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PREFACE

We would like to present, with great pleasure, the third issue of Matrix: Jurnal Manajemen Teknologi dan Informatika in Volume 15, 2025. This journal is under the management of Scientific Publication, Research and Community Service Center, Politeknik Negeri Bali, and is devoted to covering the field of technology and informatics management including managing the rapid changes in information technology, emerging advances in electrical and electronics and new applications, implications of digital convergence and growth of electronics technology, and project management in electrical, mechanical or civil engineering. The scientific articles published in this edition were written by researchers from Institut Teknologi dan Bisnis STIKOM Bali, Politeknik Negeri Bali, Universitas Pendidikan Ganesha and Universitas Warmadewa. Articles in this issue cover topics in the field of A TOGAF-based information governance model for the digital transformation of SMES, Strengthening CRM based on live chat for customer service performance audits, A decision support system for Ogoh-Ogoh assessment based on SMART and SAW methods in the context of Balinese cultural preservation, Android-based decision support system using MAGIQ-MARCOS for digital bank selection, Improving 5G wireless networks through OFDM integration with convolutional coding and pulse shaping. Finally, we would like to thank the reviewers for their efforts and hard work in conducting a series of review phases thoroughly based on their expertise. We hope that the work of the authors in this issue will be a valuable resource for other researchers and will stimulate further research into the vibrant area of technology and information management in specific, and engineering in general.

Politeknik Negeri Bali, 30 November 2025

Editor-in-chief

Dewa Ayu Indah Cahya Dewi, S.TI., M.T.

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A TOGAF-based information governance model for the digital transformation of SMES

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Abstract: Digital transformation is key in business processes, including for Small and Medium Enterprises (SMEs). With digital transformation, a company can change the way it serves its customers, but this implementation carries high risks due to limited resources and management changes. SMEs often face obstacles in adopting new technologies, such as financial constraints, lack of technical skills, and barriers in technology implementation and human resources. Good IT governance is necessary for SMEs to survive technological developments. In general, business processes that already run are still done conventionally, thus governance needs to be implemented. From these problems, a strategic plan is needed that can produce a blueprint framework which is needed by the company. The findings of this study consist of TOGAF ADM-based architectural artifact documents, which serve as a foundation for identifying technology mappings that can be developed in alignment with the existing business processes of small and medium-sized enterprises (SMEs). A blueprint framework can be used by SMEs to determine the priorities and stages of system development over the next few years to be carried out, of course, by considering internal and external factors. From the results of the framework, the development of information systems for marketing and selling SME products is carried out to overcome problems such as the lack of knowledge of partners in marketing so that it has an impact on partner income. With structured IT governance, SMEs can align IT strategies with business goals and develop information systems that support business continuity in the future.

Keywords: Blueprint Development for SMEs, Strategic Planning, Technology, TOGAF ADM

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Introduction

Digital transformation has become a central part of business processes used by many companies, including Small and Medium Enterprises (SMEs) [1]. Digital transformation enables companies to use digital technologies to change the way they deliver services to customers. Digital transformation not only involves the adoption of new technologies, but also includes fundamental changes in how companies operate, serve customers, and create added value. The implementation of digital transformation in SMEs carries considerable risks due to their smaller organizational structures and less mature change management practices. SMEs often face obstacles in implementing digital transformation, such as limited resources, financial constraints, lack of technical skills, and challenges in adopting new technologies [1]. In the current condition, SMEs operate in an environment with rapidly evolving technologies, which requires the ability to quickly adapt to technological changes [2], [3]. Many SMEs still rely on conventional processes, such as product marketing, product sales, and payment transactions [4]. SMEs that have adopted technology will remain resilient amidst technological developments, whereas those with minimal use of technology will experience decline and struggle to compete with other competitors [5], [6].

This research will focus on a group of bamboo weaving SMEs in Kayubihi Village, Bangli Regency. Here there are many bamboo weaving craft distributors, with the products all still sold in the traditional way. A number of problems in the practice of IT governance management exist. These challenges are influencing the business operations of SMEs since these cannot compete

with other (larger and multinational) firms (lacking HR and monetary resources, and the capacity to follow technological developments on quick rate) [7], [8]. It is, therefore important to have a good strategic plan that will lead to increased revenue and guarantee the sustainability of these SMEs in the digital age.

The issues described above represent the underlying background of current challenges faced by SMEs, particularly the limitations in resources and competitive pressure from other businesses. These conditions demand that SMEs align their business processes with existing technologies. One of the most common problems and challenges in SME operations lies in product marketing and sales, which are still carried out using conventional methods. This significantly affects their ability to grow and sustain their business amidst technological challenges. With the rapid development of technology, SMEs are required to remain competitive and resilient. Therefore, they have to develop their businesses by integrating current business processes, especially the products marketing and sales with information technology implementation. This alignment process requires proper governance to ensure sustainability and competitiveness. Therefore, effective governance is essential and must be supported by a structured implementation method [9], [10].

Information Technology (IT) governance is a crucial aspect to manage the technological resources across various types of organizations, including Small and Medium Enterprises (SMEs) [11]. The effectiveness of IT governance enables SMEs to align technological strategies with business objectives, improve operational efficiency, and reduce risks associated with technology system management. Nevertheless, many SMEs still lack a structured understanding of the importance of IT governance, which often results in a mismatch between technological needs and business strategies. Research indicates that digital transformation involves the integration of digital technologies into all aspects of business operations, ultimately creating added value and enhancing efficiency. Digital transformation has become a necessity for all organizations, including SMEs, to remain relevant and competitive in today's digital era. Nevertheless, many SMEs continue to face challenges in implementing digital transformation effectively. One of the key barriers to successful digital transformation is the lack of proper IT governance. Studies have shown that effective IT governance can significantly enhance operational efficiency and support data-driven decision making Hauser[12].

Thus, the implementation of TOGAF enables SMEs to design an enterprise architecture that aligns with their business needs and ensures that the technologies employed can deliver added value [13]. The research findings indicate that effective IT governance can minimize the risks of technology implementation failure and enhance the competitiveness of SMEs in the digital market. One of the main challenges that faced by SMEs in undergoing digital transformation is the limitation of resources. Some studies show that SMEs often struggle to allocate funds for new technology investments due to limited operating capital. Moreover, the low level of digital literacy among SME management teams also presents a significant barrier. Other research also has found that SMEs in Indonesia still lag behind in adopting digital technologies, particularly in traditional sectors such as manufacturing and traden [14].

In light of these challenges, a suitable strategic planning approach is required for the development of SME information systems. A blueprint framework is currently essential to guide the development of systems that align with the specific needs of SMEs. Beyond conventional and technological approaches, an integrated needs analysis process must be conducted in planning the architecture using the TOGAF ADM methodology. TOGAF ADM is a framework that can be utilized to develop a strategic planning for SME information system development. TOGAF ADM consists of eight phases used to structure architectural artifacts such as: *Architecture Vision, Business Architecture, Information System Architecture, Technology Architecture, Opportunities and Solutions, Migration Planning, Implementation Governance,* and *Architecture Change Management* [10], [15]*.* This framework also enables SMEs to accelerate the digitalization process by leveraging technologies that match their specific needs. According to research, effective IT Governance plays a critical role in enhancing the competitiveness of SMEs, particularly in today's digital era. A structured IT governance framework not only ensures that adopted technologies are well integrated into business processes but also enables organizations to improve their operational efficiency and effectiveness. The implementation of TOGAF is expected to support SMEs in aligning their IT strategies with business objectives, thereby facilitating a smoother digital transformation process [16], [17].

The implementation of TOGAF is expected to assist SMEs in managing change and reducing risks associated with the adoption of new technologies. The application of TOGAF offers several benefits, including:

1. Improved The Operational Efficiency: The implementation of TOGAF enables SMEs to design and implement more integrated IT architectures, thereby enhancing operational efficiency and reducing costs associated with technology management.
2. Enhanced Competitiveness: By adopting TOGAF, SMEs can adapt to new technologies, it is also allowing them to compete with larger companies in broader markets. Research has shown that SMEs implementing IT governance frameworks are able to increase their competitiveness by up to 25% compared to those that do not.
3. Improved Risk Management: TOGAF provides guidance in managing risks associated with technology implementation. Studies have shown that SMEs utilizing TOGAF in their digital transformation efforts have successfully reduced the risk of technology implementation failure by up to 30%.

The result of this study is a set of TOGAF ADM architectural artifact documents that can be used to identify which technologies can be developed in alignment with the existing business processes of SMEs. The blueprint framework can serve as a tool for SMEs to determine the development priorities and the stages of system implementation over the coming years, taking into account both internal and external factors. Based on the framework, a marketing and sales information system for SME products was developed to address issues such as the limited knowledge of partners in marketing, which has had a direct impact on their revenue.

Methodology

The research methodology outlines the stages which undertaken in this study. The methodology is illustrated in Figure 1. The stages of the research methodology can be described as follows:

1. Exploration of Research Concepts. The first stage involves exploring the TOGAF ADM concept to be implemented in strategic planning. This stage also includes a literature review of previous related studies.
2. Observation and Interviews. The second stage consists of direct field observation and interviews with relevant stakeholders to collect the data related to the information management processes of SMEs in Kayubihi Village, Bangli.
3. Analysis. The third stage involves analyzing the results of interviews, observations, and conceptual exploration. The analysis is conducted by applying the steps in the research to illustrate the TOGAF ADM artifacts.
4. System Design and Implementation. The fourth stage is the design and implementation of an information system used as a medium for information dissemination. The implemented system is developed in accordance with the system development documentation.
5. Conclusion. The fifth stage involves drawing conclusions based on the analysis of the TOGAF ADM artifacts and the implementation of the information system.

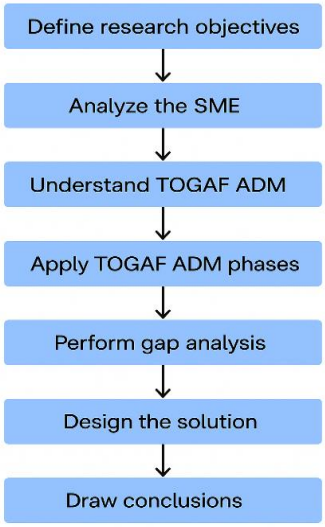

Figure 1. Research method

Results and Discussions

This section presents the results of the TOGAF analysis, covering stages from the Preliminary Phase to the Technology Architecture Phase.

Preliminary Phase

The Preliminary Phase is the beginning of the TOGAF framework stage. This phase defines the starting steps, including determining the scope of the enterprise, selecting the architectural framework, and identifying the tools to be used. In this research, the preliminary analysis involves describing the current condition of the object under study, namely the bamboo weaving SMEs. This stage serves as the foundation for analyzing and illustrating the existing business processes of the artisans. The detailed analysis in this initial phase is as follows:

1. Scope: The focus of this research is on bamboo weaving SMEs in Kayubihi Village, Bangli Regency, which require IT governance to support their digital transformation efforts.
2. Stakeholders: SME owners, artisans, local government, and customers.
3. Architecture Principles: Sustainability: Utilization of technologies that support long-term sustainability. Scalability: Technology solutions that can scale according to the evolving needs of SMEs. Efficiency: Digitalization processes that enhance and accelerate operational activities.

At this stage, an analysis is conducted for an e-commerce system that can be applied into traditional markets. It can support the transition from conventional to online sales. The Preliminary Phase is carried out by dividing the business processes into two categories, as presented in Table 1 below:

Table 1. Preliminary phase

Principle	Description
	Bussiness Architecture
Product Enhancement	Product enhancement is carried out through product development and alignment with market needs.
Business Continuity	SMEs are able to sustain their operations in the face of various challenges and competitive pressures.
Product quality	Maintaining the product quality by using high-quality raw materials and producing in accordance with established standards.
Compliance with Government Regulations	The products which are produced and marketed must comply with government regulations.

Operational Continuity	The business continues to operate despite facing several challenges.
	Data Architecture
Data as an Asset	SME data is considered an asset and holds value that must be properly protected and managed.
Data Accessibility	Data should be easily accessible and manageable.
Data Accuracy	Data must be reliable and accountable for its accuracy.
Data Security	All SME data must be protected and safeguarded against potential risks of data breaches.
	Application Architecture
Application Usability	The application should be easy to use for both users and end-users, ensuring high usability and functionality.
Application Flexibility	The application should function effectively and be compatible with existing technologies to minimize the need for frequent modifications.
	Technology Architecture
Technology Security	The technology must ensure data security to prevent risks from both internal and external threats.
Technology Evolution	To maintain the quality and ensure the continuity of business processes in product sales, regular updates are necessary by monitoring technological developments and user needs.

Architecture Vision

In the Architecture Vision phase, it focuses on assessing transformation readiness to achieve the target enterprise architecture, identifying the architecture vision, and evaluating business capabilities. This phase is divided into main activities, such as: inbound logistics, operations, outbound logistics, sales, marketing, and customer service. Supporting activities consist of: human resources, finance, inventory, and procurement. The analysis is depicted in Figure 2 below.

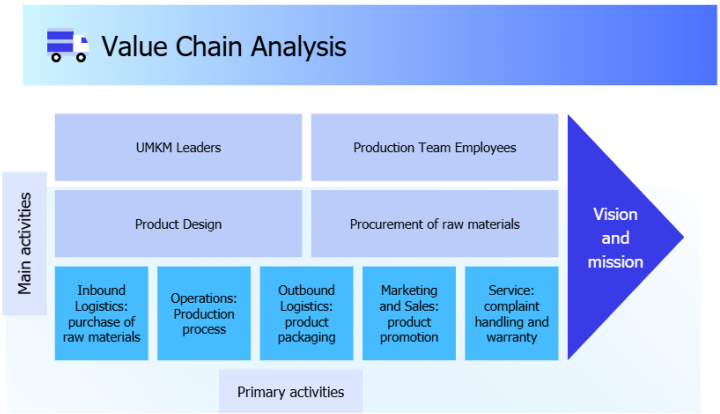

Figure 2. Value chain

Business Architecture

In this phase, an illustration is provided regarding the analysis of business processes and business functions related to the main business activities, which consist of:

1. The core processes in this business architecture are: sourcing of local raw materials, manual production by artisans, product marketing conducted directly and through local markets.
2. The required technologies include an order management system and inventory tracking system to support operational efficiency.
3. Business Process Document: A workflow diagram that integrates manual processes with digital technologies. Several stages and business processes are categorized into conventional and digital processes. The entire sequence is illustrated in a value stream map

for the business processes of bamboo weaving SMEs. Figure 3 presents the value stream map as follows:

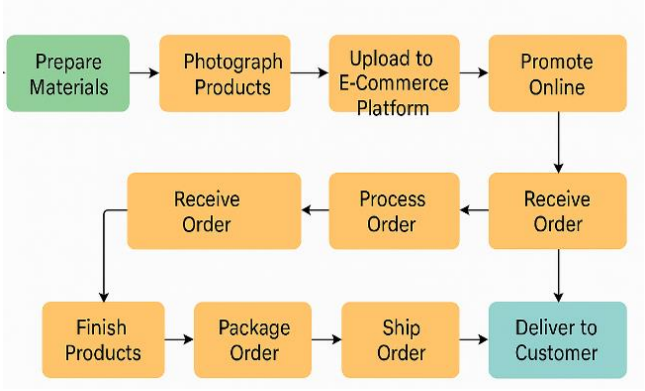

Figure 3. Value stream map

This Figure 3 Value Stream Map illustrates the business process flow of bamboo woven craft SMEs, from raw material procurement to product delivery to customers. This diagram visualizes the integration between manual and digital processes designed to improve operational efficiency of SMEs. The figure above illustrates the flow of both conventional and digital business processes, serving as a recommendation for future business operations, with the detailed analysis as follows Table 2.

Table 2. Business processes

Activity	Business Process	Notes
Raw Material Procurement	a. Contacting local suppliers. b. Purchasing and recording are done immediately	Manual
Weaving Production	a. Handcrafted by artisans traditionally b. Production results are recorded by administrative staff.	Manual
Product Data Entry	a. Product data is entered into the information system. b. Product descriptions and images are uploaded to the e-commerce platform.	Digital
Product Marketing	a. Promotion through social media and websites. b. Content distribution is managed by the marketing admin.	Digital
Ordering and Payment	a. Customers place the orders through the online system. b. Payment is made via bank transfer or digital payment gateway.	Digital
Packaging and Delivery	a. Products are packaged and shipped by delivery personnel. b. Delivery status is updated in the system.	Manual

This value stream illustrates the end-to-end process from raw material procurement to product delivery to the customer, as well as the points of digital integration within the process. The details of the Business Architecture Gap Analysis are as follows Table 3 :

Table 3. Business architecture gap

Business Are	Current Business Architecture	Business Architecture Target	GAP
Marketing Process	Manual and local	Digital via e-commerce platforms	No digital channels; low digital literacy
Inventory Management	Undocumented, manual process	Inventory management information system	Lack of system; risk of data loss or stock mismanagement
Product Ordering	By phone or in-person	Online ordering through website	Online ordering system is not yet available
Sales Recording	Manual using book	Automation using digital systems	No available online ordering system
Market Access	Limited to local/regional markets	National atau international through marketplace	No integration with marketplace platforms
Business Process Documentation	Poorly documented	Digitally documented and standardized	Standardized no digital SOPs

Information System Architecture

This stage is divided into two levels of analysis, namely data architecture and application architecture. The following is an explanation of each phase:

Data Architecture

In this phase, the focus is on identifying the data currently in use and the data required to support the proposed system development. The general concept of the data architecture is as follows:

1. Data Types: Product data, customer data, supplier data, and financial data.
2. Storage: Utilization of cloud-based databases for centralized data management.

