are no health-related mobile apps or powerful AI software's that assist healthcare services. Based on the qualitative study and thematic

analysis the following context that affect software adoption are identified (*see Figure 3.1*).

Organizational context: high cost of implementing healthcare system and long lived organization culture of working with paper, **Technical context:** lack of database infrastructure and weak telecommunication infrastructure, complexity of the system and lack time to master it, System does not satisfy our local need and nature if the health care data to collect and store, **Environmental context:** limited government support on technology area and no big internal software developer company, and **Human context:** the system required skilled and technical staff. The cost of implementation the health care system in terms of time and resource is the major challenge of the hospital.

4. The Proposed Framework

Based on the qualitative analysis thematic map, four contexts are identified as factors that influence software adoption. These four contexts are derived from several sub-themes that make-up the four contexts were from the responses of different respondents and are factors affecting the implementation and upgrading of healthcare software. This study suggests (*see figure 4.2*) a framework practice to follow to increase the adoption of healthcare software by offering a prescriptive technique of telling what to do to attend to a bigger outcome and increase the adoption of healthcare software based on the thematic findings. Organizational setting; establish financial assistance to offset the costs of technology and maintenance, provide training on the benefits of software over paper-based systems, introduce software, and maintain continuous support; Technical context: promote local investment, upgrade telecommunications facilities, address system integration, and security issues, and develop localized and user-friendly systems, Environmental context: get government supports and establishes local software developer company, and Human context: enhancing IT expertise through training and graduating qualified IT professionals would help healthcare software usage.

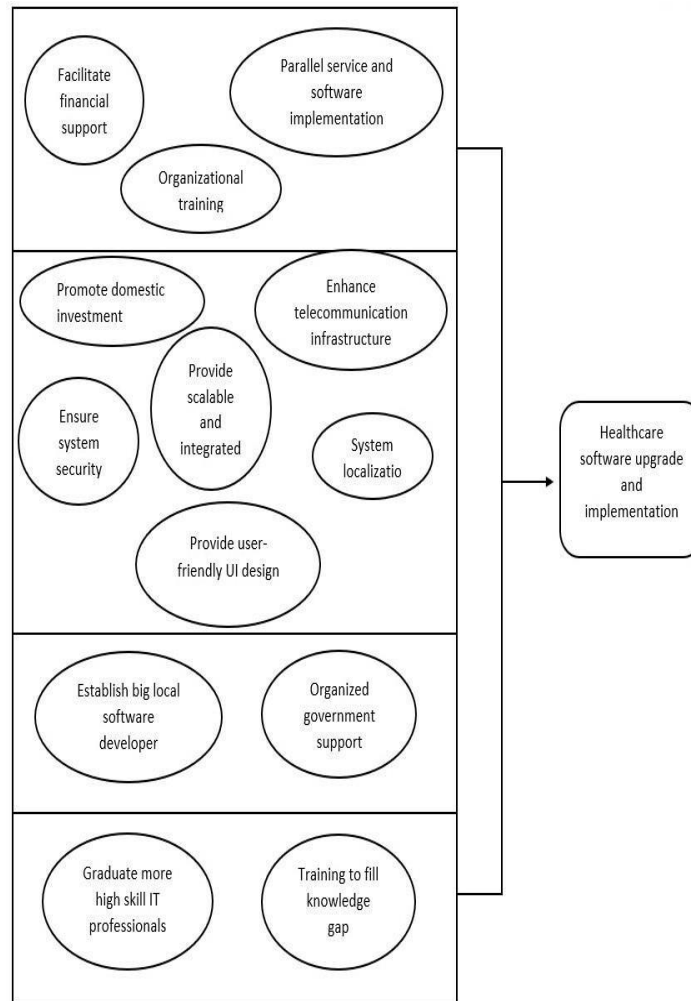


Figure 4.2: The Proposed Framework; Practices to Increase Software Adoption

5. Discussion

Study in Sweden, Germany, and United States identified three contexts that influence hospital IT adoption: Human context, organizational context, and technological context; in human context two factors are identified: internal resistance to change and lack of internal IT knowledge; organizational context: system implementation complexity and expensiveness of technology is the factor; in technological context include lack of system integration, complexity of health information system and privacy and security issues. But in my study, finding some of the factors are similar with the above study but there is one extra context that influences software adoption, which is environmental context, which is limited government support and lack of big local software development firm. Addis Ababa public and private hospitals widely use electronic medical record systems, laboratory management, pharmacy, and health information management systems but only one hospital has a medical appointment registration system and no sign of AI-supported software and mobile-based software which interacts with patients.

6. Conclusion

The backbone of most public and private hospitals' software implementations is an electronic medical recording system. Four contexts are identified as the factor of affecting health care software upgrade or implementation; Organizational context: expensiveness and complexity of system, organizational culture and knowledge; Technical context: lack of cloud and weak internet, system complexity, system incompatibility and lack of integration, and security and privacy issue; Environmental context: poor government support and internal developer, and Human context: Poor organization IT knowledge and capability.

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eGovernment Success Factors: Acceleration & Enhancement of Digital Public Services in Ethiopian Federal Institutions

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Abstract

eGovernment is the use of information technology to enable and improve the efficiency with which government services are provided to citizens, employees, businesses and agencies. The rapid advancement of information technology and the increasing demand for efficient and effective public services have prompted governments worldwide to adopt eGovernment initiatives. However, the successful implementation of such initiatives requires a thorough understanding of the factors that drive their success and the challenges they may encounter. This research seeks to contribute to the existing knowledge in the field of eGovernment implementation.

This research contributes to the existing body of knowledge by providing a comprehensive analysis of the key success factors, challenges, and barriers in eGovernment implementation. It offers practical recommendations for policymakers, project managers, and stakeholders involved in the planning and execution of eGovernment initiatives. The research recommends that organizations focus on enhancing their readiness for eGovernment implementation, ensuring active stakeholder engagement, developing robust technological infrastructure, establishing effective policy and legal frameworks, and implementing change management strategies.

Keywords: eGovernment, Information Technology, Success Factor

1. Introduction

In its theoretical definition eGovernment is the delivery of services using web technologies to reform public administration [3], [5]. The principle behind implementing of eGovernment is bringing the benefits of computers and web technology into government's administrative processes and operations. One of the driving forces of this phenomenon is the implementation of eService. eService can be described as one of the components of eGovernment. The delivery of government services to citizens is majorly

facilitated via implementation of web technologies [6]. Placing administrative services on web portals and making the Internet as the main communication channel to maximize service coverage is what most governments do in their eGovernment implementation [2], [7].

The recipients of these services are not only individual citizens but also business entities of all scale, NGOs, religious institutions, and other government institutions within the state. The service and recipients of it are different across the spectrum. The technicalities and rules of the business process vary based on the service and recipients as well [4].

Literatures suggest distinction between low & high-level success factors when embarking on eService digitization [1]. Müller's article makes the distinction between the stages of eGovernment as low level and high level. The low level being the initial stages of Lee's eGovernance maturity model; the presenting and assimilating stages. The high level being reforming, morphing and eGovernance stages. These success factors are categorized based on who the actor would be to enforce them or be the participant.

The objective of this study is to identify and analyze the success factors that significantly influence the implementation of eGovernment initiatives. By examining these factors, the study aims to provide valuable insights into the critical aspects that contribute to the success or failure of eGovernment projects. Ultimately, this study contributes to the advancement and success of digital government transformation efforts.

The successful implementation of eGovernment initiatives has the potential to transform public service delivery, enhance government efficiency, and improve citizen satisfaction. By identifying the success factors that drive eGovernment implementation, governments can allocate resources effectively, design appropriate strategies, and overcome common challenges, leading to successful and sustainable eGovernment initiatives. The findings inform government decision-makers, policymakers, and practitioners on strategies for improving eGovernment initiatives and maximizing their impact on public service delivery.

The following questions are framed to address the research.

1. What are the key success factors that drive the implementation of eGovernment initiatives?
2. How do organizational readiness, stakeholder engagement, technological infrastructure, policy and legal frameworks, and change management influence the success of eGovernment implementation?
3. What are the common challenges and barriers encountered during eGovernment implementation, and how can they be effectively addressed?

2. Related Work

According to OECD eGovernment is “The use of information and communication technologies, and particularly the Internet, as a tool to achieve better government”. This definition emphasizes that governments can achieve better performance by utilizing technology [9]. Tan and Benbasat define eGovernment as “... the application of information and communication technology to automate interactive exchanges between public institutions and their external stakeholders by redeploying conventional public services through the Internet” [10]. Such explanation covers the technological aspect, the public service business process, and the transformation of manual system in to software based services.

Researches find it vital to find out the current stage of eGovernment of a particular country before diving further in their studies. To identify the stages of eGovernment Gartner Group’s model and Layne & Lee’s developmental stages of eGovernment is usually used. Gartner Group is a management consulting firm that researches and publish their work on various topics for private corporations and government agencies. In 2017 Gartner Group formulated the “Gartner Digital Government Maturity Model 2.0”. It consists “Initial (eGovernment), Developing (Open), Defined: Data centric, Managed: Fully Digital, and Optimizing: Smart [11]. This model makes more emphasis on “open data” than their previous model only consisting of four stages.

The previous model of Gartner Group’s eGovernment stages are Presence, Interaction, Transaction, and Transformation [12]. These stage have their own unique character.

- a. **Presence:** this stage is characterized by government institutions having an online presence by displaying basic information about themselves and the services they provide usually via web-portals.
- b. **Interaction:** this stage is where government websites add features that allows users to download forms to fill out or make email communication as information exchange mechanism.
- c. **Transaction:** on these stage citizens can receive full public service from the government agency online. Users can apply to get official documents, renew licenses, and make payments.
- d. **Transformation:** this stage is characterized where by eGovernment systems integrate their data and system enabling a seamless information exchange between different government agencies.

