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Proceedings of The 4th

International Conference on the Leadership and Management of Projects in the Digital Age - ICLAMP 2025

Editors

Prof. Ahmed Abu Jrai, Dr. Saeed Aldulaimi, Dr. Meryem Masmoudi

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The 4th International Conference on the Leadership and Management of Projects in the Digital Age - ICLAMP 2025

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Preface

This Proceedings provides a comprehensive exploration of the evolving role of artificial intelligence, digital transformation, emerging technologies, and management innovation in engineering and organizational contexts. It brings together a diverse array of peer-reviewed research papers that reflect the current global discourse and practical advancements in these interdisciplinary fields.

The volume features contributions from international scholars and practitioners, selected for their scholarly rigor and relevance, and reviewed through a rigorous peer-review process. The collected works present both theoretical frameworks and empirical case studies, offering valuable insights to researchers, academics, industry professionals, and students alike.

Each research paper contributes to the collective understanding of how modern digital and technological advancements are reshaping industries, education, and societal systems. This Proceedings is not only a reflection of the current state of research but also a roadmap for future inquiry and innovation. We believe this volume will serve as a critical resource for fostering collaboration, inspiring leadership, and guiding strategic transformation efforts in the digital era.

Manama, Bahrain
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Designing an Innovative Digital Service for A Village-owned Enterprise Based on The Value Proposition

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Abstract. Village-owned enterprises (VoE) are business entities that complete any of the capital funds owned by villages to gain welfare for villagers. VoE aims to increase village economic capabilities based on village resources. The management of VoE is still dominated by manual management instead of digitalization. This study aims to develop a prototype of a digital platform to improve VoE's business. The method used was qualitative, with key informants being the representative government, Small Medium Enterprise (SMEs), VoE, and the Gedhe Nusantara community. The development of the prototype was based on VoE's business model canvas (BMC) and emphasized the value proposition. The results show that the value proposition can be translated to develop a digital service for VoE. The digital platform can be set as a reason the customers buy products by enhancing the connection between the provider of VoEs and the customers themselves. Value proposition variables such as value sharing, experience proposition, value orchestration, consumption flexibility, temporal condensation, and market expansion can be the main variables in developing a digital service to provide customer satisfaction and loyalty.

Keywords: BMC, Digital Service, SMEs, VoE, Value Proposition.

1 Introduction

A village-owned enterprise (VoE) is a business entity that completes any of the capital funds owned by villages to gain welfare for villagers (1). VoE aims to increase village economic capabilities based on village resources. Village-owned enterprises manage various resources produced by the village by the potential produced, such as agricultural products, Micro, Small, and Medium Enterprises (MSMEs), and the service sector (2). VoE was formed to improve the economy in the village so that economic prosperity increases and stays within urban areas.

The basis for the establishment of VoE is based on the Initiative of the Government and village communities based on cooperative, participatory, and emancipatory principles of village communities (3). VoE has been regulated in Law Number 32 of 2004 concerning Regional Government, which has now been amended by Law Number 23 of 2014, which mentions villages can establish village-owned enterprises following the needs and potential of the village (4).

The management of VoE is still dominated manually instead of digitalization (5), (6). In fact, in the era of the Industrial Revolution 4.0, several things concerning the community's needs have been directed digitally. The digital business model affects competition, most of the market, strong finances, more profitability, and the understanding of digital customer values (7). The scale form of VoE is relatively tiny; some still use a business model to create their businesses (8). In addition, the distribution pattern of goods is less efficient, and the products sold tend to be more expensive. Therefore, a study is needed to map the VoE business model based on innovative digital services (9). The innovative business model replaces existing or grabs new opportunities to create circular shared value propositions (10). The circular can contain product offerings, customers, resources, and capabilities strategies (11). Innovative digital services can be concerned with combining digital and physical and how much combination makes the digital products and digital technologies reuse them (12).

Therefore, this study aims to develop a prototype of a digital platform to improve the VoE business. The prototype will be developed based on VoE's business model to gain more opportunities for network creation. The creation can involve new actors to expand the idea, minimize conflictual conditions, and gain more value, such as economic and social (13). The research was conducted in Banyumas, Central Java Province, Indonesia. Banyumas was chosen because it was one of the areas that initiated the establishment of the Joint VoE. Joint VoE is a collection of several VoEs that collaborate to increase profits and have initiated national consultations with 2,000 village participants from all over Indonesia (14).