This strategic planning aims the utilization of technology by developing an e-commerce system, an inventory system, and a financial system to support SME business processes. All data and systems will be centralized and utilize cloud storage for data management. This approach requires qualified human resources to assist in system administration. In general, the data management planning for the systems to be developed is as follows:

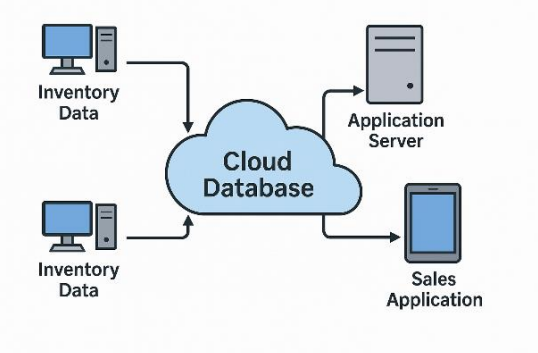

Figure 4. Data management architecture

Figure 4 above is a visualization of a cloud-based database solution that illustrates how data from the inventory system and sales application is connected to the cloud database and application server. The figure above illustrates the data management plan, which utilizes cloud technology for data storage. Based on the proposed systems to be developed, the next step is to conduct a data planning analysis, as illustrated below:

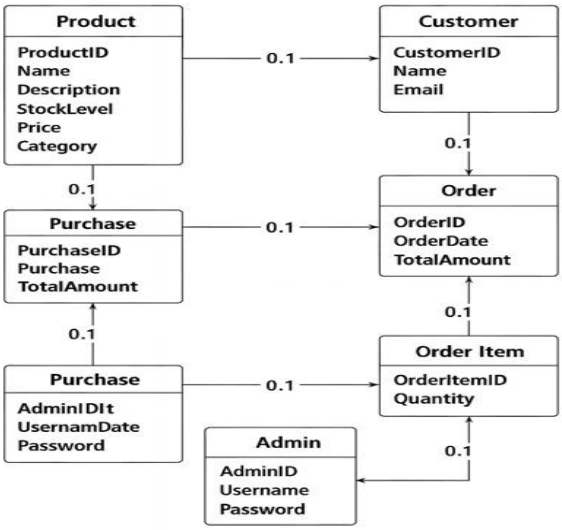

Figure 5. ERD data design

Figure 5 above shows the Entity-Relationship Diagram (ERD) of an information system designed for bamboo weaving craft SMEs. This diagram models the relationship between the main entities such as Product, Customer, Order, Order Item, Purchase, Supplier, and Admin.

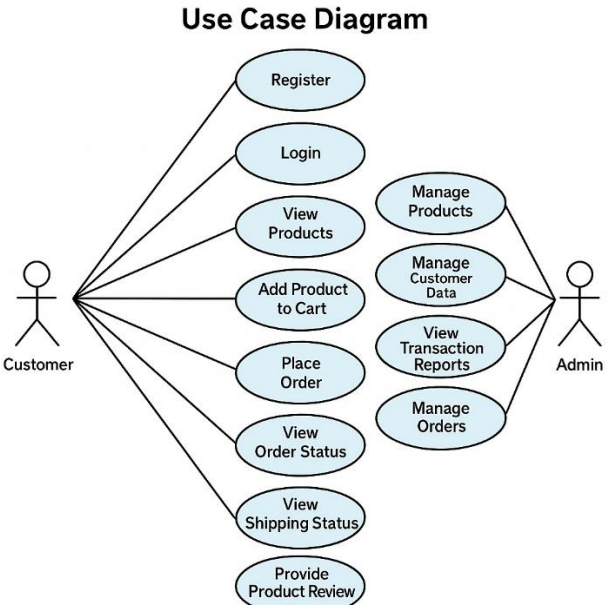

Figure 6. Use case system design diagram

Figure 6 provides a comprehensive overview of user interaction with the system, both from the customer and admin side. This diagram also shows the system boundaries and main functions that will be developed in a web-based information system to support SME digitalization. This diagram is an important basis in system design, especially at the requirement analysis stage.

Application Architecture

This phase involves analyzing the application architecture to be developed. For system planning, the proposed systems are as follows: an e-commerce system for marketing purposes, an inventory management system for stock control, and a simple financial recording application.

To ensure that the technology architecture can be optimally implemented in bamboo weaving SMEs, a needs analysis is required, covering technical aspects, human resources, and operational support. The identified requirement components are as follows:

1. Hardware Requirements: Each hardware requirement includes a computer or laptop for administrative and inventory management staff, a tablet or smartphone for mobile access by artisans or marketing staff, and a simple financial recording application.
2. Software Requirements: Each software requirement includes a web-based sales information system, a cloud-based inventory management application, and a sales and distribution monitoring dashboard.
3. Network Infrastructure Requirements: Each network requirement includes a stable internet connection with a minimum speed of 10 Mbps and an adequate router and modem for the SME's internal network.
4. Cloud Platform Requirements: Each cloud platform requirement includes cloud storage services such as Google Drive, Dropbox, or AWS S3, and cloud databases such as Firebase or Google Cloud SQL to store transaction, customer, and inventory data
5. Data Security and Protection: Each security requirement includes multi-factor authentication (MFA) for system access, the use of HTTPS for all online transactions, and automated and periodic data backups.
6. Human Resources and Training Requirements: Each HR and training requirement includes basic system usage training for SME managers and artisans, the provision of Standard Operating Procedures (SOPs) for technology usage, and technical assistance during the early stages of implementation.

Table 4 and Table 5 are the analysis for production matrix data and Table 5 is used for marketing matrix data with data types in each data entry.

Table 4. Data matrix for production and procurement

Description	Data Entity	Type of Data
Warehouse and vendor management application	Product	Master Data
	Materials	Master Data
	Tools	Master Data
	PO	Transactional Data
	Invoices	Transactional Data
	Vendor	Master Data
	Employees	Master Data
	Customers	Master Data

Tabel 5. Data matrix for marketing and distribution

Description	Data Entity	Type of Data
Warehouse and vendor management application	Product	Master Data
	PO	Transactional Data
	Invoices	Transactional Data
	Expeditions	Master Data
	Employees	Master Data
	Customers	Master Data
	Product Detail	Transactional Data
	Sales	Transactional Data
	Discount	Transactional Data

Technology Architecture

In this phase, an artifact called the Technology Portfolio Catalog is created to identify and manage the hardware, software, and network infrastructure required by the SME. The following is the technology architecture diagram for the system to be developed.

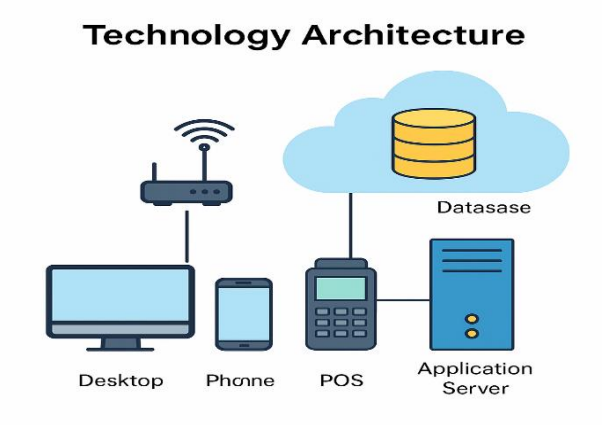

Figure 7. Architecture technology

Figure 7 illustrates the technology architecture that supports the information system in the bamboo weaving craft SME. This architecture is designed to support the digitalization process from product management to online transactions. Based on the technology architecture illustrated above, the proposed portfolio catalog is as follows Table 6.

Table 6. Technology portfolio catalog

Product	Spesification	Description
Desktop Computer	Intel i5 processor, 8GB RAM, 256GB SSD	Used to access the inventory management information system and print transaction reports.
Smartphone	Android/iOS, 6 inch touchscreen, internet connection	Used by artisans or administrators to manage orders and communicate with customers.
POS Terminal	Touchscreen, Bluetooth/WiFi connectivity, thermal printer	Used to digitally record direct sales transactions.
Wi-Fi Router	Dual Band 2.4GHz/5GHz, up to 300Mbps speed	Provides internet connectivity for devices within the SME's internal network.
Cloud Database	Google Cloud SQL / Firebase / AWS RDS	Stores product, customer, sales, and purchase transaction data in a centralized and real-time manner.
Application Server	Cloud-based hosting, supports PHP/NodeJS, 10–50GB storage capacity	Runs the web-based sales and inventory information system accessible online.

A comparison between SMEs that have implemented an IT governance framework and those that have not highlights the importance of a structured enterprise architecture. For example, a bamboo craft SME in Gianyar Regency that integrated digital order tracking and a product catalog through a mobile-based information system experienced a 30% increase in customer retention and a 22% reduction in inventory error costs. In contrast, SMEs in Kayubihi Village that did not have such a system continued to rely on manual record-keeping, which often resulted in duplicate orders and stockouts. Furthermore, research by [1] found that SMEs that implemented TOGAF-based planning demonstrated measurable improvements in operational effectiveness, reporting a 25% higher order processing speed and greater consistency in customer feedback. These examples support the finding that structured IT governance significantly improves SME competitiveness while reducing the risk of system failure by providing clear implementation path and technology alignment strategy. Other studies [2] have adopted a digital catalog and basic information system to manage product and order data. This approach resulted in a 20% increase in revenue and reduced order errors. This approach resulted in a 20%

increase in revenue and reduced order errors. Similarly, studies implemented a semi-digital process using cloud-based spreadsheets and marketplaces, achieving national market expansion.

Conclusion

Based on the results of this study, it can be concluded that the proposed model for SME marketing development planning is the implementation of an e-commerce system and an inventory management system. This study shows that the implementation of TOGAF ADM provides a strategic and structured framework to support the digital transformation of SMEs. This study has produced a depiction of: an analysis of the vision architecture described in the value chain. Business architecture described in the Value Stream Map, business process table, and business architecture gap table. Data architecture has provided a proposal for data management with a cloud database, usecase diagram and ERD. And has described the proposed application architecture and technology architecture. This framework also provides a solid foundation for long-term system development, serving as a reference for managing and advancing IT in the SME environment. The application of TOGAF in the context of SMEs, even in its balanced form, provides a practical basis for reducing implementation risk by up to 30% and improving competitive performance by approximately 25%. These results support the role of enterprise architecture as a potential strategy for small businesses undergoing digital transformation.

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Strengthening CRM based on live chat for customer service performance audits

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Abstract: The management of relationships between customers and companies is still largely carried out conventionally. Communication between companies and customers tends to be slow and is highly limited by time constraints. This condition makes it more difficult to maintain good relationships between customers and companies, even though such relationships are crucial for business continuity. Conventional communication methods also hinder the monitoring of customer service performance toward customers. Technology-based Customer Relationship Management (CRM) can be a strategic solution to overcome the weaknesses in managing and maintaining these relationships. The purpose of this research is to implement a CRM application using real-time live chat technology to enable faster customer service responses and facilitate service monitoring for the company's management, thereby making performance auditing of customer service easier. The CRM live chat application in this study was developed using the waterfall method and implemented using Visual Studio Code, Laragon as a web server, PHP, JavaScript, MySQL, and Pusher. The implementation was tested using Blackbox testing and User Acceptance Testing (UAT), with the results showing that all functions related to real-time communication and service monitoring operated properly, and the user satisfaction rate reached 85.8%.

Keywords: business sustainability, CRM, real-time live chat, waterfall

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Introduction

The continuous sustainability of a business is the goal of every company. In an effort to maintain their business in the long term, a company must consistently engage in product and service development alongside process innovation, employee competency enhancement, and the establishment of strong relationships with customers as the company's primary stakeholders [1]. The relationship between customers and the company can be fostered by implementing a Customer Relationship Management (CRM) system [2].

CRM is a business strategy focused on understanding, managing, and optimizing the interactions between the company and its customers to ensure efficiency, effectiveness, and visibility of these relationships, ultimately preserving customer loyalty [3]. CRM does not focus on the products produced by the company, but rather on the quality of service offered to customers [4]. Through CRM, companies can store a wide range of customer information, track interactions between stakeholders and customers, and identify opportunities to enhance relationships with the company's clientele [5]. CRM also simplifies the management of interactions between the company and customers, allowing for improved feedback on products or services before, during, or after usage [6].

The implementation of CRM can be realized through the use of live chat technology. Live chat technology enables real-time communication between customers and company representatives, usually provided by customer service via text messages on websites or applications [6] . The implementation of this technology can contribute to improving customer satisfaction by reducing the wait times customers experience when submitting complaints about products and services they have received [7]. This, in turn, can help maintain the company's

reputation in the eyes of customers, enhancing customer loyalty as an indicator of the quality of the company's products and services, ultimately supporting the sustainability of the business [8].

Live chat technology has evolved in recent years. What was initially a simple feature designed to facilitate basic interactions between users and system operators now supports more complex business automation, thereby improving company performance [9]. Various published studies have highlighted the importance of live chat for companies in maintaining customer relationships. Operators in the new student admission process can be replaced by chatbots available 24/7 [10]. The usability and responsiveness of chatbots influence customer satisfaction in customer service within e-commerce applications [11]. Chatbot technology is used to provide answers to customer queries via the chat application they use [12].

In this study, the live chat technology implemented connects customers directly to the company's customer service. Direct interaction without the use of chatbots offers a more human touch and a personal impression for the customer. The application of this technology in CRM is not only used as a communication tool with customers but also as a tool to strengthen the quality of CRM in evaluating customer service performance. The customer live chat application in this study will provide a summary of conversations that occur between customer service and customers through a dashboard feature for company management. This summary data can assist company leaders in evaluating customer service performance and provide new insights into customer interactions with the company's products and services.

Methodology

This study was developed by following the classical life cycle of system development using the waterfall method. The waterfall method is a straightforward system development approach that can yield optimal results for observing a system development model. The waterfall method involves a systematic and sequential development process [13]. Each phase must be completed before its results are used in the subsequent stage. This ensures that each phase is minimized for errors, making the developed system more accurate. This study chose this method because it aims to create a system prototype model that can assist customer service in serving customers without requiring continuous changes. The steps in this study are illustrated in Figure 1 below.

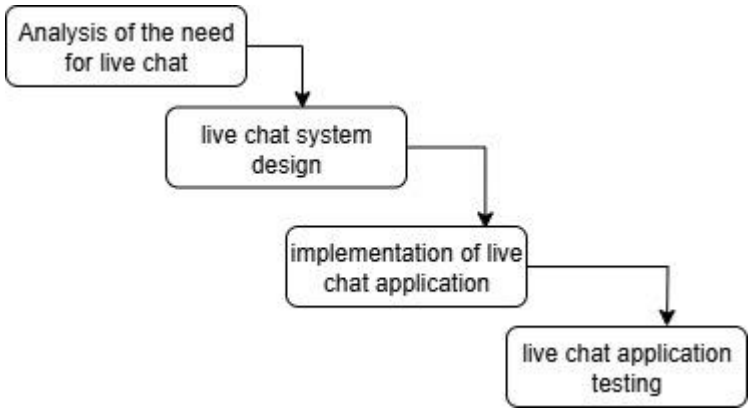

Figure 1. Research methodology

Analysis of The Need for Live Chat

This phase is intended to understand and identify the requirements of the system being developed. It generates the data necessary for the development of the live chat system. The requirements analysis process for the live chat system is carried out by applying observation, interviews, and literature study methods. Through this data collection process, an overview of the system is obtained, including the business process scenarios, the functional and non-functional requirements to be achieved by the system, the inputs managed by the system, and the outputs produced.

Live Chat System Design

The findings from the requirement analysis in the previous phase serve as the foundation for developing the new live chat system design in this study. Within this design phase, the system blueprint encompasses the proposed system architecture, database schema, and the design of the revised business processes. The resulting design is represented through relational models and structured modelling techniques.

Implementation of Live Chat Application

This stage is the process of translating the system design into a programming language. The live chat system is developed using Visual Studio Code and Laragon as the web server. PHP is used for the backend, JavaScript for the frontend, MySQL as the RDBMS, while the real-time communication is built with a cloud-based system architecture that utilizes the WebSocket protocol, with Pusher serving as the broadcaster.

Live Chat Application Testing

The results of the system implementation will be tested using two methods: black-box testing and User Acceptance Testing (UAT). Black-box testing is conducted to ensure that the features available in the built application function as intended. Testing focuses on input and output, message sending and receiving processes, real-time messaging, user authentication, and the user interface. Meanwhile, User Acceptance Testing (UAT) is used to evaluate user responses to the created system and assess their satisfaction with the system. Both testing methods help in drawing conclusions about the system's functionality and its readiness for use.

Results and Discussions

Results

The results of this study consist of the design of the system architecture, the database structure design, and the business process design, which are then implemented into an application prototype. The CRM application prototype with a live chat feature developed in this study is expected to optimize customer service through real-time communication between customers and company representatives. The developed application can be used to record the entire conversation history in detail, including response time, service time, and customer ratings. These conversation records are then utilized to evaluate the performance of customer service provided to customers. To achieve the desired results, the researcher followed the steps outlined in the research methodology. The discussion of the results based on the methodological steps carried out is as follows.

Analysis of The Need for Live Chat

In this phase, the elicitation process was conducted based on the results of observations, interviews, and literature studies. The elicitation process aims to identify the system stakeholders as well as the functional and non-functional requirements of the CRM live chat system. As a result, the users of this system consist of customers, customer service representatives, and company management. Customer service representatives are internal users responsible for providing services by responding to customer inquiries, while customers act as recipients of company information and submit inquiries to customer service. The interactions between these two groups can be monitored by company management. Each system stakeholder manages data within the business processes to achieve the desired non-functional requirements, namely customer satisfaction and service efficiency. All system users are also assigned access rights to ensure appropriate user access limitations within the developed system. The functional requirements of this CRM system are presented in Table 1 below.

Table 1. Functional requirement

Fungtional requirement	Description
Registration	This function provides a registration facility for service requesters so that customer data can be stored in the database
Live chat	This function enables real-time conversations between customers and customer service. The conversations that occur need to be stored in the database so that they can be used to draw conclusions about service quality
Chat history	This function is used by customer service to manage the chat data that occurs during conversations
Performance Management	This function is performed by the customer to provide a rating for the service from customer service. Response time and service time can be monitored by the company's management
Service Dashboard	This function will be used by management to view the evaluation results, which can then be used as a basis for auditing customer service performance in delivering services.
Knowledge Base	This function is for referencing the knowledge discussed by customer service and any supporting files that may be needed.

Live Chat System Design

At this stage, the design of the system architecture, database structure, and process design required for implementation is carried out. Based on the analysis, when customers wish to communicate their issues, they are still required to either visit in person or contact the customer service team via telephone. Such mechanisms result in suboptimal service quality due to delayed responses to customer complaints and inquiries. Therefore, to improve response time and enhance customer satisfaction, this study adopts live chat technology with a system architecture as illustrated in Figure 2 below.