In the literature review of Muller & Skau the development model of eGovernment by Lee is subdivided into two. The high and low levels; characterized by the organizational changes needed to achieve them [1]. The higher levels require more changes in the

organization than the low level eGovernment stages. The literature review places 'Presenting' & 'Assimilating' at low level and 'Reforming', 'Morphing' & 'eGovernance' at high level stages. The review also infers low level stages focuses on incremental ICT enabled service provision while high level stages demand service reformation.

2.1 Critical Success Factor

Identifying CSFs is of paramount importance to avoid the pitfalls and challenges that often lead to project failure. CSFs encompass a range of factors that are essential for achieving desired outcomes and maximizing the benefits of eGovernment initiatives [16]. By identifying these factors, governments and policymakers can make informed decisions, allocate resources effectively, and implement strategies that increase the likelihood of successful eGovernment implementation.

In developing countries, where resources and infrastructure may be limited, the identification and utilization of CSFs become even more critical [17]. The unique socio-economic and technological contexts in these countries necessitate a comprehensive understanding of the specific factors that influence the successful implementation of eGovernment services. By acknowledging and addressing these factors, developing countries can overcome challenges and unlock the potential benefits of eGovernment for their citizens.

The critical success factors (CSFs) for eGovernment encompass the delivery of excellent service, fostering good communication between government organization and users, ensuring the availability of quality human resources, and implementing a user-inclusive information system [18].

2.2 Information System Success Model

The Information Systems Success Model (ISSM) provides a theoretical framework for understanding the factors that contribute to the success of information systems, including eGovernment implementation. The ISSM focuses on the user's perspective and identifies key dimensions of system success, such as system quality, information quality, and user satisfaction [19].

2.3 Stakeholder Theory

Stakeholder theory provides a valuable framework for understanding and managing the relationships between various stakeholders [20]. In the context of eGovernment, stakeholders include government agencies, citizens, businesses, and other organizations affected by or involved in the delivery of public services. Stakeholder theory recognizes that the success of eGovernment initiatives depends on effectively addressing the needs, interests, and expectations of these diverse stakeholders.

While various studies have explored eGovernment initiatives and their impact in

different countries, limited attention has been given specifically to the Ethiopian context. Therefore, there is a need for research that specifically focuses on the success factors that drive eGovernment implementation in Ethiopia. By bridging this research gap, valuable insights can be gained to inform policymakers, practitioners, and stakeholders in the Ethiopian government on how to effectively design and implement eGovernment strategies, ultimately leading to improved public service delivery and citizen engagement.

3. Methodology

The research approach adopted in this study is qualitative, aiming to explore and understand the complex phenomenon of success factors that drive eGovernment implementation. Qualitative research is well-suited for capturing contextualized data allowing for an in-depth exploration of individuals' experiences and perspectives. Through qualitative research, the study seeks to gain a comprehensive understanding of the factors, dynamics, and complexities surrounding eGovernment implementation success factors.

The study adopts purposive sampling, surveys, interviews, and literature review to ensure robust data collection. Purposive sampling selects key eGovernment stakeholders, facilitating insights from officials, project managers, and IT professionals [13]. Surveys provide broad perspectives, while interviews offer qualitative depth on adoption factors. Moreover, a literature review complements primary data, situating the study within existing knowledge and guiding research questions [14] [15]. In conclusion, these methods enhance research validity and reliability, enriching our understanding of eGovernment success factors in Ethiopia. Analysis techniques include literary, thematic, and Likert scale analyses.

4. The Proposed Solution

The study on eGovernment success factors identifies six key themes that significantly contribute to the expedition of eGovernment and the enhancement of digital public services. These themes include organizational characteristics, employees' characteristics, project management, technology and infrastructure, legal and policy issues, and users' experience. Based on these themes, a conceptual model is developed, highlighting the interconnections and dependencies among the success factors.

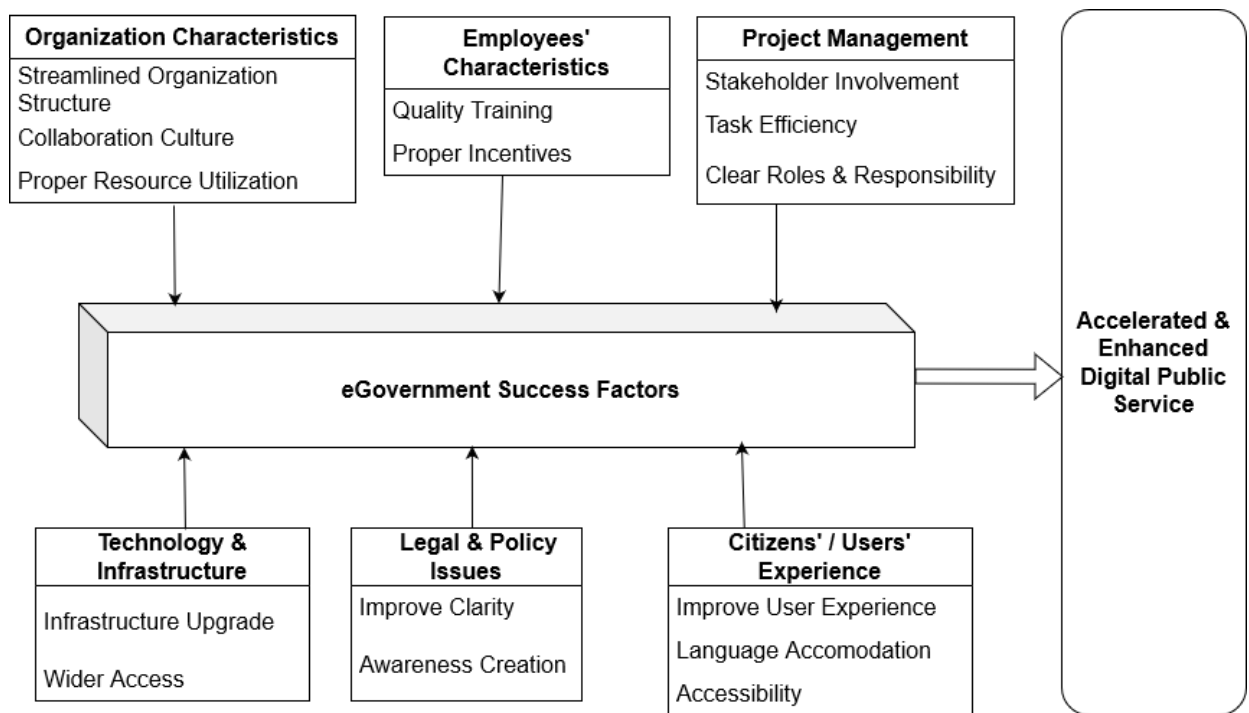


Figure 1eGovernment success factor conceptual model

The model illustrates how the organizational characteristics, employees' characteristics, and effective project management contribute to creating an enabling environment for eGovernment implementation. The model further demonstrates the significance of technology and infrastructure, legal and policy support, and prioritizing users' experience as critical drivers of successful eGovernment initiatives. This conceptual model provides a holistic understanding of the factors influencing eGovernment success and serves as a guide for policymakers and government organizations in formulating strategies and policies. It helps in recognizing the importance of integrating these themes into eGovernment initiatives to expedite service delivery, enhance citizen experiences, and foster a digitally inclusive society.

5. Discussion

The research findings highlight several areas of improvement in the eService implementation process within public service organizations. The discussion focuses on key aspects such as organization structure, collaboration culture, resource management, employee concerns, infrastructure upgrade, and the role of the legal framework.

Regarding organization structure, it is evident that streamlining the existing structure is necessary to enhance operational efficiency and effectiveness. By optimizing the organization's structure, government organizations can better align their resources and

processes with the requirements of eService implementation.

Collaboration culture emerged as another crucial factor. Increasing stakeholder involvement and promoting a culture of collaboration and cooperation are recommended. This can foster better communication and coordination among different departments, facilitating a more integrated approach to eService implementation.

The study also identified employee concerns, particularly the fear of change, as a significant barrier. To address this, it is crucial to provide comprehensive and quality training programs that address employees' concerns and enhance their confidence in using new technology. By investing in employee training and addressing their anxieties, organizations can improve overall user adoption and satisfaction with the eService system.

Infrastructure upgrade is essential for ensuring smooth and efficient operations. Upgrading the office network and workstation equipment is recommended to improve system speed, reduce downtime, and enhance the overall user experience. By investing in the necessary infrastructure, government organizations can overcome technical constraints and deliver more reliable eServices.

Furthermore, the study highlighted the importance of the legal framework. While the impact of the legal framework was perceived neutrally by respondents, improvements in its clarity, applicability, and public awareness were recommended. By focusing on these aspects, the government can ensure that the legal framework provides adequate support and guidance for successful eService implementation.

In conclusion, it is necessary to highlight the significance of addressing organization structure, collaboration culture, employee concerns, infrastructure upgrade, and the legal framework in enhancing the eService implementation process. The recommendations emphasize streamlining the organization's structure, increasing stakeholder involvement, providing quality training, investing in infrastructure, and promoting the positive impact of the legal framework. By adopting these recommendations, government organizations can successfully implement eService and provide improved services to the public.

6. Conclusion & Future Work

In conclusion, this research highlights various areas of improvement in public service organizations' eService implementation process. Organization structure, collaboration culture, and resource management were identified as crucial areas that require focused efforts. It is recommended that project managers prioritize tasks efficiently, ensure better strategy implementation, and streamline the organization's structure to achieve successful project delivery. The study also found a fear of change among employees, indicating a need for better training programs that address their concerns and improve their confidence in using new technology. The study recommends that the government invests in upgrading

office network and workstation equipment to improve the eService implementation. Moreover, there is a need to improve the quality of system training to enhance user experience and ensure wider adoption of the eService system. The study also found a neutral view on the positive impact of the legal framework on eService implementation. Therefore, the government should focus on improving the clarity and applicability of the legal framework, increasing awareness among the users, and promoting the positive impact of the legal framework to ensure the successful implementation of eService. By addressing these areas, public service organizations can achieve successful eService implementation and provide better services to Ethiopian citizens.