Furthermore, to make sure the businesses can compete and differ from competitors, the development of the business model can be emphasized based on their value proposition (15). This study is essential to enhance the role of VoE and will give an understanding of the government's ability to support economic development in the village.

2 Methods

This method used was qualitative. The steps were started from data collection through in-depth interviews and observations. The data obtained and then coded and analyzed to draw conclusions and suggestions (16). The representative government, SMEs, VoE, and the Gedhe Nusantara community were key informants. The Gedhe Nusantara is one of the practitioners who provides training to VoE activists, such as initiating business incubators in disadvantaged areas in collaboration with the Ministry.

Moreover, a business model canvas (BMC) was created to map the potential for VoE to adopt innovative digital services. BMC is a tool in strategic management that represents business ideas and concepts quickly and concisely (17). The business model aims to describe how the organization creates, delivers, and captures value to gain customer experience by using digital technology (13). After the BMC was prepared, the value proposition was discussed further using the fishbone approach.

The value proposition is one of the core elements of a business model that explains the core elements to determine the principal purpose for clients and relationships, attract more customers, and aim to distinguish itself from the competitors (15). Therefore, the correlation between the business model and the value proposition was that the business model aimed at customer experience while the value proposition was why a particular customer was willing to pay for the product (18). Fishbone was compiled using two approaches. The first approach focused on the causes of the value proposition, including value sharing, experience proposition, and value orchestration (13). The second approach used the cause of value proposition, including market expansion, temporal condensation, and consumption flexibility (19). After mapping the fishbone, the website prototype was developed using the scrum approach (20).

Scrum is an Agile framework that focuses on short iterations and team collaboration to increase flexibility in software development (21). The Scrum process consists of key roles such as the product owner, scrum master, and development team working together to manage the backlog and complete sprints (22). Each sprint lasts one to four weeks to produce a testable and usable product increment (23). The daily scrum, which lasts fifteen minutes daily, helps the team align work and identify impediments in the ongoing sprint (24). At the end of the sprint, a sprint review is conducted to demonstrate the work results to stakeholders and gather feedback for product improvement (25). After that, a Sprint Retrospective is undertaken to evaluate the team's work process and find opportunities for improvement in the next sprint (26). Scrum also encourages transparency, inspection, and adaptation so teams can quickly adjust to changing business needs. In addition, backlog grooming is performed periodically to ensure the backlog remains relevant and well-prioritized (27).

3 Result and discussion

3.1 Business Model Canvas for Innovative Digital Service

The BMC model is divided into four groups (28). The first group is the "how" group, which includes key partners, key activities, and critical resources. The second group is the "who" group, which involves customer relationships, customer segments, and channels, and the third group is a "capital" group that contains cost structure and revenue streams. The last group is the "what" group, which covers value proposition only. The Business model canvas can be seen in Table 1.

Table 1. BMC Attribute

Key Partners	Key activities	Value propositions	Customer Relationship	Customer segment
SMEs	Business Incubation	Ease to choose SME products	Fast response to customer issues	By product type
Government	Product acceleration			By quantity
Traditional market	Product data validation	Ease to do financial transaction	Guide to learning the app	By location
Hotel	Halal certification		Manage customer loyalty	By transportation type
Restaurant	PIRT certification	Intensive communication among stakeholders		
Tourist Objects	Grow digital platform	Discount price		
	Engage more SMEs	Certified product		
	Key resources	Transparent rating	Channels	
	Government		Social media acts	
	Platform developer		Website	
	Brand		Mobile app	
	Digital platform			
Cost Structure			Revenue stream	
Platform cost: incentive for developer			Village fund program	
Development and expansion platform cost			VoE capital investment	
Marketing cost			High net income for SMEs and low-cost customers	

BMC comprises several elements: key partners, key activities, essential resources, value propositions, customer relationships, customer segments, channels, cost structure, and revenue streams. Critical partners in developing business models based on innovative digital services include SMEs, government, traditional markets, hotels, restaurants, and tourist objects. SMEs are the backbone of product production, which provides food and products. Therefore, the government can regulate convenience in running a digital business. Traditional markets, hotels, restaurants, and tourist objects are marketing targets because these places are close to end customers.