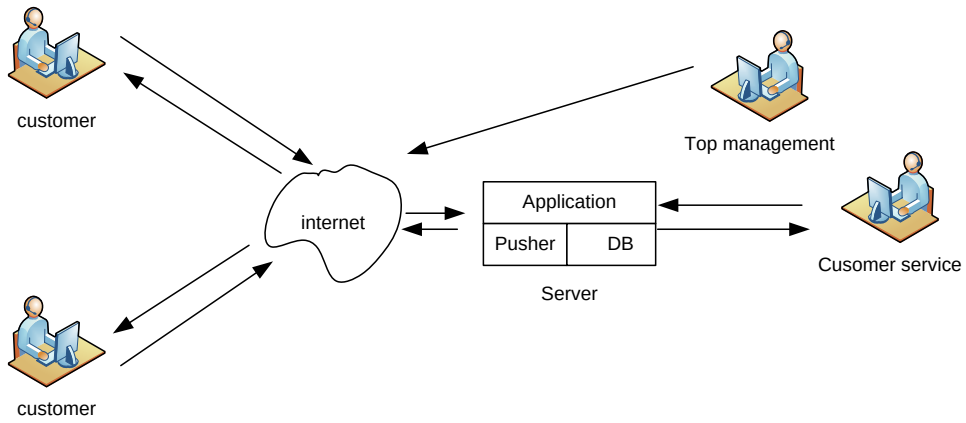

Figure 2. Live chat system architecture

As illustrated in Figure 2 above, when a customer wishes to connect with customer service to submit a complaint or other matters, the customer must access the live chat web application, which can be used from various internet-connected devices. The real-time conversation between the customer and customer service is facilitated by communication technology using a third-party

service [14]. This approach is chosen because delegating the communication infrastructure to a third party ensures better maintenance, management, and security of the infrastructure [15]. The implementation of this architecture is carried out using Pusher. Pusher is a real-time service that provides an Application Programming Interface (API) utilizing WebSocket for two-way communication between the client and the server. The Pusher API functions as a courier for delivering each message. During the communication process via the Pusher API, all transaction data is stored in the database. This is intended so that the data can be used as a reference for evaluating the performance of the services provided by customer service. The resulting system architecture is then translated into process designs result, as illustrated in the Data Flow Diagram (DFD) shown in Figure 3 below.

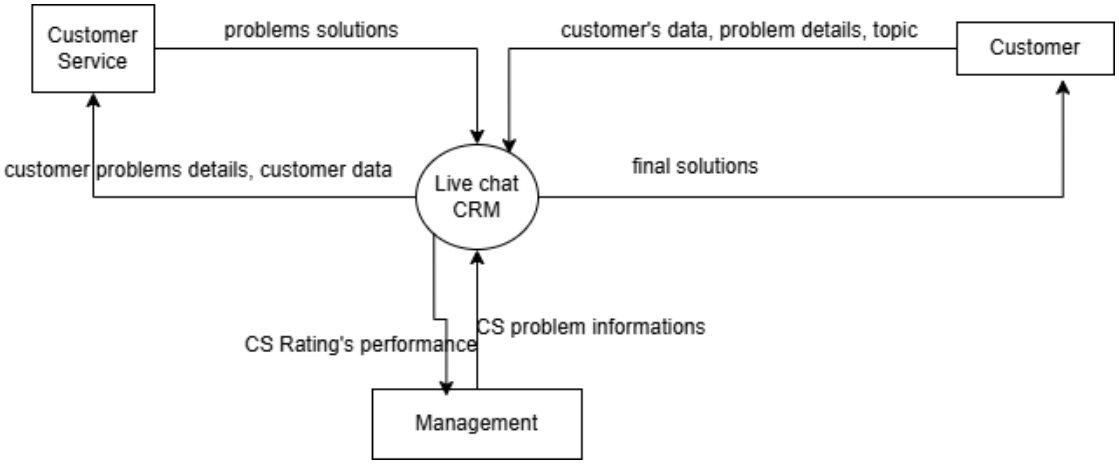

Figure 3. Data flow diagram level 0

Figure 3 above provides an overview of the business process in the developed CRM live chat system. The diagram illustrates the data flow within the Live Chat CRM system, which involves three main parties: customers, customer service representatives, and company management. Customers provide their personal data, problem details, and discussion topics through the live chat application. This information is then delivered to customer service representatives, who handle the issues according to the customer's needs. Customer service provides problem solutions, which are sent back into the system and then delivered to the customer as the final solution. In addition, all interactions between customers and customer service are recorded by the system and used as valuable information for management. The management team can monitor the data related to the issues handled and evaluate customer service performance based on customer ratings. Thus, the Live Chat CRM system not only functions as a two-way communication medium between customers and customer service but also serves as a monitoring and evaluation tool for service performance by management. To enable the implementation of the design process, the following is the result of the relational database design for the CRM live chat to store communication data, as shown in Figure 4 below.

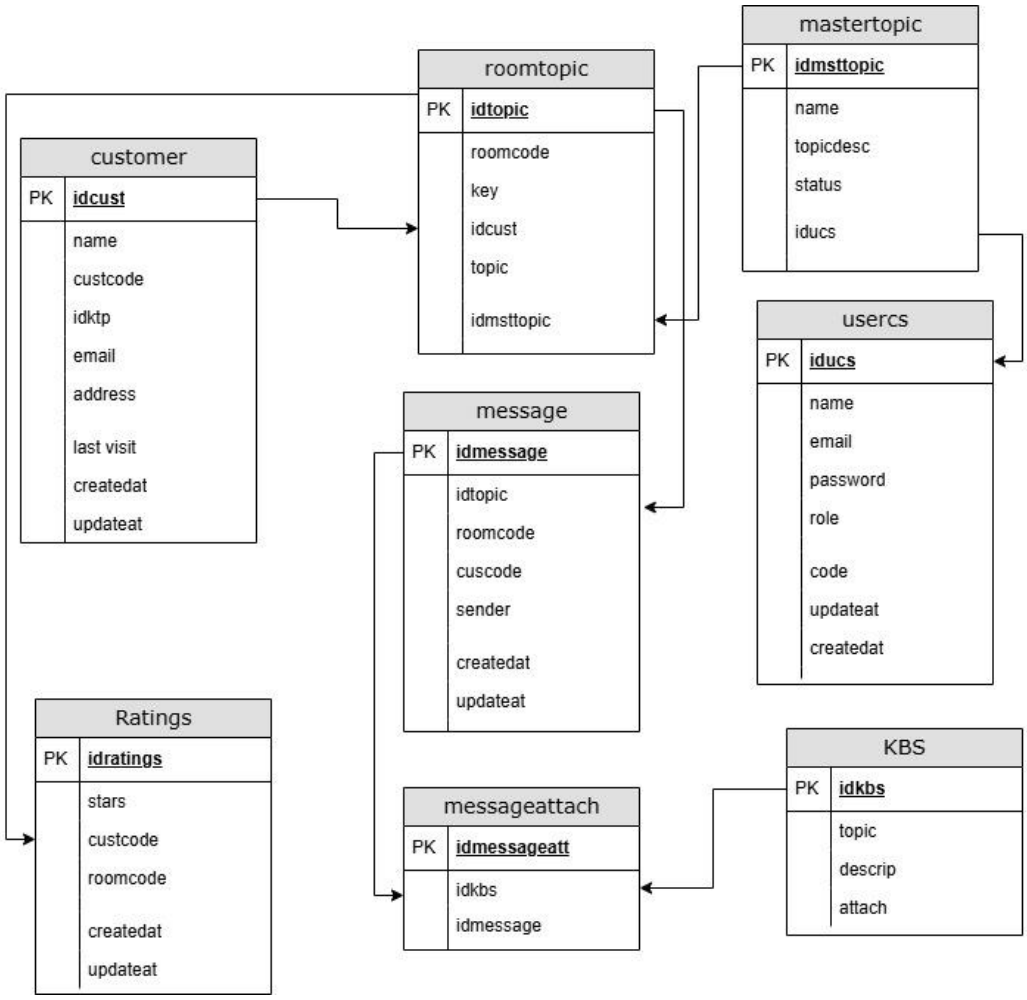

Figure 4. Database structure design

In Figure 4, it can be seen that to store user data and conversations that occur within the live chat system, eight tables are prepared and implemented in a MySQL database. These tables include: customer, ratings, room_topic, messages, messages_attach, master_topic, usercs, and KBS. When a customer enters their data into the system, it is stored in the customer table. To initiate a conversation, the customer selects a topic, which is saved in the room_topic table, the master_topic table, and the customer service data is stored in the usercs table. The conversation is stored in the messages table, including any connections to the messages_attach and KBS tables if additional files need to be shared during the conversation. This data recording is intended for storing conversation history. After completing the conversation, the customer can provide a rating, which is saved in the ratings table. The data in the ratings table is then used as a performance evaluation metric for the respective customer service representative. The designed tables are then used in each detailed feature implemented by the system. The results of the detailed process design of the live chat system and its connection to the database are illustrated as shown in Figure 5 below.

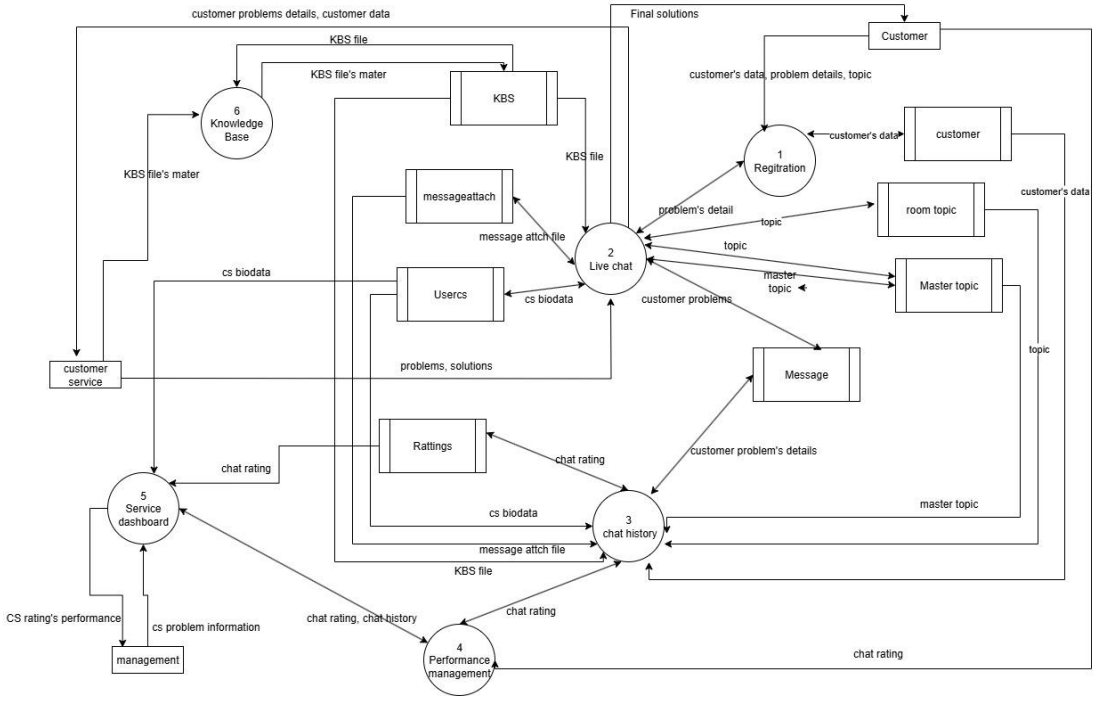

Figure 5. Data flow diagram level 1

The Level 1 DFD diagram above shows that there are six features provided in the developed CRM live chat application. The customer, as the service requester, uses the live chat application to register in the system. This process is carried out to digitally record the customer's personal data so that it is stored and can be accessed later. The registration data is then used to access the live chat service from customer service. The customer service agent responds to service requests through the chat management feature and promptly replies to questions in the live service queue. All conversations are recorded in the database to serve as a source of information on customer service quality. If the customer's inquiry is satisfactorily addressed, the customer can end the session and provide a service satisfaction rating. This customer satisfaction rating can be accessed by the management, enabling them to evaluate the customer's feedback on the service quality provided by the company's customer service team.

Implementation of Live Chat Application

The implementation of the system design into a CRM live chat prototype was successfully carried out using Visual Studio Code, Laragon as the web server, PHP, JavaScript, MySQL, and Pusher. The system provides real-time communication features that enable customers to interact directly with company representatives through a live chat dashboard. Messages in the form of text, files, and images can be transmitted and received seamlessly, as illustrated in Figure 6. To ensure user engagement and service quality, a customer rating feature was integrated at the end of each conversation session (Figure 7). This rating serves as a performance feedback mechanism for customer service representatives. The recorded data is subsequently processed and displayed through a management dashboard in the form of reports and graphical visualizations (Figure 8), allowing management to monitor and evaluate customer service performance effectively.

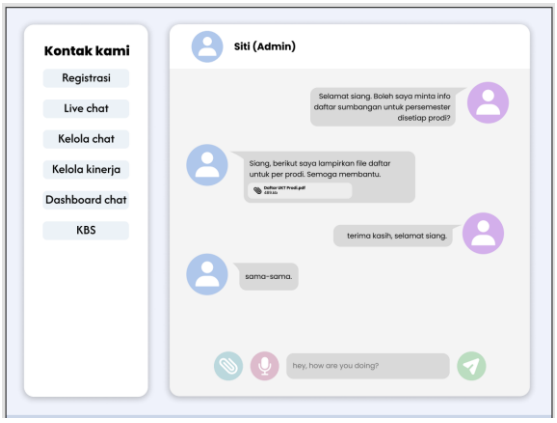

Figure 6. Live chat feature

Figure 7. Customer rating

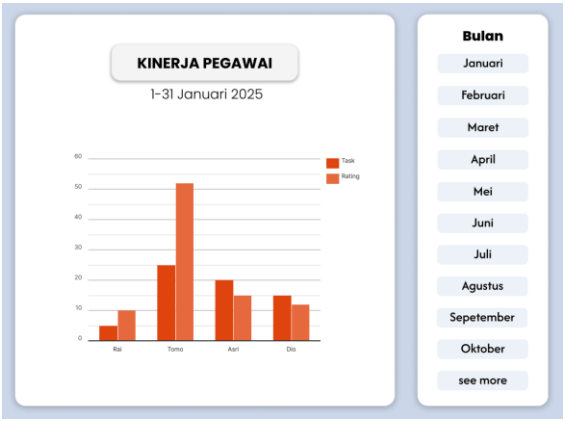

Figure 8. Management dashboard

Live Chat Application Testing

The system was tested using two methods: black-box testing and User Acceptance Testing (UAT). Black-box testing was conducted to ensure that all system functional requirements were met and that the system performed as expected, while UAT was carried out to evaluate user satisfaction with the developed system. The results of the black-box testing are shown in Table 2 below.

Table 2. Black box result

No	Feature Tested	Test Scenario	Given Input	Expected Output	Actual Output	Status
1	Registration Form	User fills out the form with complete and valid data	Name, valid Email, matching Password	Account successfully created and redirected to login page	Same as expected	PASSED
2	Registration Form	User leaves one required field empty	Leave email field blank	Error message 'Email is required' appears	Error message appears	PASSED
3	Live Chat Feature	Customer sends a message to customer service	Text message 'Hello CS'	Message appears on CS side in real-time	Appears instantly	PASSED
4	Live Chat Feature	Customer Service replies to the customer message	Reply 'Good afternoon'	Message appears on customer side immediately	As expected	PASSED
5	Chat Management	Admin opens the chat details	Click 'View History' button	Shows complete chat history	History displayed	PASSED
6	Service Dashboard	Admin opens the dashboard page	Click 'Dashboard' menu	Displays service trend graph and summary data	As expected	PASSED
7	KBS	File and knowledge base store	Click KBS	Shows files	As expected	PASSED

The testing results in Table 2 indicate that the system's functionality operates properly. Scenario testing conducted on the system's features, using specific inputs, produced outputs that matched the expected results, confirming that the system functions correctly without errors. To assess user acceptance of the application based on its functionality and performance, a User Acceptance Test (UAT) was conducted involving 25 respondents, consisting of 10 customers, 5 customer service agents, 3 managers, 4 IT administrators, and 3 operational staff. The testing was carried out through Likert-scale questionnaires (1 = Very Dissatisfied, 5 = Very Satisfied), direct observation, and real task simulations. The evaluation focused on six key aspects commonly used in UAT: functional suitability, ease of use, response speed, system stability, user interface appearance, and ease of access and navigation. The results of the UAT testing are presented in Table 3 below.

Table 3. UAT result

Testing Element	Customer (10)	CS (5)	Management (3)	IT Admin (4)	Operational (3)	Average
Functional Suitability	4.6	4.5	4.7	4.4	4.4	4.52
Ease of Use	4.3	4.2	4.4	4.1	4.3	4.28
System Responsiveness	4.1	4.2	4.3	4.3	4.1	4.20
System Stability	4.5	4.4	4.6	4.4	4.2	4.40
User Interface (UI) Design	4.1	4.0	4.2	4.1	4.0	4.10
Access & Navigation	4.2	4.3	4.4	4.2	4.1	4.25

Based on the testing results from 25 respondents with various roles in the application, it was concluded that the application is feasible for use in an operational environment, with minor improvement recommendations to enhance user experience. This conclusion is supported by the UAT results, which showed an average overall acceptance score of 4.29 out of 5, equivalent to 85.8%.

Discussions

The results of the UAT across six dimensions and the black-box testing indicate that the developed system functions optimally in providing services and effectively supports performance audits of customer service, making it easier for company management. The UAT was conducted on six features: registration, live chat, chat history, performance management, service dashboard, and knowledge base. The testing evaluated six dimensions of user acceptance: functional suitability, ease of use, system responsiveness, system stability, user interface appearance, and accessibility/navigation. Based on the test results, the application demonstrated excellent functional performance, with the highest scores in functional suitability (4.52) and system stability (4.40), indicating that the application runs stably without issues. Other aspects such as ease of use, system responsiveness, interface design, and navigation also scored well, each receiving a score above 4. All functions in the application operated without error; however, it can be concluded that improvements are still needed in the UI appearance, as it received the lowest average score among the evaluated aspects.

Conclusion

The results of this study indicate that the use of the waterfall method in developing the CRM live chat application using Visual Studio Code, Laragon as the web server, PHP, JavaScript, MySQL, and Pusher successfully produced a system that functions well. This conclusion is supported by the black-box testing, which showed the system operated as expected without errors, and by the UAT results, which recorded a user satisfaction rate of 85.8%. This research also provides a means for auditing customer service performance through a rating feature that allows customers to evaluate the service they received. The results are displayed in graphical form on the management dashboard. In future development, system service optimization is recommended by integrating AI-based chatbots and adding features for automatic sentiment analysis based on the processed chat data.

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A decision support system for *Ogoh-Ogoh* assessment based on SMART and SAW methods in the context of Balinese cultural preservation

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Abstract: Bali's cultural richness includes the *Ogoh-Ogoh* tradition, which has recently evolved from a ritualistic practice into a competitive event evaluated through multidimensional criteria. However, the current manual evaluation process faces significant challenges, including subjective bias, inconsistent scoring standards, and inefficient data processing, which often reduce public trust in competition results. This study proposes a web-based Decision Support System (DSS) integrating the Simple Multi-Attribute Rating Technique (SMART) and Simple Additive Weighting (SAW) methods to enhance objectivity and transparency in *Ogoh-Ogoh* assessment. The system was implemented and tested using a dataset of 45 *Ogoh-Ogoh* alternatives. The comparative analysis demonstrates a strong consistency between the two methods, evidenced by a Spearman's Rank Correlation coefficient of 0.81. Furthermore, performance testing revealed that the system achieved an 85% ranking accuracy compared to expert manual evaluations and significantly improved operational efficiency by reducing processing time by 40% (from 2.5 hours to 1.5 hours). These findings confirm that the proposed DSS not only minimizes subjectivity but also serves as a valid tool for the digitalization and preservation of cultural heritage assets.