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A Comparative Analysis of Digital Payment Systems for Great Ethiopian Run Plc

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Abstract

The use of digital payments in emerging and developing economies is revolutionizing the way people transact in the 3rd world. By providing access to an efficient and secure payment system, digital payments are helping to reduce the reliance on cash, which can be costly and time-consuming to manage. In addition, digital payments offer the potential to reduce poverty by providing access to financial services, such as microloans, to people who previously lacked access to such services. As a result, digital payments are helping to spur economic growth in some of the poorest countries in the world. With the right infrastructure in place, digital payments can help to reduce financial inclusiveness and increase the purchasing power of citizens in 3rd world countries.

This research aimed to compare three of the widely adopted payment platforms – YenePay, TeleBirr, and Amole - in light of the rapid growth of the payment processing platforms and the number of customers the Great Ethiopian Run Plc., an event management company, has. This study was pertinent in the context of the Ethiopian Government's Digital Transformation Policy, which is driving its clients to use payment platforms/platforms to integrate their daily lives with technology.

The comprehensive comparative analysis led to the determination that, among the three examined payment systems, Amole emerged as the most commendable service provider. This conclusion stems from the substantiated evidence of positive feedback garnered from both customers and the organization itself, further accentuating Amole's exemplary adaptability to embrace and integrate emerging technologies. Such favorable outcomes position Amole as an exemplary choice within the realm of payment systems.

Keywords: Digital payment systems, secure payment,

1. Introduction

A payment platform is a type of service provided by an e-commerce application service provider that authorizes payment processing for e-businesses, online retailers, supermarkets, or traditional shops. The Platform is called a Trusted Third Party or Entry point to any network and is used in E-commerce systems for more secure transactions. Online shopping allows

customers to sit in the comfort of their homes or wherever they want to be and buy goods from all over the world. This process similarly will enable Merchants to sell their products all over the world.

With the imminent integration of our daily lives with technology, among other reasons, Ethiopian banks are driving their clients, both merchants, and buyers, to use their payment platforms/platforms, supported by the Ethiopian Government's Digital Transformation Policy.

One of the merchants that have started to adopt this new era of payment as an early adopter is the Great Ethiopian Run Plc., an event management company that was established in 2001 G.C. The Great Ethiopian Run organizes over 6 events every calendar year and has thousands of customers throughout the country as well as abroad.

Taking the rapid growth of the payment processing platforms and the number of clients the Great Ethiopian Run has into consideration, this research aims to compare three of the widely adopted payment platforms YenPay, TeleBirr, and Amole.

The Great Ethiopian Run's registration process has two parts. Payment and Registration. These two processes are currently performed separately on the company's platform and then the payment provider's platform. In addition to the 2-step process, some issues occur such as clients not being able to understand the payment process and committing errors and the payment platform not sending timely information to the company, information that is critical for the sales and management teams for decision-making.

The purpose of this study is to compare and contrast YenePay, TeleBirr, and Amole, three platforms for processing payments. The analysis will concentrate on determining their suitability in light of the Great Ethiopian Run's business strategy and requirements. The purpose is to give the organization a well-informed suggestion on which payment platform to choose to meet its goals and objectives.

2. Related Work

A Comparative Study of Different E-Commerce Payment Platforms done by Kavita [1] which reveals that user-friendliness and ease of access are two of the most important factors for consumers when choosing a payment platform. Additionally, users want to be assured of privacy when making payments via bank accounts, and there must be a way to accurately identify customer and merchant bank accounts. Comparative studies of payment platforms can therefore be useful for informing users and helping them make decisions about which payment system is best for them. Furthermore, when users feel that they can trust the payment system they are using, they are more likely to have a positive experience.

Another research by Khan et al. [2], examined the transition in payment methods from cash to cheques, to credit cards and debit cards, and currently to electronic commerce and mobile banking. The aim was to explore the use of online payments and the adoption of electronic

commerce for making payments by customers. Supporting evidence is provided for the advancements in technology, such as mobile transactions, that are making online payments more convenient and transparent, and are leading to customers becoming habitual in using this mode of payment. The statistics presented in this review indicate that the number of customers using online payments and making online transactions are growing, showing an acceptance of online payment systems from academia as well as industry. Furthermore, the review explores the opportunities and challenges associated with the adoption and deployment of new technologies in the implementation and design of secure online payment systems in the present day and the future. This review concludes that better integration of online payment systems with the current financial and telecommunication infrastructure is essential for the success of this payment mode. Additionally, establishing a common standard, improving compatibility with customers, overcoming privacy and security concerns, and utilizing the latest technology can speed up the adoption of online payment methods and expand the market. Future work should focus on legal aspects that contribute to the successful adoption of online payment systems globally.

The authors in [3, 4] has found and indicated that perceived benefit and performance expectancy have a significant positive relationship with the intention to use e-payment systems, while perceived security/privacy and perceived risk have a significant negative relationship with the intention to use e-payment systems.

3. Comparison of Digital Payment Platforms

The selection of a payment platform is a crucial decision for any organization or individual, and there are several factors that should be taken into account to ensure that the chosen platform is the right fit. Among the most important factors to consider are transaction fees, availability, speed, usability, security, and simplicity of integration. These factors may vary significantly depending on the specific platform under consideration, so it is important to carefully evaluate each platform to determine whether it meets the client's requirements and financial constraints.

To effectively compare different payment platforms, it is useful to divide the factors into two groups: the first group consists of factors that can be obtained directly from the organizations or providers of the payment platforms, such as transaction fees and security, while the second includes factors for which user feedback is particularly relevant, such as usability, speed, and availability.

By analyzing and comparing these two groups of factors, organizations or individuals can gain a comprehensive understanding of the strengths and weaknesses of different payment platforms and make an informed decision about which platform is the best fit for their needs.

In the first level comparison, an attempt is made to make a comparative investigation of payment platform providers and their different services, thus the data collected for this purpose

from the payment service providers is organized and presented in Table 1.

Table 1: Comparison of digital payment platforms and their services.

Payment Platform	Merchant Account Available?	COST			Scalability	Integration	Security
		Initial Setup	Transaction Fee for user	Commission to Agent			
Amole	Yes	None	1%	None	Working on Scalability	REST API	Multiple Securities in Place
Tele Birr	Yes	None	10 Birr Max	Up to 20 Birr per transaction	Highly Scalable	SOAP API (deprecated and outdated)	Only Password Security
YenePay	Yes	None	Up to 5%	None	Highly Scalable	REST API and Multiple Plugins for most major platforms	Multiple Securities in Place

The second group of parameters used to compare from the end-user perspective are convenience, security, Speed, Cost of signing up and other recurring fees, User Experience, Customer Support, and Availability of the system on the network. To analyze and compare these parameters, an online questionnaire has been distributed to random Great Ethiopian Run customers using a google form.

When choosing any kind of digital service provider, end-users consider various parameters to ensure that they receive the best possible experience. These parameters include convenience, security, speed, cost of signing up and other recurring fees, user experience, customer support, and the availability of the system on the network. Each of these parameters plays a crucial role in the end-users' decision-making process and can significantly impact their satisfaction with the service. By comparing service providers based on these parameters, end-users can make informed decisions and choose a provider that best suits their needs.

Parameters:

1. **User experience:** Clients rate the overall user experience of the app, including how easy it is to use and navigate, the clarity of instructions, and the accessibility of features.
2. **Speed:** Clients rate the speed of transactions, including how quickly transactions are processed and how long it takes for funds to be transferred.
3. **Reliability:** Clients rate the reliability of the app, including how often it experiences errors or crashes and how responsive the support team is in fixing issues.

4. *Customer support:* Clients rate the quality of customer support, including how quickly and effectively support requests are handled, and how well the support team understands and addresses their concerns.
5. *Availability:* Clients rate the availability of the app, including how frequently it experiences downtime or maintenance periods that limit functionality.
6. *Features:* Clients rate the features offered by the app, including how well they meet their needs and whether there are any features missing that they would like to see added.
7. *Feedback:* Clients provide feedback and suggestions for improvement to the developers, including ideas for new features or ways to enhance existing functionality.

A random sample of Great Ethiopian Run customers has received an online survey in the form of a google form in order to compare these parameters. This method might be useful for gathering information from a lot of people and then analyzing the findings to determine which service provider performs best in each parameter. To ascertain which service provider excels in each area, a questionnaire can be created to ask particular questions about each aspect, and the replies can then be quantified and analyzed. End customers can choose the service provider that is most appropriate for their needs by comparing the performance of the various service providers in each criterion.

The information in Table 2 is the result of the analysis of data gathered via an online survey from a sample of Great Ethiopian Run consumers. The chart compares the various digital service providers based on a number of factors, including ease of use, security, speed, cost of signing up and other ongoing fees, user experience, customer support, and the system's network accessibility. It is simple to compare and contrast the various service providers and their respective performances in each parameter because the data are presented in table format. These findings can be a helpful reference for customers wanting to select the best digital service provider for their requirements.

When analyzing the data collected from the survey, it is important to break it down into specific sections to better understand how each payment platform performs in comparison to the others. This means splitting the data into three different parts, one for each payment platform, and assessing the survey results for each question per platform. By doing so, it becomes easier to identify any trends or differences in the survey results between the payment platforms. For example, if one payment platform consistently receives higher ratings for its user interface, while another consistently receives lower ratings, this could indicate that one platform is more user-friendly than the other. Similarly, if one platform consistently scores higher in terms of availability, this could suggest that it is more reliable than the other platforms. Splitting the data into different parts for each payment platform allows for a more detailed analysis, which can help provide a more accurate assessment of the overall

performance of each payment platform.