The critical activity carried out by VoE as an operator is initiating the incubation business for SMEs. In addition, they must carry out product and production acceleration to fulfill customer demand if the product information is shared widely. After developing the app, VoE can improve product and customer data validation to ensure the confidence of the right customers. In addition, VoE can facilitate halal and household industrial production permits (PIRT) to increase product acceptance. The more important things are growing the digital platform and engaging more SMEs in Banyumas.

Customer relationships can be built to respond quickly to customer issues or complaints. The customers' problems and complaints must be appropriately solved to maintain customer satisfaction. VoE can guide learning about the application not only for SMEs but also for customers. VoE can also manage customer loyalty to sustain its business. The customer segments can be divided by product types, such as food or handmade items. It will ease categorizing the customer and preparing the production planning at SME levels. Therefore, the quantity, location, and transportation type can be focused on managing the logistics activities to reduce the logistics cost and increase customer service.

VoE can examine the essential resources and channels for developing the digital service. The vital resources are government, platform developer, brand, and digital platform. The channels used are social media ads, websites, mobile apps, and engaging email to maintain customer engagement. The cost structure is derived from platform costs, such as developer incentives, platform production costs, and fixed and variable costs if the platform runs. The other cost structures are expansion and marketing expenses to gain more customers. The revenue streams are from the government's village fund program, VoE capital investment, high net income for SMEs, and low customer product prices.

The last is the value proposition. A value proposition is a decision variable to create competitive advantages (29). The value proposition focuses on the ease of choosing SME products by providing catalog and category information. It emphasizes doing the financial transaction and conducting intensive communication quickly. The value will collaborate with VoE, SMEs, and customers, giving discount prices for certain purchases, certified products, and transparent customer ratings. The value proposition underpins this study because it emphasizes the experiences in the real world through innovative digital services (30). More explanations for maintaining the value proposition can be seen in the following subsection.

3.2 Value Proposition and Website Prototype

Determining value proposition using a fishbone diagram. The fishbone diagram is a causal diagram that defines the relationship between cause and effect. The development of the fishbone diagram was based on a literature review and expert insight. In this case, the value proposition is used as an effect and reason based on the value proposition attributes. The cause attributes are consumption flexibility, temporal condensation, market expansion, value sharing, experience proposition, and value orchestration. Each cause attribute has root causes (Fig. 1).

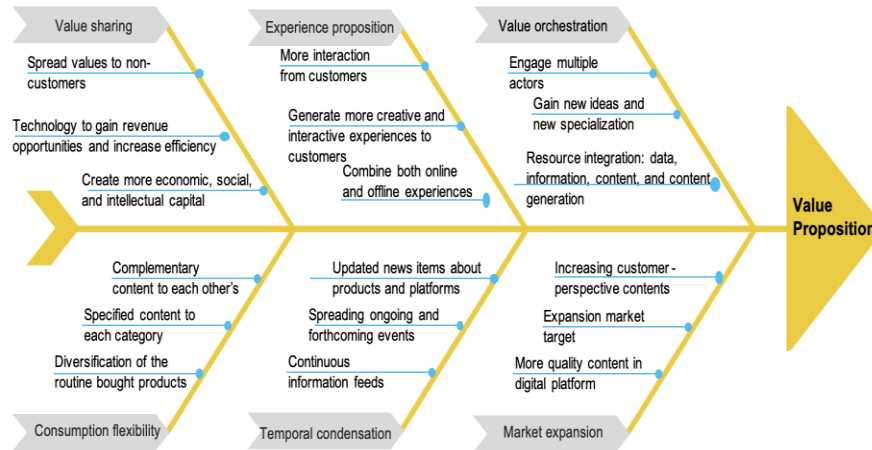


Fig. 1. Fishbone Diagram for the VoE Innovative Digital Service

By developing digital platforms, value sharing highlights new ways to increase efficiency and revenue opportunities. Value sharing has a root cause: spreading value to non-customers, adopting additional digital technology to strengthen the systems, and creating more economic, social, and intellectual capital to maintain the sustainability of innovative digital platforms. The next cause is an experience proposition that emphasizes interactive processes to customers by combining offline and online memoirs. The root cause includes conducting more customer interaction, such as commenting on available product displays, generating more creativity and interaction, and providing an offline booth if customers want to see the production process. Furthermore, value orchestration is a design activity that gains service by combining innovative methods. The root causes are that the digital platform can engage multiple actors, gain new ideas and specialization different from a competitor, and integrate data, information, and content to be more integrated.