Keywords: cultural preservation, decision support system, multi-criteria evaluation, *ogoh-ogoh*, SAW, SMART.

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Introduction

One of the Hindu religious celebrations is *Nyepi* Day, which marks the Hindu New Year in the Saka calendar. To welcome this new year, the Hindu community in Bali collectively creates *Ogoh-Ogoh*. The *Ogoh-Ogoh* tradition is one of Bali's cultural heritages. The process of making *Ogoh-Ogoh* not only reflects the spiritual and philosophical values of the Balinese Hindu community but also serves as a platform for creativity, innovation, and social collaboration among local communities *(banjar).* In recent years, *Ogoh-Ogoh* has evolved from a purely ritualistic practice into a cultural competition, where the best creations are selected based on the materials used and the symbolic meaning of the *Ogoh-Ogoh* itself. However, challenges often arise, particularly in calculating and determining the best *Ogoh-Ogoh*. The evaluation is usually based on various criteria, such as aesthetics, creativity, thematic relevance, community participation, and elements of local wisdom. Nevertheless, the process is still largely manual, lacking structured and well-documented assessment standards [1], [2], [3].

However, the transition to a competitive format introduces significant evaluation challenges. While Decision Support Systems (DSS) have been widely implemented to assist data-driven decision-making in business, education, and industrial sectors, their application within the domain of cultural preservation remains significantly underexplored. This creates a notable research gap regarding how technology can be utilized to quantify qualitative cultural aesthetics efficiently. Most existing studies focus on technical or managerial decision-making, leaving the specific complexities of traditional arts assessment—such as *Ogoh-Ogoh* competitions—largely untouched by modern MCDM implementations [4], [5], [6].

The urgency of this research stems from critical issues observed in the current conventional assessment methods. The evaluation process, typically conducted by a panel of judges using paper-based scoring, is hindered by several fundamental problems. First, the assessment suffers from subjectivity, where evaluations rely heavily on individual judges' perceptions without standardized scoring rubrics, leading to inconsistency in scoring standards across different judges. Second, the manual tabulation process is inherently inefficient and prone to calculation errors, which consumes significant time during the competition. Third, and most critically, there is a lack of transparency in how final scores are derived. Consequently, participants are often unable to verify results, which may lead to negative perceptions and reduced public trust in the competition outcomes. Therefore, a systematic and technology-based approach is needed to mitigate these issues and support objective, transparent, and fair decision-making [7], [8], [9].

To address these challenges, this study proposes a web-based Decision Support System (DSS) integrating the Simple Multi-Attribute Rating Technique (SMART) and Simple Additive Weighting (SAW) methods. Although other MCDM methods such as the Analytic Hierarchy Process (AHP) or TOPSIS are commonly used, SMART and SAW were specifically chosen for this study due to their simplicity and ease of implementation for non-technical users, such as customary committees. Unlike AHP, which requires complex and time-consuming pairwise comparisons, SMART allows for direct scoring based on criteria weights determined through stakeholder consensus, while SAW normalizes scores to simplify the final ranking process [10].

The primary objective of this research is to design a valid DSS model for *Ogoh-Ogoh* evaluation by comparing the consistency and accuracy of these two methods. The criteria integrated into the system include aesthetics, creativity, thematic relevance, community participation, and environmental sustainability. Beyond serving as an objective assessment tool, this system contributes to the digital transformation of local culture. By digitizing the evaluation process, the system creates a historical database of *Ogoh-Ogoh* creations, thereby promoting cultural preservation through technology [11], [12], [13], [14], [15].

Methodology

The research methodology describes the systematic stages carried out in this study to ensure the validity and reliability of the proposed system. The research stages are illustrated in Figure 1.

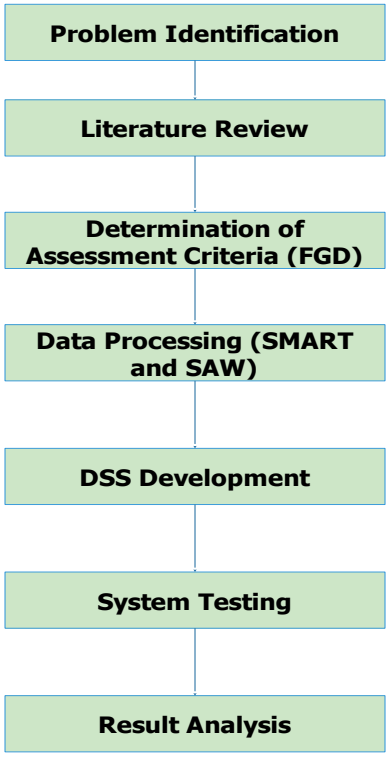


Figure 1. Research methodology

The stages of the research methodology can be explained as follows:

1. Problem Identification
   The research begins by identifying critical issues in the current *Ogoh-Ogoh* evaluation process in Bali. Observations revealed that the manual and subjective assessment approach led to inconsistencies, lack of transparency, and a high risk of calculation errors. These issues formed the basis for the urgency of developing a technology-based Decision Support System.
2. Literature Review
   This study utilized two primary data sources. First, a literature review was conducted to understand the theoretical frameworks of DSS, SMART, and SAW methods. Second, empirical data was collected from 45 *Ogoh-Ogoh* alternatives to serve as the test dataset for the system simulation.
3. Determination of Assessment Criteria (FGD)
   To ensure the validity of the assessment standards, the criteria and their respective weights were determined through a Focus Group Discussion (FGD) mechanism. This discussion involved relevant stakeholders, including traditional leaders (*Bendesa*), competition committees, and local art experts. The consensus resulted in five main criteria: aesthetics, creativity, thematic relevance, community participation, and environmental sustainability.
4. Data Processing (SMART and SAW)
   The data processing stage involves two mathematical approaches. Weighting (SMART) Weights for each criterion were normalized based on the priorities set during the FGD to produce proportional values and Ranking (SAW) The SAW method was applied to calculate the final score. Assessor evaluations were normalized and aggregated to produce a final ranking for each of the 45 *Ogoh-Ogoh* alternatives
5. DSS Development
   The system was developed as a web-based application to ensure accessibility for field judges. The technical environment for development included. Programming Language PHP with the CodeIgniter framework was used for the back-end logic Database MySQL was utilized to store alternative data, criteria weights, and assessment history User Interface The front-end was built using Bootstrap to ensure mobile responsiveness, allowing judges to input scores via smartphones or tablets directly at the competition site
6. System Testing
   System testing was conducted using two approaches Black-box Testing: To validate that all functional features (input, edit, delete, and calculation logic) worked according to the requirements without errors and Comparative Testing: To measure efficiency and accuracy. The system's ranking results were compared against manual calculations to verify the Spearman's Rank Correlation, and the processing time was measured to quantify efficiency gains.
7. Result Analysis
   The final stage involved analyzing the consistency between SMART and SAW methods and evaluating the system's impact on transparency and objectivity based on the testing results.

Results and Discussions

This section presents the experimental results of the *Ogoh-Ogoh* assessment using the proposed DSS. The analysis focuses on three key aspects: the comparison of ranking outputs between SMART and SAW, the statistical consistency test using Spearman's Rank Correlation, and the system efficiency testing.

Results

Ranking Calculation Analysis

The assessment involved 45 *Ogoh-Ogoh* alternatives evaluated against five weighted criteria. The calculation process for both methods was automated within the system. Table 1 presents the final ranking comparison between the SAW and SMART methods for the top and bottom alternatives.

Table 1. Assessment calculation of *ogoh-ogoh*

Alternative	K1	K2	K3	K4	K5	Final Score	SAW Score	SMART Score	Rank
A25	3	5	4	5	3	4.1	0.75	4	1
A11	4	4	4	5	3	4.05	0.75	4	2
A24	4	5	4	5	5	4	0.76	4.6	3
A17	5	1	5	5	1	4	0.84	3.4	3
A1	4	5	3	5	5	3.8	0.72	4.4	5
A23	2	4	5	3	1	3.75	0.76	3	6
A20	5	3	4	3	3	3.6	0.67	3.6	7
A8	5	3	5	1	2	3.55	0.66	3.2	8
A35	3	5	3	4	4	3.55	0.65	3.8	8
A45	3	5	3	3	3	3.5	0.63	3.4	10
A5	2	5	4	1	1	3.4	0.68	2.6	11
A13	2	4	5	2	2	3.4	0.62	3	11
A41	1	4	4	3	1	3.35	0.68	2.6	14
A37	3	4	4	1	1	3.35	0.68	2.6	14
A26	1	5	4	4	4	3.35	0.61	3.6	14
A21	1	3	5	3	1	3.3	0.68	2.6	16
A3	4	3	5	2	4	3.25	0.61	3.6	17
A33	2	5	4	2	4	3.15	0.57	3.4	18
A31	2	3	1	5	1	3.1	0.64	2.4	19
A27	4	4	3	2	4	3.1	0.57	3.4	19
A7	3	4	4	1	3	3.05	0.55	3	21
A36	3	4	3	2	3	3.05	0.55	3	21
A15	1	5	5	2	5	3	0.56	3.6	23
A12	1	4	2	4	2	3	0.54	2.6	23
A22	5	2	3	1	2	2.9	0.54	2.6	25
A4	2	4	5	1	4	2.9	0.53	3.2	25
A6	3	3	2	4	4	2.85	0.53	3.2	28
A29	1	4	5	1	3	2.85	0.51	2.8	28
A9	4	1	4	2	2	2.85	0.54	2.6	28
A14	4	2	2	4	4	2.8	0.53	3.2	30
A19	3	1	3	3	1	2.8	0.60	2.2	30
A43	1	4	1	5	4	2.7	0.49	3	32
A42	2	3	5	1	4	2.65	0.49	3	33
A39	2	1	4	5	5	2.6	0.52	3.4	34
A16	2	1	4	4	4	2.55	0.49	3	35
A2	2	3	3	3	5	2.5	0.48	3.2	36
A10	1	2	5	2	4	2.4	0.45	2.8	37
A44	3	1	1	4	3	2.3	0.43	2.4	38
A32	1	3	1	2	2	2.15	0.38	1.8	39
A40	3	1	1	3	3	2.1	0.39	2.2	40
A38	1	2	2	3	4	2	0.37	2.4	41
A30	1	1	2	4	4	1.95	0.37	2.4	42

A18	1	1	1	4	3	1.9	0.35	2	43
A34	2	3	1	1	4	1.85	0.33	2.2	44
A28	1	1	1	1	3	1.3	0.23	1.4	45

The comparison reveals that while the top-ranked alternatives are generally consistent, minor discrepancies exist due to the calculation nature of each method. SAW uses normalization relative to the maximum value in the dataset, making it stable for competitive ranking. In contrast, SMART uses utility functions based on criterion ranges, making it more sensitive to specific weight values.

Statistical Validation (Spearman's Rank Correlation)

To quantitatively validate the consistency between SMART and SAW, a Spearman's Rank Correlation test was conducted. This analysis determines whether the two methods produce linear ranking orders Table 2.

Table 2. Statistical summary table

Statistics	SAW Score	SMART Score
Mean	0.561	2.987
Standard Deviation	0.132	0.660

As visualized in Figure 2, the data distribution shows a linear trend. The statistical calculation yielded a Spearman correlation coefficient ρ of 0.81. A coefficient value closer to 1.0 indicates a very strong positive correlation. This statistically proves that the DSS provides reliable and consistent decision outcomes regardless of the method used, although SAW offers slightly better stability for this specific dataset

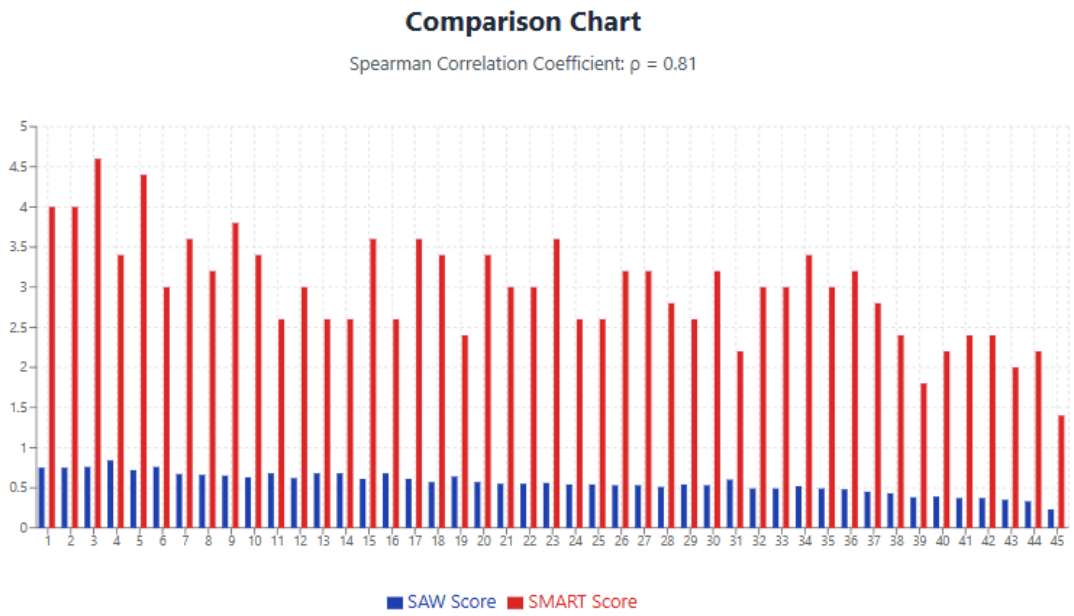


Figure 2. Comparison of SAW and SMART

System Implementation

The DSS was successfully developed as a web-based platform. The implementation covers the entire assessment lifecycle, from alternative registration to final reporting. The key interfaces are presented below:

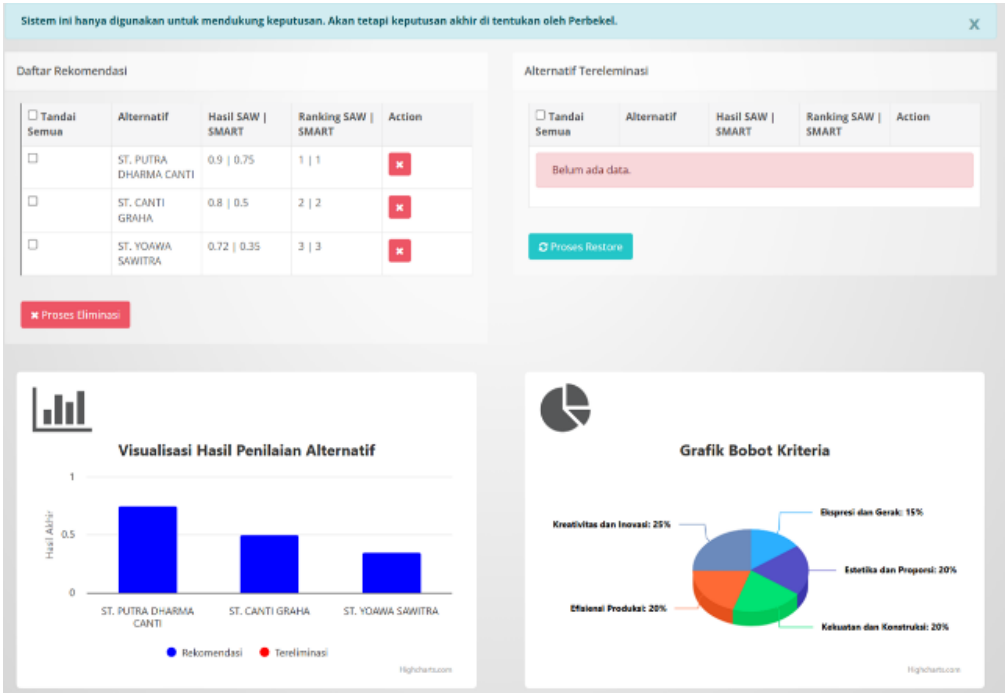
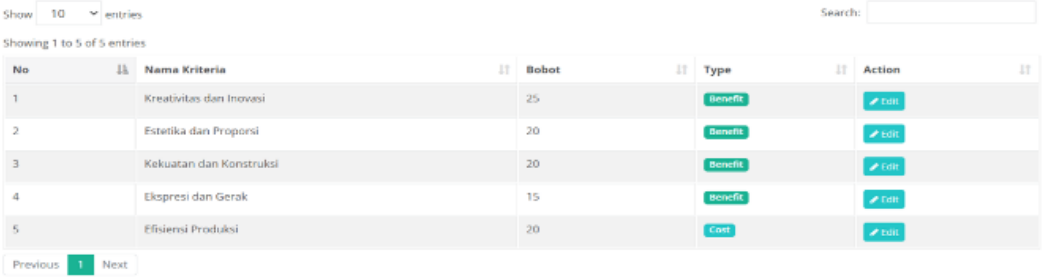


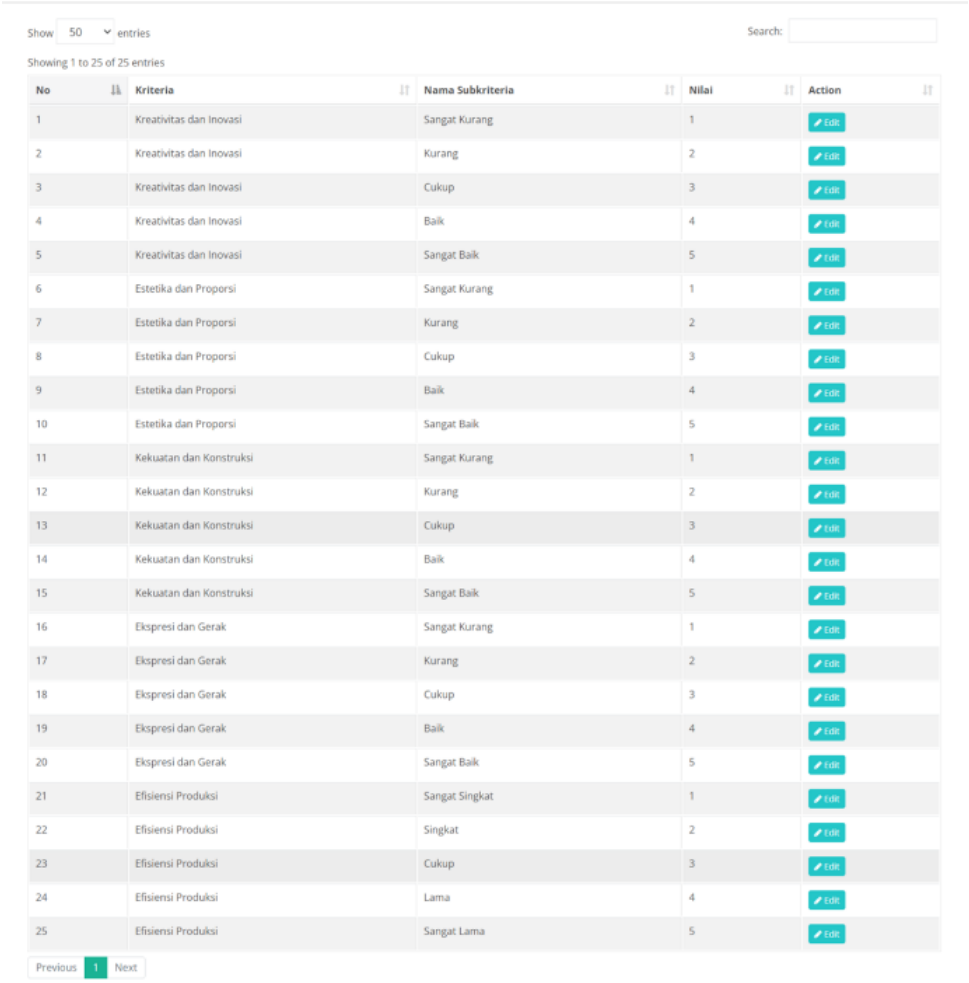
Figure 3. Assessment system dashboard

Figure 3 shows the system dashboard, where this section displays the alternative data and the calculation results using both the SMART and SAW methods.