The process of reaching out to customers of Amole who have previously taken part in the Great Ethiopian Run events was done through digital communication channels such as SMS, social media platforms like Facebook and Twitter, as well as instant messaging apps like Telegram. This was done in order to gather feedback from customers who had prior experience with the Amole platform and who were also familiar with the Great Ethiopian Run events. By targeting this specific group of customers, we were able to obtain a more accurate and targeted set of responses that would provide insight into the experiences of Amole users who are also Great Ethiopian Run participants. The use of digital communication channels allowed for a wider reach and ease of access for potential respondents, as they could respond to the survey in their own time and from the convenience of their own devices. Additionally, the use of digital communication also allowed for a quick and efficient method of collecting and collating the responses, which could then be used for analysis and comparison with other payment platforms. Overall, the use of digital communication to reach out to Amole customers who have participated in the Great Ethiopian Run events allowed for a more targeted and efficient data collection process.

Table 2: Customer Feedback Survey Results

Questions	Payment Service Provider		
	Amole	TeleBirr	YenePay
How clear are the instructions to use the app?	2.92	2.5	2.3
How easy do you find the application to use?	3	3	2.44
Do you find the app has the features you are looking for? (Percentage)	93.36	96.49	91.84
Transaction Speed?	3.05	3.5	2.51
How often do you experience errors and crashes	3	3.5	2.93
Is the support team responsive?	2.92	1	3.04
How is the customer support for this app?	3.05	2	3.03
How "available" is this app? Please answer this question with regards to the application working properly considering the network as well.	3.08	3.5	2.97
Does the team accept your feedback? (Percentage)	90.27	17.57	90.82

This section will present an analysis of the customer satisfaction survey results for the mobile payment platforms Amole, TeleBirr, and YenePay. The survey was conducted to evaluate the customer experience on the platforms, and several parameters were analyzed, including how clear and easy-to-use the app instructions were, whether the app had the necessary features, transaction speed, frequency of errors and crashes, the responsiveness of customer support, and the availability of the app. The survey also asked respondents whether the team accepted feedback. By analyzing the responses to these questions, we can gain

insights into the customer experience on each platform and identify areas of strength and areas for improvement.

According to the survey results, customers who use Amole as their preferred mobile payment platform are generally satisfied with the app's features, including the range of services it offers. Amole appears to have a comprehensive set of features that users are looking for, which is an important factor in customer satisfaction. In addition, Amole is seen as having a good support and feedback system. This means that users feel that they can easily get in touch with the support team and receive helpful assistance when needed. Furthermore, Amole's system is generally available, meaning that users can access the platform without any major issues.

Another strong point for Amole is its transaction speed. Users feel that transactions on the platform are generally processed in an acceptable amount of time. This is a critical factor for a mobile payment platform, as users expect fast and efficient transactions. Overall, these factors contribute to Amole's overall positive rating from customers in the survey.

The analysis of this result highlights a potential area for improvement for Amole. While the payment service provider has several strong points, such as being feature-rich, having good support and feedback systems, and an acceptable transaction speed, it seems that the clarity of initial instructions to use the app could be improved. This issue may have contributed to Amole receiving lower ratings from customers, suggesting that some users may have found the app's learning curve to be too steep. This finding indicates that Amole may want to consider revising its initial instructions to make them clearer and more user-friendly, thereby improving the overall user experience and customer satisfaction.

The results of the survey indicate that TeleBirr is perceived by its customers as a user-friendly and reliable mobile payment platform. The fact that customers find it easy to use and appreciate its transaction speed suggests that the platform is designed with user experience and convenience in mind. The low occurrence of errors and crashes indicates a stable and reliable system, which adds to the overall user experience.

Furthermore, customers find the service to be generally available and working, which is a crucial aspect of any payment platform. The ability of the platform to function properly and efficiently is one of the most important factors in customer satisfaction. A mobile payment platform that is frequently down or unavailable will quickly lose customers and credibility.

However, the survey also shows that TeleBirr may need to work on improving its customer support and feedback system. While it is not indicated as a major weakness, it still stands as a point of improvement for TeleBirr in order to maintain customer satisfaction and loyalty in the long run.

The results of the customer satisfaction survey showed that TeleBirr scored lower than its

competitors in terms of having a responsive support team, consistent support for the app, and accepting feedback from its users. This suggests that the company may need to focus more on improving its customer support and addressing user feedback in order to better meet the needs and expectations of its customers.

Having a responsive support team is important because it allows customers to receive timely assistance when they encounter issues with the app or have questions about how to use certain features. Similarly, providing consistent support for the app is crucial to ensure that customers can access the app and use it effectively at all times.

Accepting feedback from users is also important as it allows companies to identify areas for improvement and make changes that better align with the needs and preferences of their customer base. By failing to prioritize these factors, TeleBirr may be at a disadvantage compared to its competitors in terms of customer satisfaction and loyalty.

The survey results suggest that YenePay's customers have a positive experience with the platform's customer support. Customers appreciate that YenePay has a responsive support team, which is willing to assist them when needed. Additionally, the platform is perceived to have the necessary features that customers are looking for, which can contribute to their satisfaction with the service.

Moreover, YenePay seems to be open to receiving feedback from its customers, which can be a significant advantage in a competitive market. By listening to its customers and implementing their suggestions, YenePay can continue to improve its service and build a strong reputation among its user base.

However, the survey results do not provide clear information about YenePay's performance in other areas, such as the clarity of its initial instructions or the availability of its service. Therefore, further investigation may be needed to determine how well YenePay performs in these areas compared to its competitors.

However, the results also indicate that YenePay receives average ratings in several key areas. Firstly, users do not find the app to be particularly simple or easy to use, suggesting that there may be room for improvement in terms of the user interface and overall user experience. Additionally, users rated the initial instructions for using the app to be average, indicating that there may be some confusion or difficulty in getting started with the app.

In terms of transaction speed, YenePay receives an average rating, suggesting that the payment processing time may not be a significant strength or weakness of the platform. However, users did report experiencing crashes and errors with the app, indicating that there may be some technical issues that need to be addressed to improve the overall stability and reliability of the platform.

Finally, in terms of general availability, YenePay receives an average rating. This suggests

that users do not find the platform to be consistently available at all times and that there may be some issues with network connectivity or other technical challenges that impact the reliability of the service. Overall, while YenePay does receive high ratings for its support team, features, and feedback acceptance, there are several areas where improvements could be made to enhance the overall user experience and platform performance.

4. Conclusion

The purpose of this research was to conduct a comparative analysis of three payment processing platforms, namely YenePay, TeleBirr, and Amole, in order to evaluate their suitability with respect to the business model and requirements of the Great Ethiopian Run. Specifically, the objective was to provide a well-informed recommendation to the company for selecting the appropriate payment platform that aligns with its objectives and goals. This study aimed to investigate and compare the features and functionality of the platforms, as well as the user experience, reliability, and support provided by each platform. The findings of this research hope to assist the Great Ethiopian Run in selecting the best payment platform for their needs and improving the payment process for their customers.

Based on the research conducted and the analysis of the results, it is evident that Amole has emerged as the leading payment processing platform among the other two contenders, namely YenePay and TeleBirr. Amole has performed well in several categories, including having a feature-rich platform, good support and feedback system, high availability, and acceptable transaction speed.

In contrast, YenePay has been found to be an average performer across most of the metrics evaluated. Although it has a responsive support team, accepts feedback from its customers, and has some of the features required by clients, it has consistently scored average in terms of app simplicity, clear instructions, transaction speed, crashes & errors, and general availability.

On the other hand, TeleBirr has been found to lag behind its competitors in many areas, particularly customer support. TeleBirr scored the lowest in terms of a responsive support team, consistent support for the app, and accepting feedback from its customers. Although it was found to be easy to use and had good transaction speed, it had issues with availability, crashes & errors, and lacked the necessary features required by the Great Ethiopian Run.

Overall, the results indicate that Amole is the best-suited payment processing platform for the Great Ethiopian Run. Its feature-rich platform, responsive support team, and high availability make it an ideal choice for the company. However, it is important to note that selecting a payment processing platform involves several factors, and the decision should be based on the specific requirements and goals of the Great Ethiopian Run.

During the course of this study however, it came to light that TeleBirr under investigation underwent a substantial update subsequent to the completion of our research. This update

introduced significant changes to their system, rendering the findings presented in this paper potentially outdated and requiring further examination. It is important to acknowledge that the TeleBirr has implemented enhancements aimed at improving its functionality, user experience, and security measures. Although these updates have invalidated the specific findings presented in this study, they offer valuable insights into the dynamic nature of payment systems and the need for continuous research and analysis. As such, this development presents an opportunity for future follow-up research to assess the impact of the updated system and evaluate its performance against the criteria established in this study.

Acknowledging these recent advancements, it is important to approach the findings of this paper with caution and consider them within the context of the pre-update system state. The present study lays the foundation for further investigations that can delve into the implications of the recent changes and contribute to a comprehensive understanding of the evolving landscape of payment systems.

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Adopting CI/CD Technology for Internet and Mobile Banking Services Integrations in case of Bank of Abyssinia

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Abstract

Since the early 2000s Continuous Integration and Continuous Delivery (CI/CD) have become a part of the software development practices. However, this method is not well known and it is not being widely practiced in Ethiopia, let alone in Bank of Abyssinia. This is because the benefits are not well understood. This paper attempts to show the benefits of incorporating CI/CD in the development practices. The paper presents the comparative analysis made against four on-premise CI/CD tools that are being used worldwide. These are Jenkins, GoCD, Bamboo and TeamCity. And finally, the paper recommends a CI/CD tool out of the four that can be used in a development environment with a team such as the one at Bank of Abyssinia.