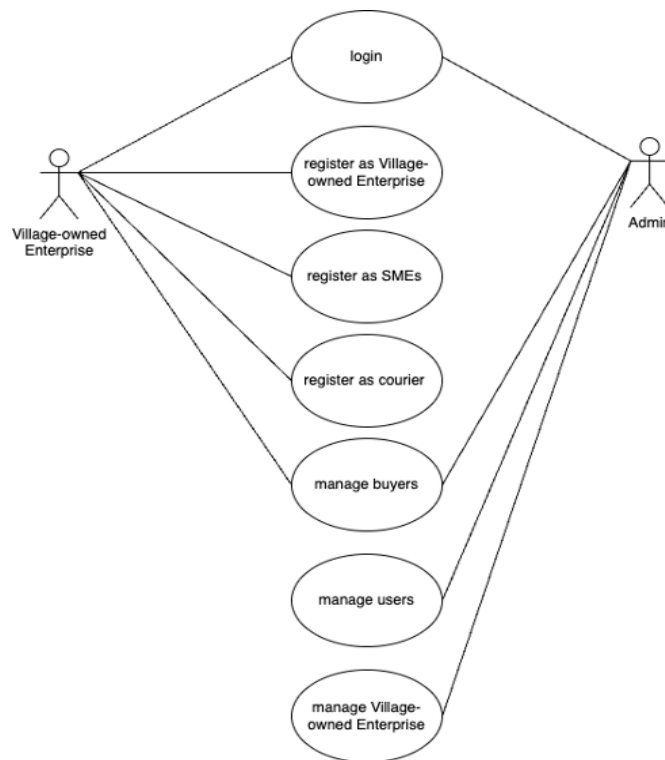


Fig. 2. Use case diagram of VoE website prototype.

Moreover, consumption flexibility emphasizes the increasing number of channels enabled, such as print, web, social media, and mobile apps. Therefore, VoE can develop and provide their innovative digital service to be complementary, specify content for each category, and diversify the routine bought product. Those root causes enable customers to get updated information. Temporal condensation indicates a shorter period for gaining continuous information feed. The root causes are updated news items, ongoing and forthcoming events, and constant information feeds about the products and digital platforms. In addition, market expansion focuses on substantial restructuring and the market, making boundaries what is expected. The root causes are increasing customer perspective content, expanding market target, and more quality content on digital platforms.

The web application prototype is based on the web application's value proposition as an innovative digital service, as shown in Fig. 2. The use case diagram has two users: a Village-owned Enterprise and an administrator. A Village-owned Enterprise has five features: login, managing buyers, registering as a Village-owned Enterprise, an SME, and a courier. The administrator has three features: managing users, buyers, and Village-owned Enterprises. After mapping the use case diagram, the web application prototype was developed and named sobatwarung.com. The prototype can be seen in Fig. 3.