Figure 4. Alternative data

Figure 4 shows the display of alternative data for evaluation, presenting each dataset that has been collected.





Show 50 entries Search:

Showing 1 to 25 of 25 entries

No	Kriteria	Nama Subkriteria	Nilai	Action
1	Kreativitas dan Inovasi	Sangat Kurang	1	Edit
2	Kreativitas dan Inovasi	Kurang	2	Edit
3	Kreativitas dan Inovasi	Cukup	3	Edit
4	Kreativitas dan Inovasi	Baik	4	Edit
5	Kreativitas dan Inovasi	Sangat Baik	5	Edit
6	Estetika dan Proporsi	Sangat Kurang	1	Edit
7	Estetika dan Proporsi	Kurang	2	Edit
8	Estetika dan Proporsi	Cukup	3	Edit
9	Estetika dan Proporsi	Baik	4	Edit
10	Estetika dan Proporsi	Sangat Baik	5	Edit
11	Kekuatan dan Konstruksi	Sangat Kurang	1	Edit
12	Kekuatan dan Konstruksi	Kurang	2	Edit
13	Kekuatan dan Konstruksi	Cukup	3	Edit
14	Kekuatan dan Konstruksi	Baik	4	Edit
15	Kekuatan dan Konstruksi	Sangat Baik	5	Edit
16	Ekspresi dan Gerak	Sangat Kurang	1	Edit
17	Ekspresi dan Gerak	Kurang	2	Edit
18	Ekspresi dan Gerak	Cukup	3	Edit
19	Ekspresi dan Gerak	Baik	4	Edit
20	Ekspresi dan Gerak	Sangat Baik	5	Edit
21	Efisiensi Produksi	Sangat Singkat	1	Edit
22	Efisiensi Produksi	Singkat	2	Edit
23	Efisiensi Produksi	Cukup	3	Edit
24	Efisiensi Produksi	Lama	4	Edit
25	Efisiensi Produksi	Sangat Lama	5	Edit

Previous 1 Next

Figure 5. Criteria and sub-criteria

Figure 5 shows the display of criteria and sub-criteria within the system

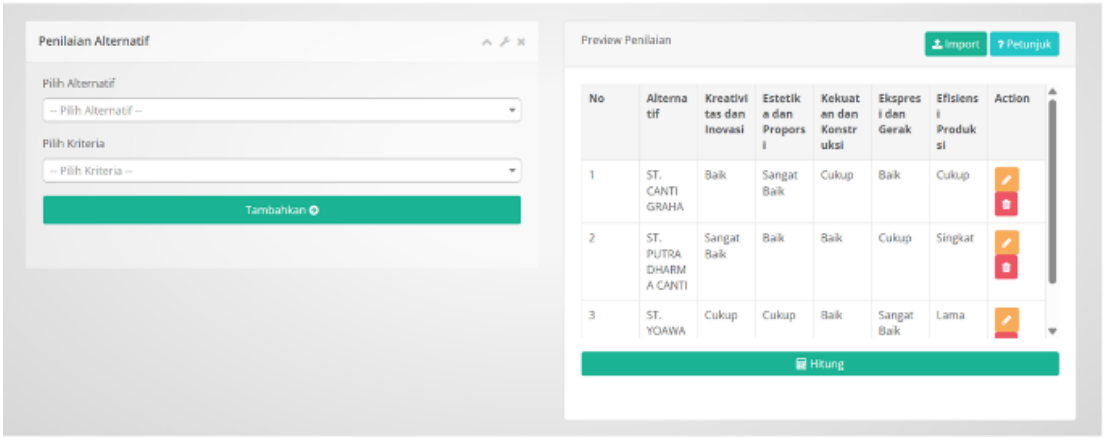


Figure 6. Assessment page

Figure 6 shows the assessment results page. Judges can view the evaluation results directly on this system interface, preventing redundancy or loss of documents. Decision-making for the evaluation can be conducted quickly, with calculations performed transparently.

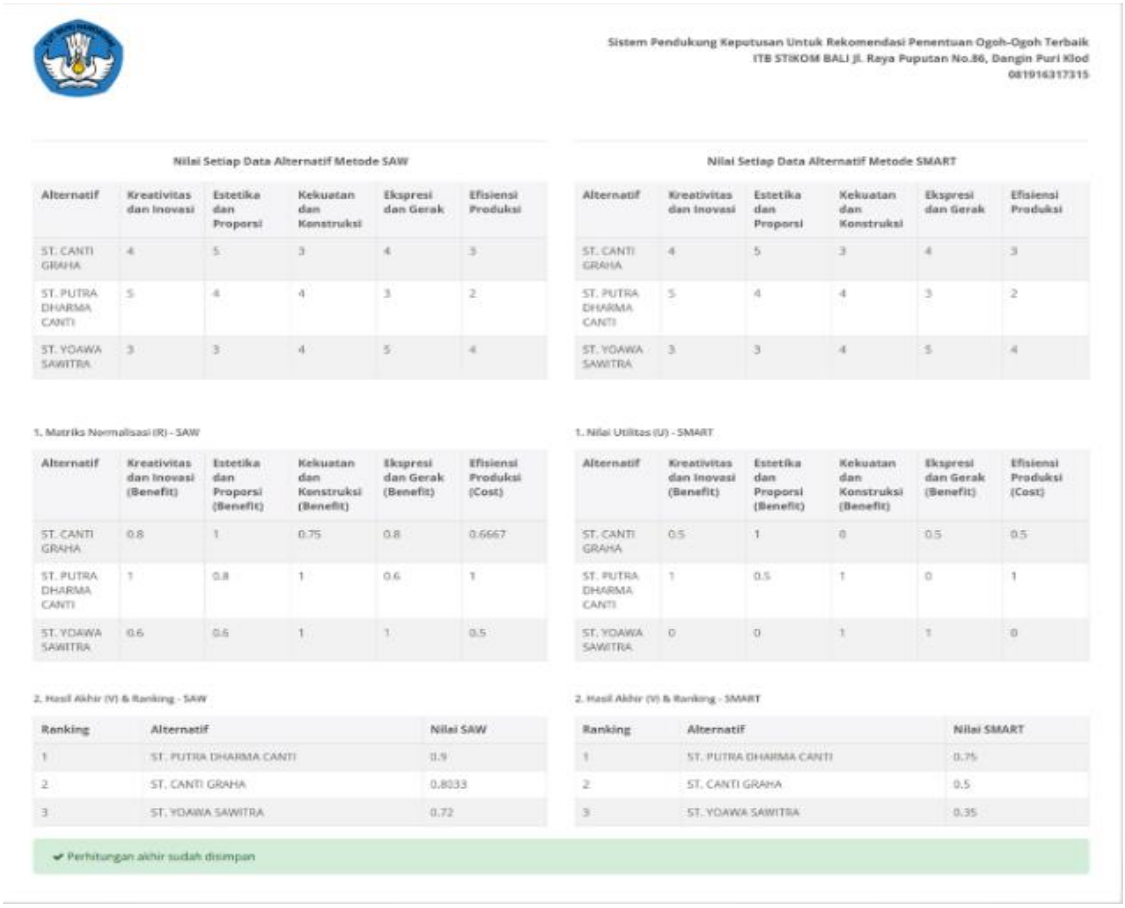


Figure 7. Calculation results and ranking

Figure 7 shows the display of the calculation results. On this page, the system performs computerized calculations, allowing the evaluation results to be obtained more quickly

System Testing and Efficiency

System testing was conducted to measure operational efficiency and accuracy compared to the previous manual method. The testing involved the competition committee and judges. The results are summarized as follows:

1. Accuracy: The system achieved an 85% ranking accuracy when cross-validated with expert manual decisions from the previous year's records.
2. Efficiency: The automated calculation significantly reduced the administrative workload. As illustrated in Figure 8, the scoring process for 45 alternatives, which previously took 150 minutes (2.5 hours) using manual tabulation, was completed in only 90 minutes (1.5 hours) using the DSS. This represents a 40% reduction in processing time, proving the system's effectiveness in real-world scenarios. Can be seen in the visualization of Figure 8.

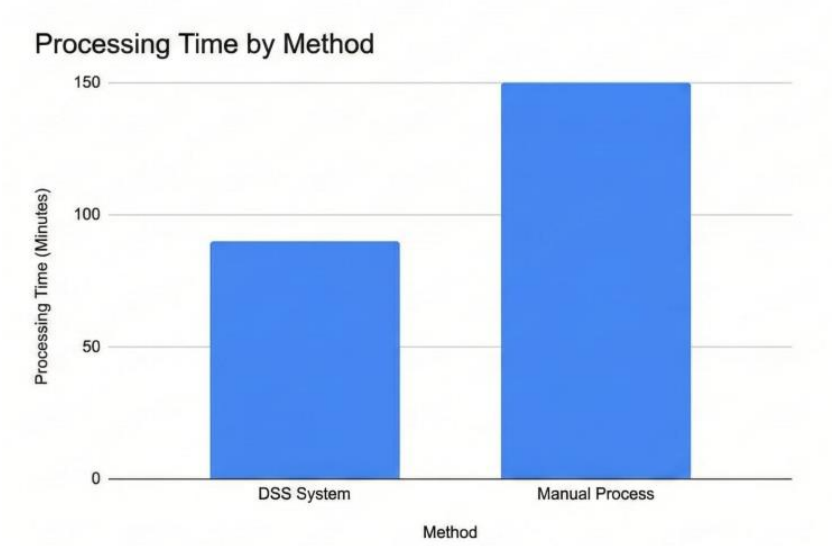


Figure 8. Comparison of processing time (Manual vs. DSS)

Discussions

The development of this DSS addresses the critical need for objectivity in cultural competitions. The integration of SMART and SAW methods successfully mitigates the issues of subjectivity and calculation errors found in manual processes.

1. Methodological Implications The comparative analysis confirms that both methods are valid for this domain. However, the SAW method is recommended as the default setting for *Ogoh-Ogoh* competitions due to its normalization technique (Benefit/Cost attributes), which is more robust in handling dynamic scores from diverse judges. SMART remains a valuable alternative when the committee requires flexibility in adjusting specific criteria weights to emphasize certain artistic themes.
2. Impact on Cultural Preservation Beyond technical efficiency, this research contributes significantly to cultural preservation. The "Preservation" aspect is quantified through the digitalization of 45 *Ogoh-Ogoh* artifacts into a structured database. In the manual system, assessment sheets were often lost or discarded. With this DSS, 100% of the assessment data is archived, creating a historical record of artistic trends, materials used, and community participation levels. This digital archive supports the long-term sustainability of the *Ogoh-Ogoh* tradition by providing future generations with referenced data on artistic evolution.
3. Operational Transparency The web-based nature of the system ensures transparency. Participants can view the criteria and final scores, reducing suspicion of bias. The 40% efficiency gain allows the committee to focus more on event management rather than administrative tabulation, making this model highly replicable for other cultural festivals in Bali.

Conclusion

This study successfully developed a web-based Decision Support System (DSS) for *Ogoh-Ogoh* assessment by integrating the SMART and SAW methods. The comparative analysis confirms that both methods produce objective and consistent rankings, statistically evidenced by a Spearman's Rank Correlation coefficient of 0.81. While SMART offers flexibility in criteria weighting according to evaluator preferences, SAW ensures greater stability through its normalization process.

The implementation of this system significantly enhances the effectiveness of cultural competitions. Testing results demonstrated an 85% ranking accuracy compared to expert manual evaluations and a 40% increase in efficiency, reducing the processing time from 2.5 hours to 1.5 hours per session. By minimizing subjective bias and automating calculations, the system fosters greater transparency and public trust. Furthermore, this study contributes to the preservation of Balinese culture by digitizing the assessment data of 45 *Ogoh-Ogoh* artifacts, creating a valuable historical database for future reference. Future research can expand this model by integrating

other MCDM methods or developing mobile-based applications to further broaden its accessibility in various cultural contexts

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Android-based decision support system using MAGIQ-MARCOS for digital bank selection

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Abstract: Choosing a digital bank is a challenge for anyone, especially due to cognitive biases that influence decision making. This study aims to develop an Android-based Decision Support System (DSS) using the MAGIQ MARCOS method to provide recommendations for digital banks that suit users' preferences. The MAGIQ method is used to weight the main criteria, namely Application Performance (C1), Financial Reports (C2), and User Experience (C3), while MARCOS is used to rank digital banking alternatives. This study includes data collection through surveys and interviews, data processing using MAGIQ for weighting, and ranking alternatives using MARCOS. The results indicate that Jenius ranked first with a preference value of 0.7632 followed by Seabank with 0.7164 and Krom Digital Bank with 0.6983. These findings show that the system is able to differentiate alternatives based on user priorities. The system achieved an accuracy of 80.39 percent compared with students' manual selections confirming that the recommendations align with actual user preferences. The recommendations generated by the system are consistent with the priorities of decision makers who value application quality and user experience. Use case testing also shows that all test scenarios function as expected. This research contributes to the development of technology based DSS to help students make more rational and data driven decisions in choosing a digital bank. Future work may integrate real time data updates and predictive analysis to improve recommendation accuracy and expand the MAGIQ-MARCOS method to other sectors that require multi criteria decision making.

Keywords: android, digital banking, DSS, MAGIQ, MARCOS

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Introduction

In today's digital age, digital banks have become the main alternative for the public, especially students, to conduct banking transactions efficiently and practically [1]. Digital banks, which operate entirely through electronic platforms such as mobile applications or websites, allow customers to access various banking services without having to visit a physical branch office [2]. The main advantages of digital banks are ease of access, lower administrative costs, and the convenience of conducting transactions anytime and anywhere [3]. However, despite the many options available, students often find it difficult to choose a digital bank that suits their needs and preferences.

The main problem students face in choosing a digital bank is cognitive bias, which influences their decision-making process. Cognitive biases, such as confirmation bias or bandwagon bias, often lead students to choose banks that are already popular or the most accessible, without carefully considering whether the services provided suit their needs [4]. Factors such as hidden costs, service quality, and additional features are often not considered in depth, leading to suboptimal decisions. Therefore, to help students make more rational decisions that suit their needs, a system is needed that can provide objective, data-driven recommendations.

One solution that can be implemented is to use a Decision Support System [5]. A Decision Support System (DSS) is a technology-based solution designed to assist decision makers in addressing complex situations that involve multiple criteria [6]. It provides structured analytical support by processing diverse data inputs and transforming them into meaningful information for evaluation [7], [8]. Through this capability, a DSS enables users to make more objective, consistent, and informed decisions in environments where manual judgment alone may be insufficient [9], [10]. In the context of choosing a digital bank, a DSS can provide recommendations based on several important criteria, such as administrative costs, transaction security, ease of use of the application, and customer service quality. A DSS allows users to make more objective decisions by simplifying the complex decision-making process [11], [12]. Through structured evaluation and systematic weighting of relevant criteria, the system helps users arrive at decisions that are more consistent, transparent, and aligned with their actual preferences [13], [14]. A DSS is an interactive computer-based system that helps decision makers utilize data and models to solve unstructured and semi-structured problems [15], [16], [17].

This study aims to develop an Android-based Decision Support System that uses the MAGIQ-MARCOS method to provide recommendations for digital banks that best suit student preferences. MAGIQ (Multi-Attribute Global Inference of Quality) is a method used to weight various criteria based on the order of priority set by the user [18], [19], [20], [21]. This method converts comparison attributes into normalized numerical weights, enabling faster and easier evaluation of alternatives. MARCOS (Measurement Alternatives and Ranking according to Compromise Solution) is used to rank alternatives based on their proximity to the ideal solution and how far they are from the worst solution [22], [23], [24], [25]. The combination of these two methods enables the system to provide recommendations for digital banks that more accurately match students' needs and preferences.

In the initial stage of this research, an analysis was conducted on the problems faced by students in choosing a digital bank. The results of the preliminary study showed that students often choose a digital bank based on factors such as ease of access or popularity, without carefully considering the more technical and specific features of each bank. Some students also tend to be influenced by social or emotional factors, such as choosing a bank used by their friends, which means that the decisions they make are not always rational. In addition, students often find it difficult to compare the various digital banking alternatives available due to their limited knowledge of the features and services offered by each bank.

From the results of this problem identification, it can be concluded that students need a system that can provide objective and data-driven recommendations. A technology-based Decision Support System can be an effective solution to help students overcome this decision-making problem. Using the MAGIQ-MARCOS method, the DSS can provide recommendations for digital banks that suit students' preferences, based on criteria they consider important, such as transaction security, administrative costs, and ease of use of the application.

This study also aims to test the effectiveness of the developed Android-based DSS. This test will be conducted by comparing the recommendations provided by the system with the choices selected manually by students. This aims to ensure that the developed system is capable of providing accurate recommendations that are relevant to user preferences. In addition, this study will also test the performance of the application, including its speed and accuracy in providing recommendations for digital banks that match user criteria.

With the Android-based DSS that integrates the MAGIQ-MARCOS method, students are expected to be able to make better and faster decisions in choosing a digital bank. This system will simplify the complex decision-making process and help students focus more on the criteria that are truly important to them. Thus, this research has the potential to make a significant contribution to improving the quality of students' decision-making in choosing a digital bank that suits their needs and preferences.