Keywords: continuous, integration, delivery, method, tools

1. Introduction

Bank of Abyssinia (BOA) is one of the preceding banks in Ethiopia. The Bank opened and started giving service to its customers in 1996. The bank currently has more than 10,000 employees. BOA used to be considered as one of the very late joiners in the technology sectors compared with the banks that had started along with it. However, in the past few years, it has emerged as one of the leading banks by introducing multiple pioneer technological products for its customers. BOA was the first bank to introduce Virtual Banking using ITMs, the first bank to acquire a payment gateway platform and the first bank to complete integrations telebirr. Currently BOA has finalized implementation of the first Digital banking platform in Ethiopia by acquiring a product called Temenos Infinity. BOA has more than 700 branches all over the country. And to increase its accessibility, BOA has deployed more than 1000 ATM machines and more than 2000 Point of Sale machines.

In Bank of Abyssinia a service integration with the Internet and Mobile banking solution is done very frequently. These integrations are mainly features that will be visible for customers. An Integration with DSTV, so that customers can pay their Bills on time or with EthSwitch, so that customers can send money to other member banks within the country instantly, or different kinds of billers, or merchants. But there are also constant bug fixes and enhancements that are done on a weekly basis. As the number of customers increase and the product is used frequently by a large sum of users, such developments of new features, enhancements and bug fixes have

also increased at a very rapid rate. And due to this, unlike before, more than one developer will be working on the code at the same time.

While multiple individuals are working on the code at a time, the current practice is teams take the latest code into their work station and they make all the necessary changes, such as add a new feature or fix a bug or make an enhancement without affecting any of the working functionalities that were previously done. Once the team working on the changes have finished applying their updates, the product will be built and the generated artifact is moved to the test servers for deployment. The team will then carry out the necessary tests on the new environment. If the expected result is achieved, the development team informs the business team about the new changes, so that they can perform the tests and approve the changes to be moved to the production server. After the business team approves the changes then the team makes the necessary changes to the package and will deliver the artifact to the infrastructure team for production deployment. However, when simultaneous works are done parallelly with other teams, the process will be quite different. Each team will proceed with their own updates to the code and test on their own environment, then they will prepare a separate build and test it on a different environment. All changes done by the team will be tested by the business teams separately. The business teams that will be testing the separated updates might be different as well. After the business team has finalized tests and the expected results are achieved, the process will be different, this is because all changes have to be compiled together. This is where the difficulty arises. One team must incorporate the changes done by the other team or teams and merge the changes together manually. This is a process of manually copying pieces of code from the other team or teams to their own. While doing this, usually the changes are affected and all teams must be involved, so that the issues on the features they have done will be troubleshooted and fixed. After the merge is completed, just like a new feature the steps will be repeated, internal tests by developers, move to the test environment and then let the business team carry out their tests and approve. Only then the changes can be delivered to the infrastructure team for production deployment.

This process is tedious and time taking. This way the team as a whole cannot be effective. In order to avoid the manual labor where teams merge their codes manually, the primary step will be to use some kind of git repository. By utilizing a git repository, the teams can work on their own branch and merge their changes all together. However, this will not solve the issues we face while merging the codes. Which is a merging conflict. If concurrent changes refer to the same file, we say that these changes are conflicting. As [1] states that, conflicts on a file can be automatically resolved or they need user intervention for their resolution. So, the best solution that is currently being practiced by developers all over the world is the continuous integration and continuous delivery. The idea is instead of compiling or merging the changes done by the teams after the delivery of a new feature, to merge the code very frequently and perhaps on a daily basis or even multiple times a day. The merging also will be monitored by a

CI/CD tool which senses a new merge and builds the package automatically or manually depending on the configuration to see if the code is okay. Also, the CI/CD tool will perform a series of tests that are preconfigured by the developers to make sure the code base is intact and functional.

By incorporating this process in the development practice, the teams can focus on their own features only and they do not have to worry much about manually integrating the changes made by other teams. This alone will remove a huge burden for the development team. The business team does not have to test the features separately and multiple times, because the delivery will be together. Multiple test environments do not have to be ready and configured in order to deploy multiple updates that are done at the same time. This way the overall process will be very efficient and effective. Hence, the objective of this paper is to showcase the list of available CI/CD tools and their unique features in order to help the BOA development teams in selecting a tool that will best fit their needs.

2. Related Work

According to [2] a Software Development Life Cycle (SDLC) adheres to important phases that are essential for developers, such as planning, analysis, design, and implementation. [2] continues to explain that a number of software development life cycle (SDLC) models have been created: waterfall, spiral, V-Model, rapid prototyping, incremental, and synchronize and stabilize. As stated in [2] the oldest of these, and the best known, is the waterfall model: a sequence of stages in which the output of each stage becomes the input for the next.

However, it is nearly impossible to follow the waterfall methodology while working on a product where new features are required constantly and they have to be released frequently. Hence, for projects with such nature it will be highly advisable to follow the agile approach, and sometimes it is the only way. This is mainly because new features are required frequently, but also, the requirements are usually dynamic. A new proclamation will be declared by the National bank of Ethiopia to enforce some kind of regulation, and the changes might need a new development, or the management of the bank decides that the transfer to other banks should be temporarily disabled using the digital channels. These reasons will force the development team to be very agile and practice the methodology in their product delivery process.

According to [2] agile software development is a group of software development methodologies based on iterative and incremental development where requirements and solutions evolve through collaboration between self-organizing, cross functional teams. As [2] continues agile methodology has an adaptive team which is able to respond to the changing requirements. According to [4] the Agile software development process focuses mainly on fast delivery, and CI helps Agile in achieving that speed.

Continuous Integration (CI) is a software development practice, where developers frequently integrate their work with the project's Integration branch and create a build. It is

necessary to bring out issues encountered during the integration as early as possible. According to [3] CI/CD pipelines are the perfect complement to any team using agile methodologies, in ideal situations development teams are building features that are committed to source control often. As [4] states it helps because a build failure can occur due to either an improper code or a human error while doing a build (assuming that the tasks are done manually).

Continuous Delivery (CD) is the process of moving the code base into the production environment. Continuous delivery, according to [6], is the ability to get changes of all types – including new features, configuration changes, bug fixes, and experiments – into production, or into the hands of users, safely and quickly, in a sustainable way. Traditionally, what has become a trend is that, whenever a developer or a team of developers have finished their features, they will compile their works together, run a series of tests manually, move the changes to another environment where additional tests can be done by a testing team, and if all things go right, then move it to production. [5] notes that with Continuous Delivery, the artifacts that are produced by your CI server are deployed to the production server with a single button click. This can be achieved by automating the steps that are in between the development and the production deployment.

According to [4] a CI tool is at the center of the CI system, connected to the Version Control System, build tools, Binary Repository Manager tool, testing and production environments, quality analysis tool, test automation tool, and so on.

There are many advantages to incorporating the process of CI/CD in the software development practice.

CI/CD Helps to automate testing phases: The tool can automate tests; this is done by predefining the series of tests that should be performed before a product is said to be working properly. CI/CD tool, can compile and build a source code automatically when a commit to the code happens. But testing is a manual, time-consuming, and repetitive task, automating the testing process can significantly increase the speed of software delivery. However, automating the testing process is a bit more difficult than automating the build, release, and deployment processes. According to [4] it usually takes a lot of effort to automate nearly all the test cases used in a project. It is an activity that matures over time.

CI/CD Helps in working on small batches and avoid big bang: By committing or submitting the codes to the git continuously, we can avoid colossal setbacks. This is because the more frequently we submit, the less code base we change. And since the tests are done automatically, the CI/CD tool will inform us if there's any issue or incompatibility has occurred with the existing code and anything has been broken.

CI/CD Helps reduce errors and bugs in production environment: By committing the codes more frequently and carrying out automated tests more rapidly the team can catch error at a very early age and giving a fix before it affects any other functionality, this will help increase

the quality of the code, and will greatly reduce any errors or issues that will happen in the production environment, because we have a relatively more robust system.

CI/CD Makes easy the process of recovery from failure: Each commit is registered on the git repository, but without the CI/CD tool we can't be certain which code was working properly or not. With the help of the tool, we can easily rollback to the last working build instantly and easily.

CI/CD Increases the development productivity: development teams can focus and work on their own segment, and the time they spend solving merging conflicts will be much less.

CI/CD Creates Teams efficiency: not only the developers but the entire team involved in the product, from requirement to the release will have a smoother process.

CI/CD Accelerates speed to market: the time to release a product to the market will be much faster, since many time taking tests are automated, code delivery to environments can be automated, and integration process is quickened. Though it's not recommended, the production deployment can also be automated, but it is best to do that manually, because there might be a test that can't be automated and must be done manually.

Jenkins as stated in [6] is an open-source automation server written in Java, with very active community-based support and a huge number of plugins, it is one of the most popular tools for implementing continuous integration and continuous delivery processes.

A Jenkins Pipeline is a workflow with a group of events or jobs that are chained and integrated with each other in sequence. A continuous delivery (CD) pipeline as noted in [10] is an automated expression of your process for getting software from version control right through to your users and customers. [10] also notes that a Pipeline is a user-defined model of a CD pipeline. A Pipeline's code defines your entire build process, which typically includes stages for building an application, testing it and then delivering it.

Bamboo as stated in [9] is a continuous integration (CI) server that can be used to automate the release management for a software application, creating a continuous delivery pipeline. The product is supplied by Atlassian, which provides tools such as Jira, Trello, Confluence, Bitbucket and others. These products are used by many project managers and their respective teams due to their easy to use and rich interfaces. As a result, it can also be integrated with these products.

GoCD is one of the recently emerged competitors in software automation, and claims to have been designed for complex workflows that can be defined as code. GoCD integrates with many popular external tools and services via its extensible plugin architecture. [12] argues that GoCD helps to troubleshoot a broken pipeline by tracking every change from commit to deploy in real time. GoCD was originally released by ThoughtWorks in 2014, and it is based on the CruiseControl automation tool.

Volodymyr Melymuka [7] described TeamCity as a very light instrument, easy to install, integrate, and maintain. According to [7] TeamCity is a tool which helps to ensure that a software project not only compiles properly but can be assembled and (ideally) allowed to be delivered to operational destination production servers merely by glancing at the TeamCity welcome page. As claimed by [7] for distributed teams, it could give a priceless experience of having a reliable codebase free from some forgotten to be committed source files and resources.

For comparing these technologies, it is mandatory to select the parameters first. [13] has mentioned 7 criteria that are crucial while selecting a software. Functionality & Ease of Use, Vendor Viability, Technology, Cost, Support and Training, Industry Expertise and Implementation. Since we are currently taking an off the shelf product without any customization, we can ignore the vendor related criteria and focus on the others.

3. Methodology

I have selected four CI/CD technologies to be compared in this paper. These technologies are selected out of many because they can be configured and used on-premise. In a bank, usually the connectivity in the work stations with access to the banks servers are kept out of Internet access or with a very limited access to the Internet. This is due to security concerns and having an on-premise solution for such tasks is advantageous. After selecting the four CI/CD technologies five parameters were used to compare each of them, these are: Learning Curve, Initial Setup, Supported Plugins, Resource & Support Community and at last License & Cost. These parameters were measured by referring to the literature found, the contents found on the technology providers web pages and finally by experimenting on the technologies on my local machine. Some parameters are assigned ordinal variables. Learning curve, with rating variables, easy, medium and difficult based on the amount of time it will take the BOA team to adopt the technology and the complexity of the system. Supported Plugins, with rating variables, low and high based on the available numbers mentioned or indicated. Resource & Support Community, with rating variables low and high based on the literature found. All parameters are combined together and presented in a tabular form.

For selecting the final technology out of the four, License & Cost has been given the most priority and only the most rated technologies for this criterion are selected to be recommended. The final CI/CD technology selected shall make the development team at BOA more effective.

4. Comparative Analysis

4.1. Learning Curve

While adopting any new technology, we need to consider the learning curve of the product we are going to adopt. Currently many of the developers at Bank of Abyssinia do not yet understand the necessity of a CI/CD tool. Even if they are aware or became aware of the advantages it can give them, it means nothing if the product is complex to understand and that it requires long hours of training and dedication to make it useful for the team. The team will

definitely be very hesitant to adopt such technology and it is more likely that the product itself will be inefficiently used. Hence, we have to consider this before selecting any product and introducing it to the team.

All products selected here in this paper have more or less similar Interfaces and navigation and they appear to be somewhat easy to use from a glance. But for someone who is not familiar with the concept of CI/CD, it is very tricky to understand what the front-page supplies.

In Jenkins creating a series of tasks to make a pipeline can be easy if one is using a Freestyle project. And a freestyle job will be used to execute one specific task. However, in the Post-build actions, we can attach or link another Project to an existing one to address the subsequent actions. This could be a Unit test then an Integration Test, then a User Acceptance test and so on. However, this has its own downside, this is because of the UI. The UI based configuration in Jenkins is very limited, it presents predefined fields to be used based on the specific plugin selected. So to address this limitation, Jenkins uses Pipeline types of projects which is a scripting based project. Using Pipeline Jenkins introduced a much more flexible process. In order to use Pipeline, we need to learn the scripting language used. Pipelines are built with simple text scripts that use a Pipeline DSL (domain-specific language) based on the Groovy programming language. Groovy [14] is an object oriented and Java syntax compatible programming language built for the Java platform. This will be an easy process for the BOA team to adopt it, since the team is capable of writing java codes.

In bamboo, the process is more or less similar with that of Jenkins, however some of the terminologies are different. Here, we do not create a pipeline, rather we create a project. A project contains a plan and a plan contains jobs. Configuration of basic projects and running different builds are very easy. For a more complex configuration, Bamboo provides the scripting method called Bamboo specs. The specs can be written using Java or YAML. For a naive user the YAML seems to be very easy to understand and more preferable, but this too means the team needs to understand such scripting languages to make the best out of the product. However, since the team is capable of understanding and writing java code, it will be easy to adopt it.

GoCD gives a setup that is very similar to Jenkins. It uses a pipeline, while creating a new pipeline, the steps are very simple to follow. The setup is segregated by parts. Each part briefly explains what is expected. First a repository, then a pipeline name, a stage name and finally jobs & tasks. It presents an easy process for anyone who is well aware of what they are going to do, regardless of their experience on the GoCD platform. GoCD also provides the option Pipeline as a code, in which a more experienced user can utilize it for a rapid and complex setup. GoCD allows the configuration of Pipeline as a code using a declarative language rather than an imperative language, and for this it utilizes JSON, YAML and XML formats. The configuration could be part of the repository or it could also be separate from the code

repository. For the BOA team they work with both JSON and XML, however the tags used need to be understood, and it might take them time to get familiar with those. Hence the effort will not be as easy as writing java code.

The way TeamCity handles build configuration relates with that of Bamboo. We initially set up a project and the project configuration contains VCS (version control system) steps and a build step. When the code is fetched from the git repository, it automatically detects the possible build that can be configured. For Example: if the repository contains a java maven project, it senses the project type and provides build steps for the maven test. For a non-UI configuration, TeamCity provides configuration as code, but for this they use a full featured programming language called Kotlin. Even if using this full-fledged programming language makes it possible to create a configuration with complex requirements, it also adds an additional headache for anyone who will be administering the CI/CD tool. And for the team at BOA this is a new language that has not been used before, as a result it will be time taking to learn this new language.

4.2. Initial Setup

All tools presented here have a relatively very easy setup process with the exception to Bamboo. Jenkins installation is easier and it does not require any additional database for installation. This can also be a downside depending on the requirement we have. While setting up bamboo, the initial license key has to be requested from the Atlassian account, without the license no one can proceed and use the tool even for the free version available only for 30 days. Bamboo, GoCD and TeamCity have provided the options to install the tool using internal database H2 for GoCD and Bamboo, HSQLDB for TeamCity or using external DBs such as MySQL and PostgreSQL. In addition to these, bamboo supports MSSQL and Oracle as well. All tools support major operating systems, Multiple Windows and Linux Distributions and MacOS. On top of these, they all support docker setup as well. For initial installation all tools require Java 1.8 and above. The hardware specs differ for each tool. GoCD, with the least recommended requirement, suggests 2GB for server and 256MB for agent RAM, 2 cores(2GHz) for server and 1 core(2GHz) for agent CPU and 1GB minimum free space. Bamboo recommends (for individual and small teams) 4GB RAM and 20GB space should be allocated, though the installation size is 144MB. Jenkins recommendation is very generic with 4GB of RAM and 50GB of Storage. TeamCity is the most resource intensive compared to the listed tools, the size of the installer itself is more than 1.7GB. They note that for a minimal setup, 8GB Ram with Intel 3.2 GHz dual-core CPU and 1GB Network adapter can provide acceptable performance. All tools are web-based applications; hence they require a web browser to run the interfaces.

4.3. Supported Plugins

Jenkins, according to their official website, have more than 1800 plugins that are contributed by the open-source support community. The others even if they do not advertise their number

of plugins, compared to Jenkins they have a very lesser count. However, this doesn't mean we have a problem with building, testing and deploying a project. Unlike Jenkins, which requires a plugin for each task to be done, the others come with built-in plugins which allow the tools to do certain tasks. TeamCity has built-in capability for triggering builds automatically, or using specific versions of maven and gradle (as long as the gradle and maven versions are not newer than TeamCity release date). Bamboo has built-in plugins for all Atlassian project integrations, such as Jira, bitbucket and confluence. GoCD comes with bundled plugins for LDAP, YAML, JSON and password file authentication.

4.4. Resources and Support Community

As one of the oldest and most popular products, Jenkins has a lot of resources online. The website itself provides a well-documented guide for a beginner and there can be found numerous resources outside of the official website. According to [6] Jenkins is highly plugin-oriented, it has a great community that constantly extends it with new features. GoCD has sufficient documentation for a beginner, but [8] states that the quality of the official documentation was found to be uneven and it was sometimes lacking or confusing, which can be a hindrance. GoCD and TeamCity have an active forum where a participant can raise any question and receive any support directly. Unlike Jenkins, the resources found outside the forum and official website are somehow limited. Considering Bamboo and TeamCity, their documentation is very sufficient for anyone who is using them for their common features. But they are enterprise solutions and they provide SLA with the paid subscription

4.5. License & Cost

While Jenkins and GoCD are open-source tools they do not come with any license cost. The only cost they will incur is the resources to be used. However, TeamCity and Bamboo have license options. TeamCity for minimal operation the license is free, but it's limited to 100 build configurations, 3 agents and support via forum and issue tracker. But for dedicated technical support, unlimited build configuration and 3 agents there is a \$1,999 payment for the first year and \$999 for the second and onwards. The price increases as the number of agents increase. An agent according to [11] listens for the commands from the TeamCity server, it can be configured separately from the server. The main advantage of the separation is to set it up in different operating systems, so that we can test our codes using different system setups. But for the case of Bank of Abyssinia, 3 agents can be considered very sufficient. Bamboo provides the application free of charge for the first 30 days, which is a trial period, after that the license will expire unless it is purchased. The product is available for \$1,200 with 1 agent, \$3,200 with 5 agents. The 5 agents are more than enough for our use cases.

Finally, all parameters are combined together in Table 1 below.