Methodology

This study aims to develop and implement an Android-based Decision Support System (DSS) using the MAGIQ-MARCOS method in selecting a digital bank that suits the preferences and needs of students. The method used in this study consists of several integrated stages, ranging from preliminary studies, field studies, to system implementation and testing stages. The stages of the research methodology that were carried out are shown in Figure 1.

Preliminary Study Phase

This initial phase aims to understand the overall context and challenges faced by students in choosing a digital bank. An analysis of various digital bank alternatives available in Indonesia is conducted to map common issues experienced by potential users. Factors influencing decision making such as administrative fees, accessibility, service features, and social influence are examined. The output of this phase is a foundational understanding of the decision-making difficulties that students encounter when selecting a bank that fits their needs.

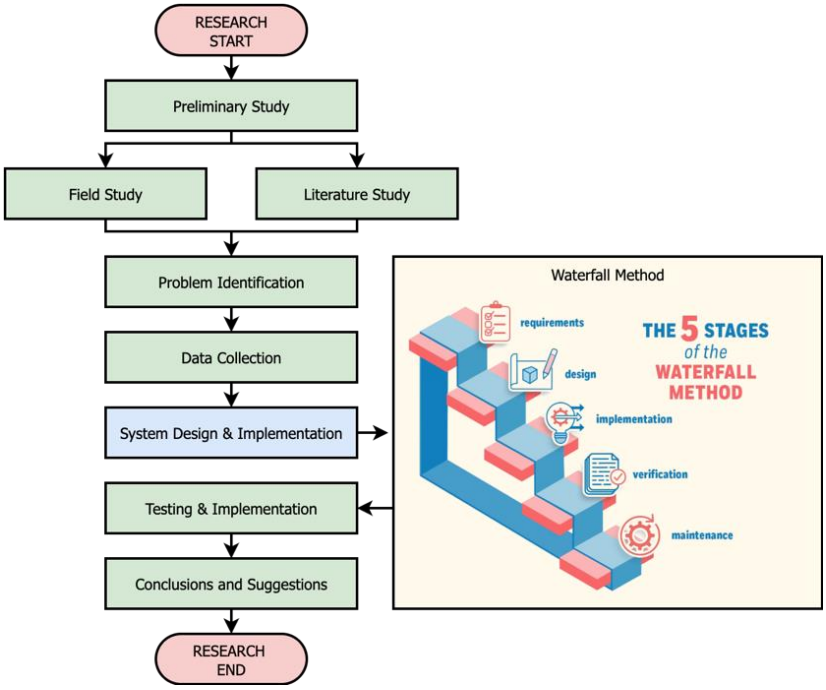

Figure 1. Research methodology

Field and Literature Study Phase

The field study is carried out to gather in-depth insights into student preferences. A total of ten student participants were involved in a Focus Group Discussion (FGD). Participants were selected using purposive sampling with eligibility requirements that included being active undergraduate students aged 18 to 25 years and having used at least one digital banking application within the past six months. Interviews, observations, and FGDs are used to explore preferred criteria, decision priorities, and experiences with digital banking services. To ensure rigor, data validation procedures include triangulation through cross-verification of FGD results, interview data, and observation notes.

The literature study supports the field findings by reviewing academic publications on Decision Support Systems, Multi-Criteria Decision-Making (MCDM), and the implementation of MAGIQ and MARCOS. This phase ensures that the system design is grounded in established theoretical frameworks.

Problem Identification Phase

In this phase, findings from the preliminary study, field study, and literature review are synthesized to formulate the core problem addressed by the DSS. The analysis reveals that students often experience cognitive biases, such as choosing digital banks based on popularity or peer influence rather than evaluating objective criteria. Students also demonstrate a limited understanding of technical indicators, including application performance metrics, financial stability indicators, and user experience variables, due to the complexity and lack of accessible information. Furthermore, the field study results, which involved eight students selected through purposive sampling, show that participants struggle to systematically compare digital banking alternatives because available information is scattered across different platforms.

These issues collectively hinder rational decision-making and highlight the need for a system capable of presenting structured, validated, and multi-criteria information. The insights from interviews, observations, and FGD sessions were validated using methodological triangulation, ensuring consistency across data sources. Based on this synthesis, the functional needs of the DSS are determined, it must objectively evaluate multiple criteria, eliminate cognitive bias, simplify comparison of alternatives, and produce data-driven recommendations tailored to user-defined preferences.

Data Collection Phase

The data collection phase consists of two primary components: user preference data and technical digital banking data. This phase also includes methodological details required by the reviewer, such as sampling, eligibility criteria, and validation procedures.

User preference data is obtained from interviews and FGDs involving eight eligible student participants, with selection based on the following criteria: active undergraduate status, age range 18–25 years, and experience using at least one digital bank within the past six months. Purposive sampling is used to ensure that participants possess relevant experience in digital banking. Through FGDs, participants describe their decision priorities, such as ease of navigation, security, and transaction cost, and identify factors contributing to their satisfaction or dissatisfaction with digital banks. The data is analyzed using thematic categorization and validated by cross-referencing interview narratives, field observations, and participant feedback to maintain reliability.

Technical data encompasses operational, financial, and experiential indicators that serve as quantifiable input for multi-criteria analysis. This includes app store metrics, installation counts, user ratings, financial report components, and user engagement indicators. Data is collected from publicly verifiable sources, including financial disclosures, Google Play Store analytics, and secondary research repositories. Data validation is performed using source triangulation to ensure consistency across databases.

Criteria and Sub-Criteria Data

Three main criteria are used to evaluate digital banks such as Application Performance (C1), Financial Reports (C2), and User Experience (C3). Each criterion is further divided into more detailed sub-criteria. For example, the Application Performance criterion includes sub-criteria such as application file size (C1-A), application rating (C1-B), user rated (C1-C), Total installations (C1-D), and release date (C1-E). Meanwhile, the Financial Reports criterion uses data on current accounts (C2-A), savings accounts (C2-B), deposits (C2-C), and net profit(C2-D), which indicate the financial stability of digital banks. The User Experience criterion assesses the level of user happiness (C3A), engagement (C3B), adoption (C3C), retention (C3D), and task success (C3E) in using the application.

Alternative Data

There are 17 digital banks as alternative data used in this study. These alternatives include banks such as Line Bank, Jenius, Bank Jago/Jago Syariah, Aladin, UOB TMRW Indonesia, Seabank, and others. Data related to the criteria and sub-criteria of each digital bank was collected through surveys, observations, and relevant field data. Each bank was assessed based on predetermined factors, and the results were used to calculate the ranking of each digital bank.

Data Processing

The collected data was then processed using the MAGIQ method to assign weights to each criterion and sub-criterion. These weights were adjusted according to the priorities set by the decision makers involved in this study. These weights are very important to provide an overview of how much each criterion influences the final decision in choosing a digital bank. The decision-maker provided the criteria data, which were subsequently analyzed using the MAGIQ method. The results of this analysis are presented in Figure 2.

The MAGIQ-MARCOS method combination consists of 3 main stages, namely alternative normalization calculation, weighted alternative normalization calculation, and utility function value calculation. Since this study is a 2-level hierarchy, the calculation is performed from the bottom level upwards. The following shows the calculation process at the bottom level in MAGIQ-MARCOS, focusing on the Application Performance Criteria (C1) section, with a sample calculation for the Line Bank Alternative. Alternative data for the Application Performance criterion (C1) are presented in Table 1.

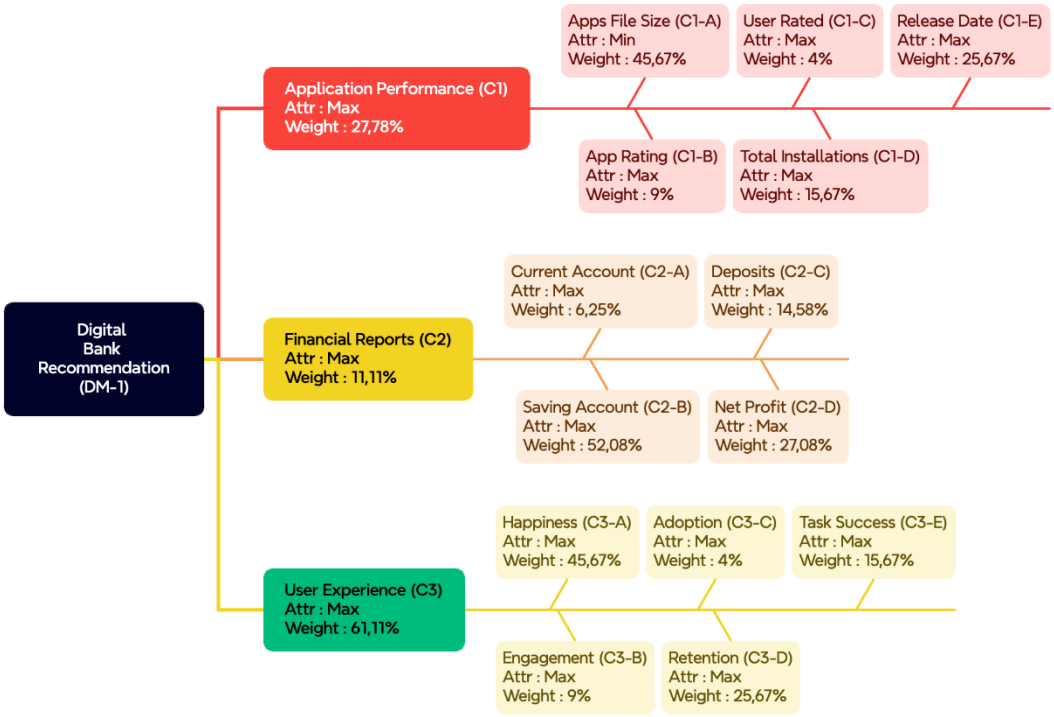

Figure 2. Criteria Weight using MAGIQ

Table 1. Alternative data for application performance criteria (C1)

Alternative ID	Alternative	C1-A	C1-B	C1-C	C1-D	C1-E
Bank01	Line Bank	51	3.12	26,482	4,127,684	1474
Bank02	Bank Jago/Jago Syariah	72	4.50	195,249	14,224,225	1524
Bank03	Aladin: Bank Syariah Digital	26	4.22	40,223	5,204,447	1203
Bank04	UOB TMRW Indonesia	116	4.37	51,456	2,968,246	1988
Bank05	Seabank	88	4.87	1,937,756	25,478,632	1574
Bank06	Jenius	66	3.31	202,007	12,784,553	3235
Bank07	Blu by BCA Digital	129	4.53	108,244	4,268,444	1424
Bank08	Raya - Digital Bank	59	4.38	9,954	1,408,317	970
Bank09	MotionBank	27	3.57	11,683	1,219,611	1771
Bank10	Neobank by BNC Digital	49	3.36	279,555	30,989,349	1555
Bank11	Capital Flex	30	3.79	179	33,512	490
Bank12	Digibank by DBS Indonesia	81	4.42	90,576	3,227,431	3109
Bank13	Krom - Bank Digital	14	4.82	20,358	913,111	613
Bank14	Superbank	23	4.40	26,446	3,355,124	531
Bank15	Bank Saqu	93	4.70	57,681	4,407,612	587
Bank16	Allo Bank	51	3.98	52,904	9,939,041	1204
Bank17	HiBank	46	4.91	1,813	104,742	118

Alternative normalization stage

$$n_{C1-A;Bank-01} = \frac{\min(51;72;\cdots;51;46)}{51} = \frac{14}{51} = 0.275$$

$$n_{C1-B;Bank-01} = \frac{3.12}{\max(3.12;4.5;\cdots;3.98;4.91)} = \frac{3.12}{4.91} = 0.653$$

$$n_{C1-C;Bank-01} = \frac{26482}{\max(26482;195249;\cdots;52904;1813)} = \frac{26482}{1937756} = 0.014$$

$$n_{C1-D;Bank-01} = \frac{4127684}{\max(4127684;14224225;\cdots;9939041;104742)} = \frac{4127684}{30989349} = 0.133$$

$$n_{C1-E;Bank-01} = \frac{1474}{\max(1474;1524;\cdots;1204;118)} = \frac{1474}{3235} = 0.456$$

Weighted alternative normalization stage

$$v_{C1-A;Bank-01} = 0.275 \times 45.7\% = 0.125$$

$$v_{C1-B;Bank-01} = 0.635 \times 9.0\% = 0.057$$

$$v_{C1-C;Bank-01} = 0.014 \times 4.0\% = 0.001$$

$$v_{C1-D;Bank-01} = 0.133 \times 15.7\% = 0.021$$

$$v_{C1-E;Bank-01} = 0.456 \times 25.7\% = 0.117$$

The outcomes of the normalization stage and the subsequent weighted normalization for the Application Performance criteria (C1) are summarized in Table 2, which provides a structured representation of how each digital banking alternative is standardized based on MAGIQ-derived weights. This table demonstrates the conversion of raw attribute values into normalized scores, followed by the application of criterion weights to produce weighted normalization values. These values serve as the foundation for the utility function calculations in the MARCOS method, ensuring that each alternative is evaluated consistently and in accordance with user-defined priorities.

Table 2. Alternative normalization and weighted alternative normalization data for application performance criteria (C1)

Alternative ID	Alternative Normalization					Weighted Alternative Normalization				
	C1-A	C1-B	C1-C	C1-D	C1-E	C1-A	C1-B	C1-C	C1-D	C1-E
Bank01	0.2745	0.6354	0.0137	0.1332	0.4556	0.1254	0.0572	0.0005	0.0209	0.1169
Bank02	0.1944	0.9165	0.1008	0.4590	0.4711	0.0888	0.0825	0.0040	0.0719	0.1209
Bank03	0.5385	0.8595	0.0208	0.1679	0.3719	0.2459	0.0774	0.0008	0.0263	0.0954
Bank04	0.1207	0.8900	0.0266	0.0958	0.6145	0.0551	0.0801	0.0011	0.0150	0.1577
Bank05	0.1591	0.9919	1.0000	0.8222	0.4866	0.0727	0.0893	0.0400	0.1288	0.1249
Bank06	0.2121	0.6741	0.1042	0.4125	1.0000	0.0969	0.0607	0.0042	0.0646	0.2567
Bank07	0.1085	0.9226	0.0559	0.1377	0.4402	0.0496	0.0830	0.0022	0.0216	0.1130
Bank08	0.2373	0.8921	0.0051	0.0454	0.2998	0.1084	0.0803	0.0002	0.0071	0.0770
Bank09	0.5185	0.7271	0.0060	0.0394	0.5474	0.2368	0.0654	0.0002	0.0062	0.1405
Bank10	0.2857	0.6843	0.1443	1.0000	0.4807	0.1305	0.0616	0.0058	0.1567	0.1234
Bank11	0.4667	0.7719	0.0001	0.0011	0.1515	0.2131	0.0695	0.0000	0.0002	0.0389
Bank12	0.1728	0.9002	0.0467	0.1041	0.9611	0.0789	0.0810	0.0019	0.0163	0.2467
Bank13	1.0000	0.9817	0.0105	0.0295	0.1895	0.4567	0.0884	0.0004	0.0046	0.0486
Bank14	0.6087	0.8961	0.0136	0.1083	0.1641	0.2780	0.0807	0.0005	0.0170	0.0421
Bank15	0.1505	0.9572	0.0298	0.1422	0.1815	0.0687	0.0862	0.0012	0.0223	0.0466
Bank16	0.2745	0.8106	0.0273	0.3207	0.3722	0.1254	0.0730	0.0011	0.0502	0.0955
Bank17	0.3043	1.0000	0.0009	0.0034	0.0365	0.1390	0.0900	0.0000	0.0005	0.0094

Utility function value calculation stage

$$K_{(K1;Bank-01)}{}^{-} = \frac{0.1254+0.0572+0.0005+0.0209+0.1169}{\min(0.1254;\cdots;0.1390)+\cdots+\min(0.1169;\cdots;0.0094)} = \frac{0.3209}{0.0496+0.0572+0.0000+0.0002+0.0094} = \frac{0.3209}{0.1163} = 2.7597$$

$$K_{(K1;Bank-01)}{}^{+} = \frac{0.1254+0.0572+0.0005+0.0209+0.1169}{\max(0.1254;\cdots;0.1390)+\cdots+\max(0.1169;\cdots;0.0094)} = \frac{0.3209}{0.4567+0.0900+0.0400+0.1567+.02567} = \frac{0.3209}{1.0000} = 0.3209$$

$$f\left(K_{(K1;Bank-01)}{}^{-}\right) = \frac{0.3209}{0.3209+2.7597} = 0.1042$$

$$f\left(K_{(K1;Bank-01)}{}^{+}\right) = \frac{2.7597}{0.3209+2.7597} = 0.8958$$

$$f\left(K_{(K1;Bank-01)}\right) = \frac{0.3209+2.7597}{1+\frac{1-0.8958}{0.8958}+\frac{1-0.1042}{0.1042}} = 0.3171$$

The complete dataset for the Financial Reports criteria (C2) and the User Experience criteria (C3) is provided in Table 3, which presents the operational, financial, and experiential attributes for all digital banking alternatives considered in this study. These values form a crucial input for the evaluation process, as they represent the quantitative measures used to assess financial soundness (such as current accounts, savings, deposits, and profit) and user interaction performance (including happiness, engagement, adoption, retention, and task success). The structured presentation of this information in Table 3 ensures consistency and transparency in subsequent normalization, weighting, and ranking procedures within the MAGIQ MARCOS framework.