Table 1: All Comparison parameters combined together

	Jenkins	Bamboo	GoCD	TeamCity
Learning Curve	Easy	Easy	Medium	Difficult
Initial Setup	RAM Size: 2GB for Server and 256MB for agent CPU: 2 cores (2GHz) for server and 1 core (2GHz) for agent Storage: minimum 1GB space	RAM: 4GB Storage: 20 GB	RAM: 4GB Storage: 50 GB	RAM: 8GB CPU: 3.2 GHz dual core Network Adapter: 1GB Installer: 1.72 GB
Supported Plugins	High	Low	Low	Low
Resource and Support Community	High	Low	Low	Low
License & Cost	Free	\$1,200 with 1 agent \$3,200 with 5 agents	Free	\$1,999 - year 1 and \$999 for subsequent years

4.6. Recommendation

The practice followed by the development team of Bank of Abyssinia working on Mobile and Internet banking products is currently outdated. The team is responsible for major product releases that directly affect the customer. This practice needs to be updated soon. The initial and major step to take is to have a centralized git repository. There are numerous git repository options, some provide an online service such as github, gitlab and many others and some could be configured on-premise. Once this is accomplished the subsequent step will be incorporating a CI/CD method to the process of the development. Selecting a tool that can facilitate this can be a difficult process, especially in an environment where the necessity of the method is not yet well understood. In order to select the best tool for the team and the bank, four well known CI/CD tools are selected. I have compared the tools based on their Learning curve, initial setup, supported plugins, resource & support community and finally their license & cost. As shown in Table 1.0, Jenkins has an easier learning curve, is relatively less resource intensive, has a high number of plugins and high resources available with a support community and most importantly it is free. Hence, Jenkins is the obvious choice to be selected based on the parameters defined.

5. Conclusion

CI/CD has been part of the software development life cycle since the early 2000s. The practice introduced many advantages for teams consisting of multiple individuals and with

frequent updates and maintenance are involved. The tools presented in this paper will help Bank of Abyssinia's development team to utilize their time efficiently, have a cleaner and maintainable Internet and Mobile Banking product and assist them greatly in the collaborative work they do within the team from build to test until the product is deployed and delivered to the customers. My final recommended tool is Jenkins, which is a free and open CI/CD technology. While utilizing a completely open-source product some unresolvable issues might occur, the support from the community might not be sufficient. During such times an enterprise solution comes in handy because they come with an SLA. But before going forward with such solutions, it is ideal to use free tools to get familiar with the process of CI/CD. The performance of the tools has not been measured and brought for analysis. This is because of the lack of the proper lab resources to conduct such tests. In the future, it will be ideal to incorporate such parameters in order to give a more reliable recommendation.

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A Comprehensive Analysis of Enterprise Architecture Frameworks for Information Network Security Administration

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Abstract

The majority of firms these days find it difficult to select the best Enterprise Architecture (EA) framework, mainly because there are so many intricately different frameworks available, each of which is designed to meet particular organizational requirements. When faced with distinct business requirements and complex frameworks, decision-makers frequently find it challenging to identify the best course of action. There are more layers of complexity due to the requirement for alignment with business goals and the need for a flexible framework that can adjust to changing market conditions and technologies. To overcome these obstacles, a thorough assessment procedure is necessary.

This research conducted a comparative analysis on three well-known EA frameworks in the context of INSA: Federal Enterprise Architecture (FEA), Zachman Framework and The Open Group Architecture Framework (TOGAF). The evaluation covers each framework's core components, including its scope, purpose, usability, adaptability, tool support, community, governance and compliance, cost and licensing, updates and evolution, and alignment with organizational goals which will give a better perspective in selecting an outstanding framework.

Keywords: Enterprise architecture framework, TOGAF, Zachman, Federal Enterprise Architecture

1. Introduction

An enterprise architecture framework is an organized way that provides direction, principles, and methodologies for designing, planning, applying, and managing enterprise architectures. It serves as a foundational structure to organize and align various architectural artifacts, processes, and tasks within an organization. Furthermore it help organizations align their business objectives, technology investments, and capabilities, ultimately supporting effective decision-making process.

Architectural frameworks serve as a shared vocabulary and set of best practices for architects, stakeholders, and teams engaged in architecture design. They promote consistency,

compatibility, and alignment with business goals across domains (e.g., business, data, applications, technology). Embracing architectural frameworks empowers organizations to navigate the intricacies of technology adoption and attain strategic objectives effectively.

Choosing the best architectural framework for INSA is a strategic decision that can have a long lasting impact on its architecture development and management practices. By considering the factors mentioned above, this research will conduct analysis on different frameworks that will assist the decision making of the organization in selecting a framework that best supports its unique needs [1].

Hence, the objective of this study is to conduct a comparative analysis to recommend the most prominent and outstanding Enterprise architectural Framework providing Information Network Security Administration with good insights that support the decision-making process to select the most appropriate framework that can strategically align technology with business objectives.

2. Related Work

Architectural Frameworks are differ based on their effectiveness in providing guidance and structure for enterprise architecture development and management. While the specific findings were not mentioned, the study likely analyzed factors such as the comprehensiveness of the frameworks, their ability to align business goals with technology decisions, the clarity of communication and understanding they facilitate among stakeholders, and their adaptability to different organizational contexts. By considering these essential elements, the evaluation provides insights into the strengths and weaknesses of the enterprise architecture frameworks, aiding organizations in selecting the most suitable framework for their needs[2].

The authors in [3] evaluated and compared different enterprise architecture frameworks in the relation to e-government projects. The authors provide a comprehensive evaluation methodology, considering factors such as alignment with e-government principles, scalability and security. The paper also tries to analyze the strengths and weaknesses the frameworks and emphasize the importance of customization to meet the specific needs of e-government. The article tries to provide valuable insights to assist the adoption of the right enterprise architecture frameworks for decision-makers and practitioners involved in e-government initiatives [2].

In this article [4], the author conducts a comparative analysis of four prominent enterprise architecture frameworks. The frameworks analyzed in the research are Zachman Framework, TOGAF and FEA. The author evaluates these frameworks based on different key criteria this are scope, purpose, structure, flexibility, and adoption. The analysis aims to identify the strengths and weaknesses of each framework and provide insights into their applicability and effectiveness in different organizational contexts. By comparing and contrasting these

frameworks, the paper offers valuable guidance to practitioners and organizations seeking to select an appropriate enterprise architecture framework for their specific needs.

As modern organizations struggle with the complexity and dynamicity of their business environments, they increasingly turn to Enterprise Architecture as a means to organize their capabilities. However, adopting Enterprise Architecture is hardly a straightforward matter as the practical guidance available is plagued by disparity in nomenclature as well as content[5].

It is clear that the modern organization needs a new blueprint in order to stay ahead of the game – or at the very least stay in the game. To this end, much attention has been paid to Enterprise Architecture over the past couple of decades – not just as a means to improve competitiveness, but also to reduce complexity, increase changeability, provide a basis for evaluation [6].

EA in strategic context is directed at the current and future purposes of the organization as well as to assist in reaching organizational goals and objectives, including ensuring that the business with its technologies and resources are aligned. However, enterprises often experience challenges with the implementation of EA initiatives and capabilities, resulting in sentiments documented mostly in popular press [7].

TOGAF is a widely adopted enterprise architecture methodology and framework that provides a systematic approach for designing, planning, implementing, and governing an enterprise's information architecture. A comprehensive set of tools and resources, including a structured methodology, guidelines, and a framework for developing and managing enterprise architecture, are provided by The Open Group, which is responsible for its development and upkeep. TOGAF divides the enterprise architecture process into phases, addressing areas such as business, data, application, and technological architecture. It highlights how crucial it is to coordinate business and IT objectives, encourage standardization, and guarantee resource efficiency. In the realm of enterprise architecture, TOGAF has established itself as the de facto standard, offering businesses a scalable and adaptable method for controlling system complexity and advancing their strategic goals [8].

Zachman is a widely recognized and influential enterprise architecture framework which provides a structured approach for organizing and understanding complex enterprises. Six viewpoints are used in its classification of architecture artifacts: What (data), How (process), Where (location), Who (people), When (time), and Why (motive). Each viewpoint is then broken down into columns that show the opinions of many stakeholders, ranging from senior management to in-depth system developers. Zachman Framework: Promoting a shared understanding among stakeholders and facilitating efficient communication between different organizational levels, the framework highlights the necessity of an all-encompassing and integrated approach to enterprise architecture. For companies looking to match their information systems, technology infrastructure, and business procedures with their strategic

goals, it acts as a cornerstone tool[9].

The Federal Enterprise Architecture (FEA) is a framework developed by the U.S. government to enhance the efficiency, effectiveness, and transparency of federal agencies' operations. The FEA provides a structured approach to organizing and aligning an agency's business processes, data, applications, and technology. It comprises five reference models: Performance Reference Model, Business Reference Model, Service Component Reference Model, Data Reference Model, and Technical Reference Model. These models work collaboratively to guide federal agencies in developing and implementing enterprise architectures that support their mission and business goals. The FEA aims to facilitate interoperability, information sharing, and collaboration among federal agencies, ultimately improving the delivery of government services and enhancing the overall effectiveness of federal programs[10].

3. Comparative Analysis

Conducting a comparative analysis of three prominent enterprise architecture frameworks, namely TOGAF, Zachman, and Federal, offers valuable insights into their effectiveness and applicability within diverse organizational contexts. This research focuses on evaluating these frameworks across seven criteria: SCOPE, Usability, Adaptability, Tooling Support, Community and Support, Cost and Licensing, and Updates and Evolution. And since INSA is an organization with multiple and complex functional units these criteria will give a better point of view in identifying suitable architectural framework.

Scope: Scope describes the extent and detail of a framework. It defines what characteristics of an organization (e.g., departments, processes, systems) the framework encompasses. By stating the framework's boundaries, the scope guides its application and ensures a clear understanding of its applicability[11].