Table 3. Alternative data for application financial reports (C2), and user experience (C3)

Alternative ID	C2-A	C2-B	C2-C	C2-D	C3-A	C3-B	C3-C	C3-D	C3-E
Bank01	9,108,419	1,619,459	16,201,040	519,430	3.63	3.40	3.60	3.20	3.71
Bank02	990,303	1,087,125	4,629,116	128,518	4.33	4.16	4.35	4.12	4.00
Bank03	678	665,213	4,744,140	(73,727)	3.46	3.80	3.63	3.40	3.93
Bank04	32,135	35,076	49,701	406,240	3.43	3.40	3.75	3.40	3.83
Bank05	7,646,091	10,658,970	8,348,328	378,769	4.23	3.92	4.15	3.84	4.37
Bank06	25,586,525	16,909,498	67,926,531	2,230,270	3.97	4.00	4.15	3.80	4.17
Bank07	4,680	5,542,457	6,182,903	107,972	3.43	4.04	3.85	3.96	3.94
Bank08	9,160	39,341	359,965	39,084	3.83	3.80	3.88	3.45	3.93
Bank09	1,123,635	1,855,261	11,451,750	74,850	3.97	3.68	3.95	3.76	3.89
Bank10	514,834	3,095,982	9,452,976	37,483	3.88	3.95	4.00	3.90	4.21
Bank11	2,012,703	3,508,919	7,050,639	220,838	3.08	3.35	3.31	3.10	3.64
Bank12	16,237,212	5,055,926	29,382,955	1,488,080	3.83	3.55	3.75	3.85	3.82
Bank13	12,176	496,140	2,650,460	124,060	3.87	3.48	3.85	3.72	3.91
Bank14	113,672	1,258,347	3,570,807	(384,957)	3.40	3.56	3.60	3.28	3.63
Bank15	561,701	634,614	5,211,170	(334,719)	3.93	3.72	3.95	3.56	3.66
Bank16	85,336	693,272	5,316,510	467,106	3.87	3.80	4.05	3.84	3.91
Bank17	4,426,221	839,852	7,377,070	131,797	3.00	3.10	3.06	2.95	3.36

The results of the utility value computation for the three main criteria, namely Application Performance (C1), Financial Reports (C2), and User Experience (C3), are detailed in Table 4, providing a quantitative representation of each alternative's performance relative to the ideal and anti-ideal benchmarks. These utility values are subsequently integrated into the Level 1 preference calculation, as illustrated in Table 5, which consolidates the weighted utility function outputs along with the final ranking outcomes for DM1. Together, these tables present the complete analytical progression from criterion-level evaluation to the final decision recommendation, thereby demonstrating the effectiveness of the MAGIQ MARCOS framework in identifying the most suitable digital bank alternative.

Table 4. Utility value for C1, C2, C3

Alternative ID	C1		C2		C3	
	K_i^-	K_i^+	K_i^-	K_i^+	K_i^-	K_i^+
Bank01	2.7597	0.3209	-3.7312	0.1700	1.1489	0.8220
Bank02	3.1658	0.3681	-1.3488	0.0614	1.3791	0.9867
Bank03	3.8340	0.4458	-0.4768	0.0217	1.1637	0.8326
Bank04	2.6574	0.3090	-1.1106	0.0506	1.1445	0.8189
Bank05	3.9180	0.4556	-9.0193	0.4109	1.3487	0.9650
Bank06	4.1537	0.4830	-21.9498	1.0000	1.2984	0.9290
Bank07	2.3166	0.2694	-4.3266	0.1971	1.2197	0.8726
Bank08	2.3471	0.2729	-0.1482	0.0068	1.2265	0.8775
Bank09	3.8625	0.4491	-2.0537	0.0936	1.2683	0.9075
Bank10	4.1095	0.4779	-2.6661	0.1215	1.2923	0.9246
Bank11	2.7659	0.3216	-3.4011	0.1550	1.0504	0.7516
Bank12	3.6531	0.4248	-9.6399	0.4392	1.2468	0.8921
Bank13	5.1484	0.5987	-0.7917	0.0361	1.2442	0.8902
Bank14	3.5968	0.4183	0.0010	0.0000	1.1221	0.8028
Bank15	1.9344	0.2249	0.1874	-0.0085	1.2358	0.8842
Bank16	2.9684	0.3452	-1.9689	0.0897	1.2669	0.9064
Bank17	2.0546	0.2389	-1.5041	0.0685	1.0000	0.7155

Table 5. Alternative data level 1, utility function (preference value) and rank for digital banking recommendation for DM1

Alternative ID	Alternative	C1	C2	C3	$f(K)$	Rank
Bank01	Line Bank	0.3171	0.1696	0.6331	0.5673	Rank 12
Bank02	Bank Jago/Jago Syariah	0.3637	0.0613	0.7599	0.6611	Rank 6
Bank03	Aladin: Bank Syariah Digital	0.4405	0.0217	0.6413	0.6076	Rank 9
Bank04	UOB TMRW Indonesia	0.3053	0.0505	0.6307	0.5500	Rank 14
Bank05	Seabank	0.4502	0.4100	0.7432	0.7164	Rank 2
Bank06	Jenius	0.4772	0.9978	0.7155	0.7632	Rank 1
Bank07	Blu by BCA Digital	0.2662	0.1967	0.6721	0.5761	Rank 11
Bank08	Raya - Digital Bank	0.2697	0.0067	0.6759	0.5623	Rank 13
Bank09	MotionBank	0.4438	0.0934	0.6989	0.6544	Rank 7
Bank10	Neobank by BNC Digital	0.4722	0.1212	0.7121	0.6771	Rank 4
Bank11	Capital Flex	0.3178	0.1546	0.5788	0.5296	Rank 16
Bank12	Digibank by DBS Indonesia	0.4197	0.4382	0.6870	0.6692	Rank 5
Bank13	Krom - Bank Digital	0.5915	0.0360	0.6856	0.6983	Rank 3
Bank14	Superbank	0.4133	0.0000	0.6183	0.5794	Rank 10
Bank15	Bank Saqu	0.2223	-0.0085	0.6810	0.5456	Rank 15
Bank16	Allo Bank	0.3410	0.0895	0.6981	0.6131	Rank 8
Bank17	HiBank	0.2361	0.0684	0.5510	0.4707	Rank 17

System Design and Implementation Phase

The design phase focuses on developing the system architecture capable of integrating the MAGIQ MARCOS workflow. The user interface is designed to allow users to input their preference priorities, initiate computations, and receive ranked recommendations. The database schema is structured to store criteria, sub-criteria, weights, and alternative values. During implementation, the Android application is built using Java and XML, and the multi-criteria decision-making algorithms are embedded into the application's backend logic. This ensures a seamless computational flow from user input to recommendation output.

Testing Phase

Testing is undertaken to ensure the reliability, accuracy, and usability of the application. Black-box testing is first conducted to assess whether all features operate according to specifications, such as preference input, weight assignment, and recommendation generation. User acceptance testing (UAT) is conducted with student participants to evaluate the clarity, responsiveness, and overall usability of the application interface. Additionally, accuracy testing is performed to measure the degree to which DSS-generated recommendations align with the participants' manually chosen alternatives. The system demonstrates high reliability, with all test scenarios producing valid outcomes and the ranking results showing consistency with stated user priorities.

Conclusion and Suggestion Phase

In the final phase, conclusions are drawn regarding the effectiveness of the DSS, particularly its ability to provide objective, preference-based recommendations for selecting digital banks. Suggestions for future work include integrating real-time financial data, implementing predictive analytics to improve recommendation accuracy, and adapting the MAGIQ MARCOS methodology to other decision-making contexts, such as insurance or investment product selection.

Results and Discussions

System Design and Implementation

After the data is prepared, the next step is to design and implement a system that integrates the collected data with the MAGIQ-MARCOS method. The developed system is Android-based and requires users to select their preferences based on existing criteria.

System Design

The system design includes an intuitive user interface, allowing students to easily enter their preferences for the specified criteria. The main page of the application displays options for selecting criteria and user preferences, while the weighting page allows users to assign weights to each criterion. The recommendation results are displayed in the form of graphs and tables to facilitate user understanding.

The structural overview of the developed Decision Support System is presented in Figure 3, which illustrates the integration of key components including the user interface module, the database management layer, and the computational engine responsible for executing the MAGIQ MARCOS procedures. This design framework clarifies how user inputs are processed, transformed through multi-criteria decision-making algorithms, and subsequently returned as ranked digital bank recommendations. The figure provides a comprehensive visualization of the system's workflow, ensuring transparency in the functional relationships and data pathways implemented within the Android application.

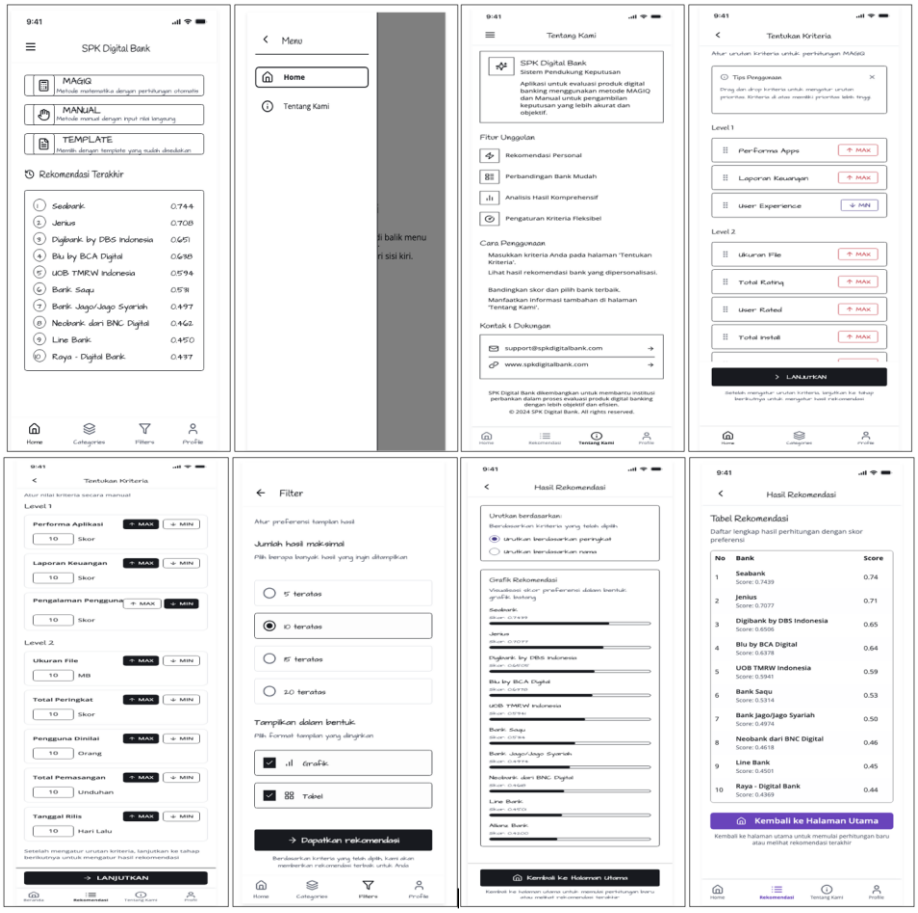

Figure 3. System design

System Implementation

The system implementation is carried out by developing an Android-based application using Java and XML for the user interface. The MAGIQ method is used for weighting criteria, while

MARCOS is used for ranking digital banks. Users are asked to enter their preferences, and the application then calculates the ranking of digital banks based on the weights given by users.

This application also allows users to choose manual weighting, giving them more flexibility in determining criteria priorities. After that, the application provides digital bank recommendations based on the preferences entered by the user.

The operational form of the developed Decision Support System is depicted in Figure 4, which presents the implemented Android application reflecting the system design and computational framework previously outlined. This figure demonstrates how the user interface, preference input modules, and recommendation output features have been translated into a fully functioning mobile application. It also highlights the integration of MAGIQ MARCOS algorithms within the backend processes, ensuring that user selections are accurately converted into structured decision outputs. The visualization provided in this figure affirms the alignment between the conceptual design and its practical deployment on the Android platform.

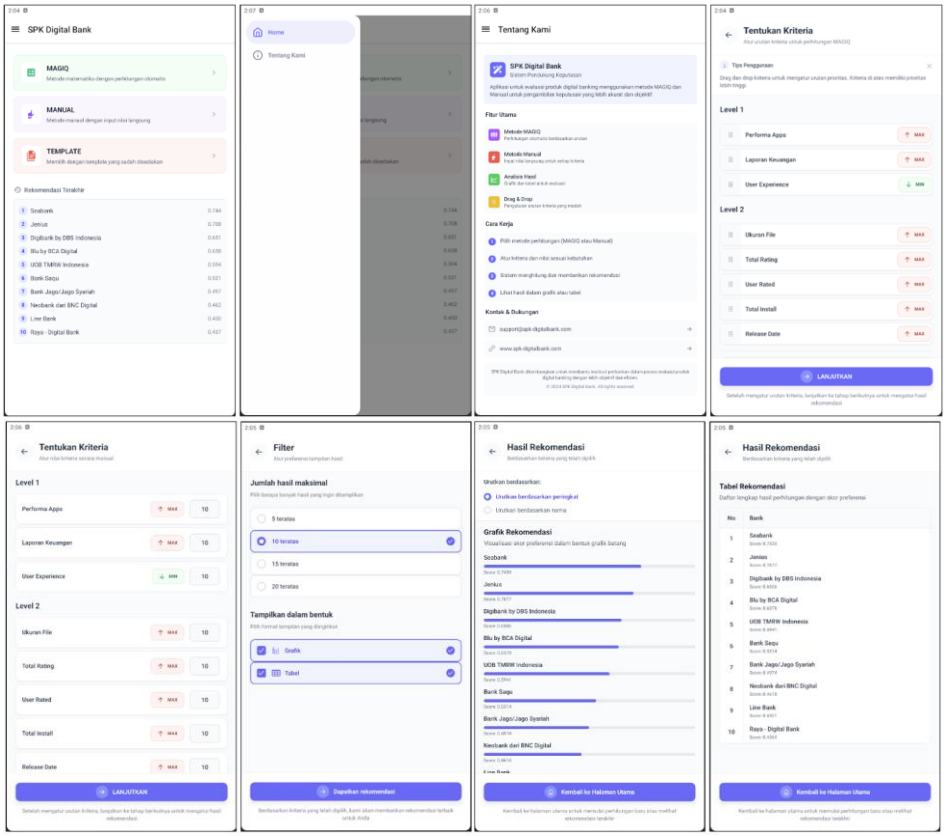

Figure 4. System implementation

Testing and Evaluation

After the system has been implemented, the next step is testing and evaluation to ensure that the application functions as expected and provides accurate recommendations. The testing conducted in this study used use case testing.

This testing ensures that every feature in the application functions properly in real-world situations. The test results show that all features, including manual preference weighting, preference storage, and recommendation results presentation, work as expected. No significant problems were found in the navigation and use of the application. As shown in Table 6, the use case testing results confirm that all system functionalities operate as expected, with each scenario validated successfully.

Table 6. Use case testing result

No	Testing Scenario	Expected Result	Obtained Result	Validation
1	Access the main page of the application, both on the web and mobile	The main page opens and displays a list of options for selecting digital bank preferences using MAGIQ or performing manual weighting	The main page opens and is in accordance with the design, displaying the expected options	Valid
2	The user selects one of the criteria on the "Select Criteria" page	The system displays a list of digital banks based on the criteria selected by the user	The system successfully displays a list of digital banks according to the criteria selected by the user	Valid
3	The user attempts to perform manual weighting to determine preferences	The system allows the user to enter preference weights for the available criteria	Manual weighting is successfully performed and the system accepts the input as desired by the user	Valid
4	Saving the preference weights entered on the manual weighting page	The system saves the user's preference weight data and displays a successful save notification	The preference weight data is successfully saved and a notification appears as expected	Valid
5	The user requests recommendations based on the preference weights that have been set	The system generates a list of digital bank recommendations according to the preference weights that have been entered and displays the ranking results	Digital bank recommendations appear according to the weights entered, with a ranking display	Valid
6	Accessing the recommendation results page with ranking and name display options	The system displays recommendation results in two display options: by ranking and by name	Recommendation results appear according to the display settings selected by the user	Valid
7	The user presses the "Back" button on the recommendation results page to return to the weighting page	The system returns the user to the manual preference weighting page or district selection page	The user successfully returns to the previous page as expected	Valid
8	Loading the application on various mobile devices with different resolutions	The application adapts responsively and displays a neat interface on various screen resolutions	The application appears responsive and neat on various tested devices	Valid
9	Closing the application or returning to the main menu while on the recommendation results page	The system allows users to return to the main page without losing data or settings that have been configured	Users return to the main page with settings intact	Valid

Discussions

This study successfully developed an Android-based decision support system (DSS) using the MAGIQ-MARCOS method to provide recommendations for digital banks that suit student preferences. In this study, three main criteria were used to assess digital bank alternatives, namely Application Performance, Financial Reports, and User Experience. These criteria were each divided into more detailed sub-criteria, which measured technical aspects such as application ratings, number of installations, bank financial stability, and user experience in using the application. From the data processing results, Jenius ranked first based on the system's recommendation results for DM1, followed by Seabank in second place, and Krom - Bank Digital in third place. These recommendations are in line with the preferences expected by DM1, which tends to choose digital banks with high application performance and a better user experience. These results demonstrate the effectiveness of the MAGIQ-MARCOS method in providing relevant and objective recommendations based on the criteria priorities determined by users.

Use-case testing shows that all application features function as expected. The application can accommodate user needs in selecting a digital bank through manual weighting and generate recommendations that match the preferences entered. These results emphasize the importance of implementing technology-based DSS systems to simplify complex decision-making, such as selecting a digital bank. This research provides significant benefits for students who have difficulty choosing a digital bank, as this system can provide data-driven and objective recommendations. In addition, this research opens up opportunities for further development in creating similar systems in other sectors that require multi-criteria decision making, such as insurance or investment selection. Future work could include improving the system by introducing real-time data updates and predictive analysis features, which could improve the accuracy of recommendations as market dynamics and user preferences change.

Conclusion

This study successfully developed an Android-based Decision Support System (DSS) using the MAGIQ MARCOS method to provide recommendations for digital banks that suit student preferences. Based on three main criteria, namely Application Performance, Financial Reports, and User Experience, the system was able to generate objective recommendations, with Jenius ranking first, followed by Seabank and Krom Digital Bank. These findings confirm the effectiveness of the MAGIQ MARCOS approach in simplifying complex decision-making and producing accurate results that reflect user-defined priorities.

Despite its successful implementation, the developed system has several limitations. First, the data used for evaluation is static and does not incorporate real-time financial or application performance updates, which may reduce accuracy when market conditions change rapidly. Second, the system relies on a relatively small number of respondents in the weighting process, particularly the eight FGD participants, which may limit the generalizability of the preference model. Third, only three main criteria were included, and certain qualitative aspects such as customer support responsiveness or long-term reliability were not assessed due to data availability constraints. Finally, the system currently supports a single decision maker at a time and does not yet include collaborative or group decision-making features.

In the future, this research can be expanded through the integration of real-time data updates, predictive analytics, and automated data scraping mechanisms to improve recommendation accuracy over time. Additional user studies with more diverse respondents could also be conducted to enhance the robustness of the weighting process. This system additionally holds potential for application in other sectors, such as investment or insurance selection, that require multi-criteria decision-making. Thus, this research contributes to the advancement of DSS for digital banking while opening opportunities for broader application in other data-driven decision analysis domains.