Scope	Rating
Large Scale (e.g., scoped to an entire organization or involving multiple organizations)	High
Medium Scale (e.g., scoped to multiple departments or teams within an organization)	Medium
Small Scale (e.g., scoped to a single department or team)	Low

Usability: Usability of a framework directly influences its adoption, effectiveness, and the overall success of architectural initiatives within an organization. Usability encompasses how easily and efficiently users can interact with and derive value from the framework[12].

Usability	Rating
Users can quickly grasp how to use the product/service, even without prior experience.	High

Users require some time and effort to learn how to use the product/service effectively.	Medium
Users struggle to understand how to use the product/service even after repeated attempts.	Low

Adaptability: Adaptability ensures that a framework can evolve and respond effectively to changes in business strategies, technological advancements, and organizational priorities. Adaptability is vital for maintaining the relevance and effectiveness of an architecture framework over time[13].

Adaptability	Rating
The system/process/product is highly flexible, allowing for easy modification and customization to meet diverse needs.	High
Some degree of flexibility exists, but significant changes require substantial effort or expertise.	Medium
The system/process/product is rigid and difficult to modify or customize.	Low

Tooling Support: Availability and effectiveness of tools also impact the efficiency, productivity, and success of architectural initiatives within an organization. Tooling support refers to the list of software tools and utilities that aid and enhance the capabilities of the architecture framework [14].

Tooling Support	Rating
Support many tools	High
Support limited tools	Medium
Support few tools	Low

Community and Support: The strength of the community around a framework and the availability of support and resources affect the success and effectiveness of architectural within an organization. The community encompasses practitioners, users, developers, and experts who contribute to discussions, share insights, and provide assistance

Community and Support	Rating
Active and vibrant user community, with frequent discussions, contributions, and interactions, fostering a sense of collaboration and knowledge-sharing.	High
Some engagement within the user community, with occasional discussions, contributions, and interactions among users.	Medium
Limited activity and participation within the user community, with few discussions, contributions, or interactions.	Low

Cost and Licensing: Financial aspects of adopting and maintaining a framework another concern of organization in budget, resource allocation, and overall cost-effectiveness. Careful

consideration of cost and licensing assist organizations make informed decisions that align with their financial objectives and constraints.

Cost and Licensing	Rating
Free(Open source)	Very High
The product or service offers excellent value for its cost, with pricing options that cater to a wide range of budgets and needs.	High
The pricing is reasonable for the value provided, but may still be a significant investment for some users or organizations.	Medium
The cost of the product or service is prohibitively high for many users, making it inaccessible to all but the largest organizations or budgets.	Low

Updates and Evolution: The capacity of a framework to become accustomed, grow, and stay up to date with technological advancements directly impacts its long-term viability and effectiveness.

Updates and Evolution	Rating
Updates are infrequent, with long intervals between releases, resulting in delays in addressing bugs, adding features, or improving performance.	High
Updates are released periodically, but may not always address user feedback or introduce significant new features.	Medium
Updates are frequent and regular, with continuous improvements, bug fixes, and feature enhancements based on user feedback and market trends.	Low

Based on the parameters discussed above, a qualitative rating is made and the results obtained are shown in the table below.

Framework	Scope	Core Concepts	Rating
1. TOGAF (The Open Group Architecture Framework)	- Comprehensive, holistic approach to EA. - Spans business, data, application, and technology architecture.	- Business Architecture - Data Architecture - Application Architecture - Technology Architecture	High
2.Zachman Framework	- Matrix-based structure with six perspectives and six interrogatives. - Offers a structured view of an enterprise.	- Planner's View - Owner's View - Designer's View - Builder's View - Subcontractor's View - Functioning Enterprise's View	High
3. FEA (Federal Enterprise Architecture)	- Tailored for the U.S. federal government. - Encompasses various domains and perspectives.	- Performance Reference Model - Business Reference Model - Data Reference Model	Medium

		- Service Component Reference Model - Technical Reference Model - Transition Strategy	
Framework	Usability		Rating
1. TOGAF (The Open Group Architecture Framework)	- Ease of Use: Generally considered user-friendly with a well-defined methodology. - Training and Documentation: Abundant resources available for training and documentation.		High
2. Zachman Framework	- Ease of Use: Requires a deep understanding and training due to its matrix-based structure. - Training and Documentation: Resources available but may be more specialized.		Medium
3. FEA (Federal Enterprise Architecture)	- Ease of Use: Usability may vary; tailored for the U.S. federal government context. - Training and Documentation: Specific resources available for federal agencies; may not be as widely applicable.		Low
Framework	Adaptability		Rating
1. TOGAF (The Open Group Architecture Framework)	- Flexibility: Offers a modular and flexible structure, allowing organizations to adapt and tailor the framework to their specific needs. - Customization: Provides guidance for customization, ensuring alignment with organizational goals.		High
2. Zachman Framework	- Flexibility: Structured approach may limit flexibility for adaptation, especially for organizations with specific needs outside its matrix structure. - Customization: Customization may be challenging due to its detailed matrix structure.		Medium
3. FEA (Federal Enterprise Architecture)	- Flexibility: Tailored for the U.S. federal government context, which may limit flexibility for organizations outside this scope. - Customization: Customization may be more challenging due to its specific focus on federal requirements.		Low
Framework	Tooling Support		Rating
1. TOGAF (The Open Group Architecture Framework)	- Abundance of Tools: Supported by a wide array of specialized tools designed to assist in various phases of the TOGAF ADM (Architecture Development Method). - Maturity of Tools: Tools are often mature and well-established in the industry.		High
2. Zachman Framework	- Limited Specialized Tools: While tools exist, the availability of specialized tools is more limited		Medium

	compared to frameworks with a broader industry adoption. - General Modeling Tools: Often used with general-purpose modeling tools.	
3. FEA (Federal Enterprise Architecture)	- Alignment with Federal Standards: Tools aligned with federal standards are available to support FEA implementation within the U.S. federal government. - Limited Industry Adoption: Tools may have limited adoption outside the federal sector.	Low
Framework	Community and Support	Rating
1. TOGAF (The Open Group Architecture Framework)	- Large Community: Boasts a large and active community globally, facilitating knowledge exchange and collaboration. - Official Support: Supported by The Open Group, providing official documentation, training, and certifications.	High
2. Zachman Framework	- Smaller Community: Has a smaller community compared to TOGAF, which may limit the availability of resources and knowledge sharing. - Official Support: Officially supported by the Zachman Institute, offering training and certifications.	Medium
3. FEA (Federal Enterprise Architecture)	- Specialized Community: Has a specialized community primarily within the U.S. federal government sector. - Official Support: Supported by federal agencies and specific training programs tailored for government use.	Medium
Framework	Cost and Licensing	Rating
1. TOGAF (The Open Group Architecture Framework)	- Framework Cost: TOGAF itself is free and open-source, allowing organizations to access its standard without direct costs. - Training and Certification: Costs are associated with training and certification programs, often provided by third-party entities.	Very High
2. Zachman Framework	- Framework Cost: The framework itself is available for use without direct costs, as it is primarily a conceptual framework. - Training and Certification: Costs are associated with training and certification programs, often provided by third-party entities.	Very High
3. FEA (Federal Enterprise Architecture)	- Framework Cost: The FEA framework is publicly available and does not have direct costs associated with its use. - Training and Certification: Costs may be incurred for specialized training programs aligned with federal requirements.	Very High

Framework	Updates and Evolution	Rating
1. TOGAF (The Open Group Architecture Framework)	- Regular Updates: TOGAF undergoes regular updates facilitated by The Open Group, ensuring alignment with contemporary industry practices. - Community Contributions: Open to contributions from the community, fostering continuous improvement.	High
2. Zachman Framework	- Stable Core Concepts: The core concepts of the Zachman Framework have remained relatively stable over time with periodic refinements. - Moderate Evolution: Evolution occurs, but major updates are less frequent compared to some other frameworks.	Medium
3. FEA (Federal Enterprise Architecture)	- Government Focus: Primarily tailored for the U.S. federal government, updates align with government standards and mandates. - Adaptations for Modernization: Periodic adaptations to modernize and align with changing federal requirements.	Medium

Based on a comprehensive analysis and the results obtained, the Open Group Architecture Framework (TOGAF) is a superior choice for INSA. It aligns with organizational objectives, fosters collaboration, and maintains governance and compliance standards. TOGAF's cost-effective licensing options, regular updates, and evolution make it a compelling choice for architectural excellence and future-proofing IT landscapes.

4. Conclusion

In conclusion, TOGAF stands out as the best architecture framework when taking into account a thorough evaluation across a range of criteria for Information Network Security Administration, even though the Zachman Framework, Federal Enterprise Architecture (FEA) and TOGAF each bring distinct strengths to the field. Because of TOGAF's wide breadth, INSA can handle a wide range of architectural issues and provide an all-encompassing approach to enterprise architecture. Because of its clear objectives, which prioritize the development and enhancement of enterprise architectures, TOGAF is positioned as a flexible and strategic instrument for INSA seeking to match its IT strategy with business objectives. Mature and well-established, TOGAF is distinguished by its robustness and reliability, which are a result of its substantial documentation, standardized methods, and broad industry acceptance.

Additionally, TOGAF excels in usability, scalability, and adaptability, providing a user-friendly environment, scales with organizational growth, and adapts to evolving technological landscapes. The framework's strong tooling support, rich ecosystem, and engaged community contribute to its overall usability and effectiveness in real-world scenarios. TOGAF's commitment to governance, compliance and alignment with

organizational goals reinforces its suitability for INSA seeking a comprehensive architecture framework that addresses regulatory requirements, mitigates risks, and aligns architectural activities with overarching business objectives. While cost and licensing considerations may vary, TOGAF's prominence and the breadth of its features make it a compelling choice, and its continuous updates and evolution underscore its commitment to staying at the forefront of architectural practices. In this comparative analysis, TOGAF emerges as the best-suited architecture framework for Information Network Security Administration seeking a holistic, adaptable, and strategically aligned approach to enterprise architecture.

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