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Improving 5G wireless networks through OFDM integration with convolutional coding and pulse shaping

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Abstract: The telecommunications industry has evolved significantly, with advancements from 1G to 4G and now towards 5G, promising enhanced data speeds and connectivity. Orthogonal Frequency Division Multiplexing (OFDM) is crucial in this transition due to its efficient spectrum utilization and ability to handle frequency-selective fading. However, OFDM is susceptible to Carrier Frequency Offset (CFO), leading to Inter-Carrier Interference (ICI) and degraded performance. This research investigates the impact of CFO on conventional OFDM systems and proposes mitigation techniques using Improved Sinc-power (ISP) pulse shaping and Convolutional Channel Coding. MATLAB simulations were conducted to analyze CFO-induced ICI in a standard OFDM system, followed by performance comparison with ISP-OFDM and ISP-OFDM combined with Convolutional Coding. The results demonstrate that CFO significantly increases ICI, causing a higher Bit Error Rate (BER). The application of ISP pulse shaping reduces the side-lobe interference of each subcarrier, while the combination of ISP pulse shaping and Convolutional Coding provides the best performance improvement, achieving a BER of approximately 0.0018. Overall, the integration of ISP and Convolutional Coding effectively mitigates CFO-induced degradation, offering a robust and reliable solution for future 5G wireless communication systems.

Keywords: 5G, CFO, Convolutional, ISP, OFDM

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Introduction

The telecommunications industry has undergone significant transformation from generation to generation, starting from 1G to 4G, with each evolution bringing advances in mobile communication technology. Today, the evolution towards 5G is expected not only to improve data speeds and capacity but also to support various applications such as the Internet of Things (IoT) and augmented reality (AR) [1]. OFDM technology plays a key role in addressing challenges and meeting increasingly complex demands in modern wireless communication systems [2], [3], [4].

The implementation of 4G technology, particularly Long-Term Evolution (LTE), has revolutionized data transmission, providing higher speeds and more reliable connectivity. However, with increasing demand for data usage and the need for more responsive connectivity, further evolution is required [5]. The development of 5G presents a solution to meet these challenges by offering extremely high internet speeds, very low latency, and the capability to support millions of connected devices simultaneously [6]. Furthermore, the harmonization of infrastructure regulation and digital policy is essential to achieve optimal deployment in emerging smart regions such as Bali [7], [8]. OFDM remains a key component in the transition from 4G to 5G. By dividing the signal into a number of orthogonal frequency subcarriers, OFDM minimizes frequency-selective fading and optimizes the use of available spectrum, resulting in high throughput and reliable wireless communication [9]. Such technology also supports smart city infrastructure by enabling reliable IoT communication, as seen in regional implementations across Bali [10], [11].

One of the main characteristics of OFDM is its efficiency in bandwidth usage. By allowing overlapping adjacent frequencies, OFDM avoids the need for guard bands as required in conventional multicarrier systems. This enhances spectral efficiency, although it increases susceptibility to CFO, which can degrade system performance due to interference between subcarriers ICI [12]. Various methods, including frequency domain equalization, windowing on the receiver side, and pulse shaping, have been proposed to mitigate ICI effects, with pulse shaping methods like Improved Sinc-power Pulse (ISP) offering promising solutions.

Additionally, to enhance the system's resilience against changing channel conditions, convolutional channel coding combined with pulse shaping emerges as a potential solution for improving OFDM performance, particularly in the transition towards 5G technology. Convolutional channel coding plays a crucial role in maintaining data integrity by detecting and correcting errors that occur during transmission, making the system more resistant to interference [12]. When applied to OFDM, this coding technique provides an additional protective layer that is highly valuable in wireless environments prone to multipath fading and interference.

The integration of OFDM, convolutional channel coding, and pulse shaping is critical to the success of 5G networks, which demand not only speed but also reliability, high service availability, and support for various applications and devices. Empirical studies also reveal that the performance of telecommunication infrastructure contributes directly to inclusive economic growth in Indonesia [13]. This research aims to explore how these technologies can work together to create a more efficient and reliable communication system for the 5G era. Using MATLAB simulations, this study will evaluate the performance of OFDM in frequency-selective fading channels, particularly in mitigating ICI through pulse shaping and convolutional coding methods. By exploring the combination of these technologies, this study aims to provide in-depth insights into optimizing wireless communications for the next generation of telecommunications.

Methodology

OFDM is a transmission technique that utilizes multiple carrier frequencies (multicarrier). Each sub-carrier is made orthogonal and harmonic with one another, allowing adjacent sub-carriers to overlap without causing Inter-Carrier Interference (ICI). OFDM offers higher spectral efficiency compared to conventional modulation techniques such as Frequency Division Multiplexing (FDM) [14]. In the Multiple Input Multiple Output (MIMO) OFDM spectrum, each subcarrier consists of a main lobe and several side lobes, and when the orthogonality between subcarriers decreases, the side lobes have the potential to generate ICI power within the central area of each subcarrier. The ICI power increases with carrier frequency offset. The pulse shaping method is designed to minimize or eliminate the side lobe amplitude of subcarriers that may cause ICI, thereby reducing ICI and enhancing the performance of the MIMO OFDM system [15]. Carrier Frequency Offset (CFO), also known as frequency offset, occurs due to the Doppler effect or a mismatch between the transmitting and receiving oscillators, leading to a loss of orthogonality. This loss causes ICI as the side lobe of one subcarrier interferes with others. CFO is represented by a normalized value symbolized by ε, indicating the degree of subcarrier shift detected by the receiving oscillator [16], [17], [18], [19].

Data Collection Method

In this research, the data is generated through simulations. The simulation steps involve creating an OFDM Simulink model for a Selective Fading channel affected by frequency offset. The model includes random bit generation, Quadrature Phase Shift Keying (QPSK) modulation, OFDM processing, and running the OFDM system through both Additive White Gaussian Noise (AWGN) and selective fading channels. Performance metrics such as BER and energy per bit to noise power spectral density ratio (Eb/No) are calculated to evaluate system efficiency. The parameters used in the simulation are presented in Table 1 below.

Table 1. Simulation parameter

Parameter	Values used	Block
Number of Bit	1.000.000	Input Data
Modulation Type	QPSK	Mapping Data
User Type	Single User	
Channel Type	AWGN + Frequency Selective Fading	Transmission Type
System Type	OFDM	
Subcarrier spacing	15 kHz	Transmitter

Research Flow

This research follows a structured process to implement each stage of the study. The research and simulation flow is shown in Figure 1 below.

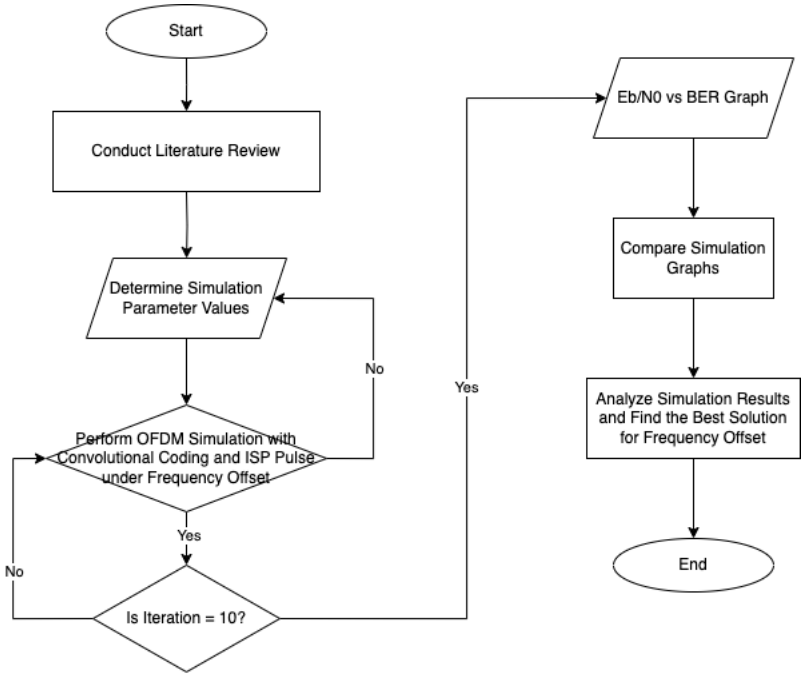

Figure 1. Research flow

The simulation is carried out by applying frequency offset parameters to both standard OFDM and ISP-OFDM techniques. The effects of frequency offset on system performance are then analyzed. After identifying the impact of frequency offset, two mitigation approaches are evaluated: ISP pulse shaping alone and the combination of ISP pulse shaping with Convolutional Coding. This allows comparison between standard OFDM, ISP-based OFDM, and the enhanced ISP + Convolutional Coding system.

Simulation Procedure and Process

Initially, the parameters are selected based on references from the literature and aligned with the objectives of the simulation. This research aims to evaluate the effect of frequency offset on the ISP OFDM system, identify problems, and provide solutions to those problems. To observe the impact of frequency offset, the simulation is conducted using specific parameters to compare channels with and without frequency offset. The frequency offset values vary to assess their influence, which is reflected in the BER. Higher BER values indicate a more significant negative impact of frequency offset. In this study, the CFO values of 4 kHz and 6 kHz were selected to limit the simulation scope and maintain clarity in result interpretation. The purpose is not to

represent all possible CFO variations, but rather to illustrate the system's behavior under representative offset conditions and to verify the improvement achieved by ISP pulse shaping and Convolutional Coding. Testing a wider range of CFO values would produce repetitive trends without significantly changing the overall conclusions.

Once the problems caused by frequency offset are identified through BER values, the next step is to develop a solution. In this study, the convolutional coding method is used to mitigate the impact of frequency offset on ISP OFDM.

In the simulation, the performance of three systems is compared: OFDM, ISP OFDM, and ISP OFDM combined with convolutional coding. The comparison is illustrated by plotting BER against Eb/No, where a lower BER value indicates better system performance.

Results and Discussions

Performance Comparison of OFDM, OFDM ISP, and OFDM ISP with Convolutional Coding on Selective Fading Channels

The block diagram of the OFDM system, integrated with pulse shaping and convolutional coding techniques, is illustrated in Figure 2. Pulse shaping modifies the pulse of the transmitted symbols, where each symbol is multiplied by the pulse shaping function to compress the side lobes, leading to ICI reduction.

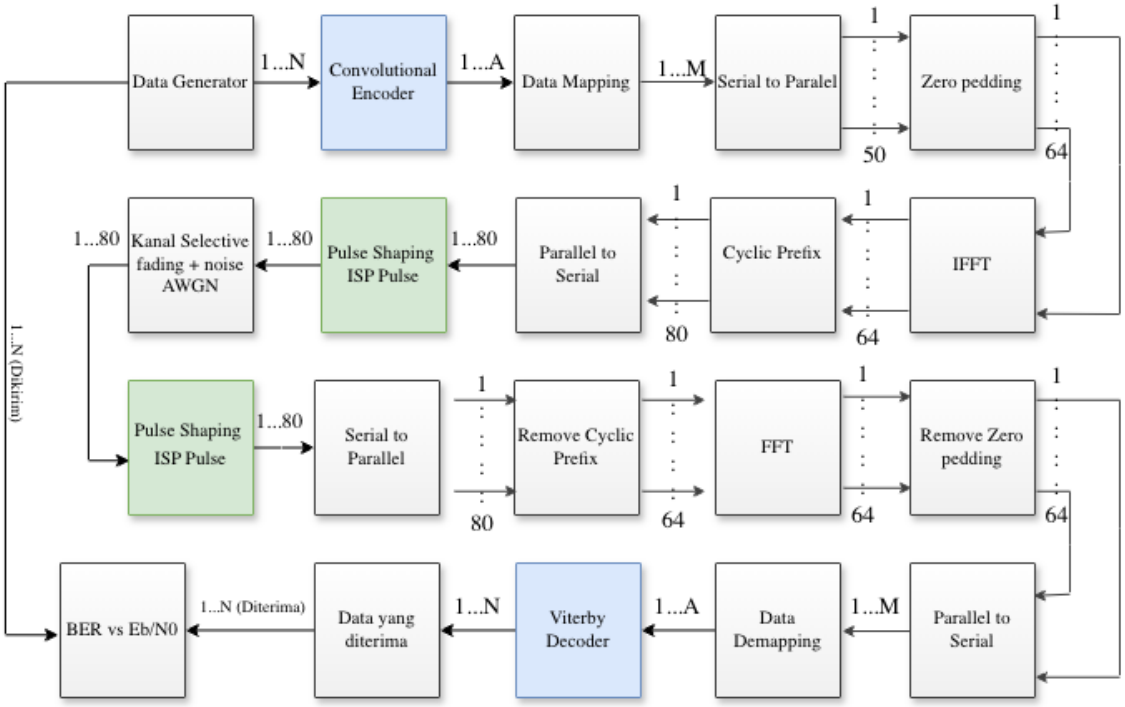

Figure 2. Diagram block of OFDM ISP system with convolutional code

Channel coding plays a crucial role in protecting the data bits from potential errors during transmission by adding redundancy bits. Simulation based on the block diagram in Figure 2 produced a comparative graph shown in Figure 3, with a 6 kHz frequency offset as a sample. The red line illustrates the effect of frequency offset on the OFDM system without pulse shaping. The green line reflects the impact of a 6 kHz frequency offset with the application of ISP pulse shaping, and the blue line demonstrates the effect of the same frequency offset with Improved Sinc Power Pulse and Convolutional code on the OFDM system. From Figure 3, it is evident that the inclusion of convolutional coding significantly enhances ICI reduction. This is achieved as convolutional coding shields data bits from errors by introducing redundancy bits. Upon reception, the data is decoded to detect and correct errors, delivering an output that closely aligns with the original transmission.

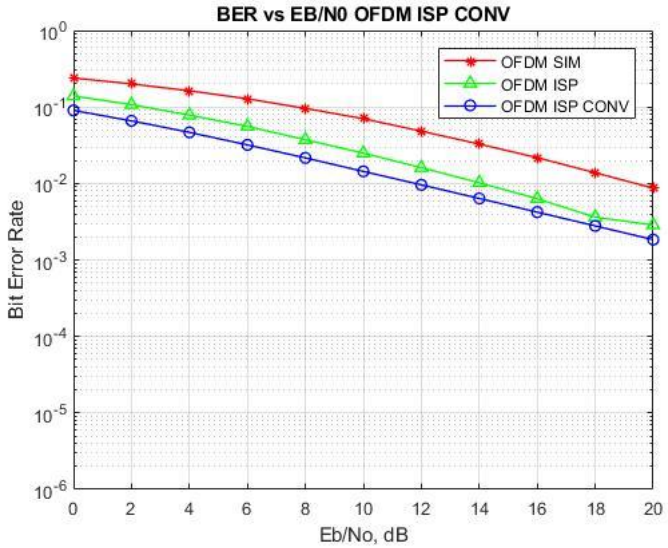

Figure 3. Comparative performance with convolutional code

The simulation results analyzing the influence of Convolutional coding on the OFDM ISP system with frequency offset suggest that Convolutional coding improves system performance by minimizing interference among subcarriers and reducing ICI power. It was also concluded that convolutional coding is more effective in mitigating ICI. In this simulation, the OFDM ISP system, with Convolutional coding, delivered the best solution for addressing CFO, achieving a BER of approximately 0.0018, reflecting optimal system performance through the reduction of BER.

Performance Comparison Analysis of OFDM, OFDM ISP, and OFDM ISP with Convolutional Code: The Impact of Frequency Offset

CFO negatively impacts OFDM signals by disrupting their orthogonality, causing signal degradation. Figure 4 illustrates a comparison of the performance of OFDM under the effect of frequency offset. In this simulation, the BER is compared with Eb/No for each system. The frequency offset values used in this simulation vary as follows: 4 kHz and 6 kHz.

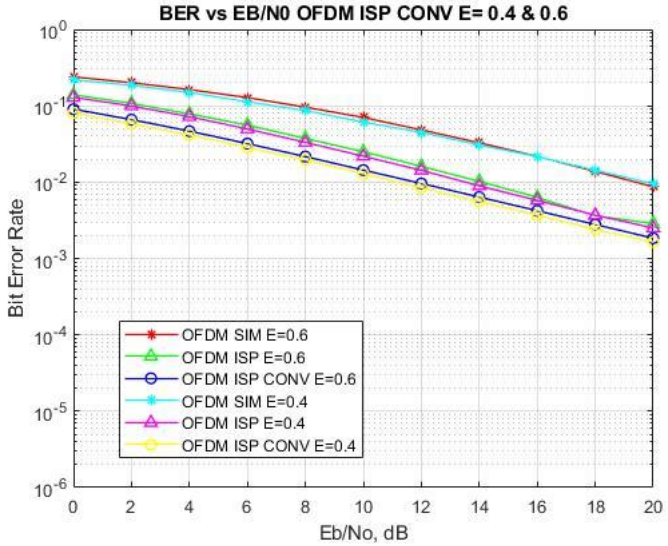

Figure 4. Comparative performance with CFO

Figure 4 shows the comparison of the influence of frequency offset on the OFDM system. The red line represents the effect of a 6 kHz frequency offset on OFDM, the green line represents the effect of a 6 kHz frequency offset on OFDM ISP, and the blue line shows the effect of a 6 kHz frequency offset on OFDM ISP with Convolutional code. The cyan line shows the effect of a 4 kHz

frequency offset on OFDM, the magenta line shows the effect of a 4 kHz frequency offset on OFDM ISP, and the yellow line shows the effect of a 4 kHz frequency offset on OFDM ISP with Convolutional code.

By observing the BER vs Eb/No graph in Figure 4, it is clear that the larger the frequency offset used, the higher the BER value in the OFDM system. Based on this, it is evident that the performance of the OFDM ISP Convolutional system with a 4 kHz frequency offset is better compared to other frequency offset effects. The larger the simulated frequency offset, the higher the BER. This is because the frequency offset causes the loss of signal orthogonality by shifting the side lobes of the subcarriers. This subcarrier side lobe shift causes intercarrier interference (ICI), which degrades the performance of the OFDM system.

Conclusion

The analysis of Carrier Frequency Offset (CFO) effects on the OFDM system shows that CFO introduces significant Inter-Carrier Interference (ICI), which increases the Bit Error Rate (BER) and degrades overall system performance. This degradation is clearly observed in the baseline OFDM simulation, where higher CFO values lead to noticeable BER elevation.

When ISP pulse shaping is applied, the system exhibits better resilience to CFO-induced ICI, as seen in the BER vs Eb/No plot where ISP-based OFDM consistently achieves lower BER than the conventional OFDM system. The improvement occurs because the ISP technique effectively reduces the side-lobe energy of each subcarrier, thereby minimizing interference among adjacent subcarriers.

Furthermore, combining ISP pulse shaping with Convolutional Coding yields the best performance. The joint implementation not only suppresses ICI but also strengthens error correction, resulting in a BER value around 0.0018 at high Eb/No. Overall, the results confirm that CFO severely affects OFDM performance through ICI, and that the integration of ISP pulse shaping and Convolutional Coding provides a robust solution for mitigating these effects in future wireless systems. This finding aligns with national reports emphasizing the role of reliable network ducting and cable infrastructure to sustain next-generation connectivity [20].

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