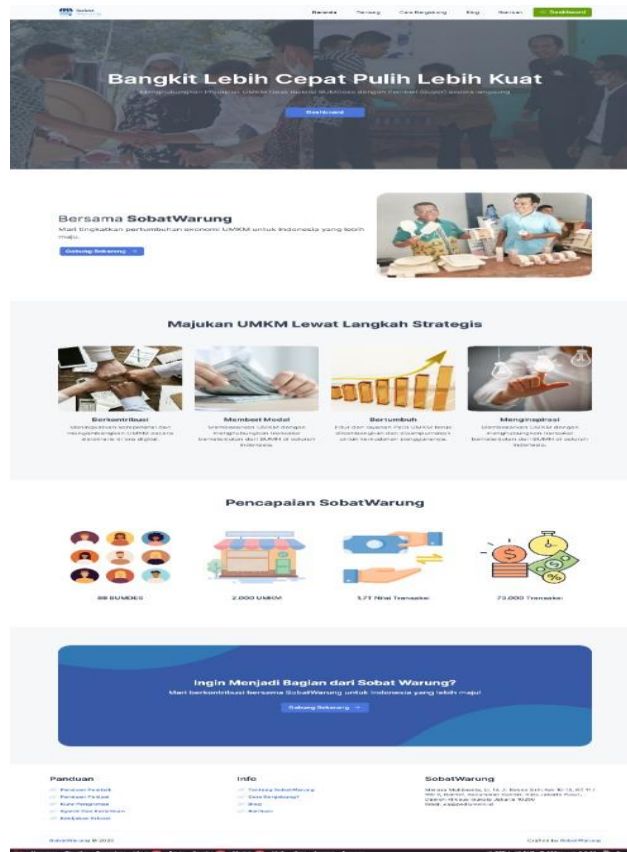


Fig. 3. Website Prototype

3.3 Findings Implications

This study has offered many insights into VoE. First, it will guide VoE in evaluating its business strategy and whether it will collaborate with SMEs by conducting innovative digital services. The systems must consider all BMC elements, including What, Who, How, and capital group. Second, they must collaborate with the developer and prepare the capital for production until the platforms are expanded. The platform's capability and usability can be measured to increase customer satisfaction and gain customer loyalty. Third, VoE has to focus on reaching more comprehensive customers by enhancing the knowledge of their staff about how to maintain the app based on value proposition causes. For VoE employees, it can avoid inconsistency and non-acceptance occurrences because of breaking VoE rules by conducting inefficiency and withdrawal from the network in developing innovative digital services (31).

Our findings show that value proposition can be translated as reasons the customers to buy products by enhancing the connection between the provider of VoE and the customers themselves (19). The innovative digital platform can be developed to fulfill customer requirements if the value proposition is described well. The consideration attributes such as value sharing, experience proposition, value orchestration, consumption flexibility, temporal condensation, and market expansion can be implemented well to make the innovative digital service more sustainable. The attributes are new perspectives to define value propositions based on digital business. To leverage the innovative digital company, VoE can create targeted team composition, continuous learning, iterative goal setting, and talent management (32). Furthermore, the value proposition describes the core elements to determine the principal purpose for related actors, especially in the development of innovative digital services (15).

4 Conclusions

This study depicts how VoE in Banyumas, Indonesia, develops its business model based on innovative digital services. The business model used BMC design to map the potential opportunity to gain customer experiences. The value proposition is depth-elaborated after acquiring the business model to create the actual value of VoE. Then, it can provide an innovative digital service. The development value proposition is based on many attributes, including value

sharing, experience proposition, value orchestration, consumption flexibility, temporal condensation, and market expansion. Those values enable digital service development and platforms to gain customer satisfaction and loyalty.

The research may focus on a specific village-owned enterprise (VoE) or a limited number of case studies, making it difficult to generalize the findings to other regions or industries. Stakeholder participation and the effectiveness of the proposed digital service may depend on local stakeholders' engagement and digital literacy, which can vary widely across different communities. Technology adoption barriers and infrastructure limitations, such as internet connectivity and access to digital devices, may hinder the successful implementation of the designed service. In addition, in time constraints, the research may be conducted within a short timeframe, limiting the ability to observe long-term impacts and user adoption trends. Then, evaluation and validation of the effectiveness of the digital service may not be thoroughly tested in real-world scenarios, leading to uncertainties regarding its practical implementation and success.

Further research can be conducted to determine whether the values are relevant to deciding value propositions for specific digital business models such as education, healthcare, or tourism. Moreover, the following research can measure both quantitative and qualitative the process of implementing the business model based on the value proposition attributes.

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Transformational Leadership and Lean Methodologies in Civil Engineering: An Approach to Sustainable Project Delivery and Management

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Abstract. In the construction industry, transformational leadership encourages innovation, safety, and modification, though lean construction maximizes productivity by reducing waste. In order to ensure balanced and effective project execution, sustainable project delivery includes environmental, social, and economic concerns. The efficiency, sustainability, and general performance of civil engineering projects are improved when transformational leadership and lean approaches are combined. Research highlights how they can enhance team dynamics, promote innovation, and maximize resource management in building projects. This study examines how transformational leadership, lean methodology, and sustainable project management are integrated in civil engineering through bibliometric analysis and a comprehensive literature review. In order to visualize data and uncover important research themes, trends, and interdisciplinary ties, VOS viewer software is used. The results show how important transformational leadership is for improving project outcomes, inspiring groups, and encouraging creativity in civil engineering. Applying lean approaches into construction project management also enhances sustainability, minimizes waste, and maximizes resource efficiency.

Keywords: Transformational Leadership, Lean Methodologies, Sustainable Project Management, Civil Engineering.

1 Introduction

Transformational leadership involves inspiring devotees to match with organisational goals, driving performance beyond expectations. It is characterised by its influence on followers through enchantment, motivation, intellectual stimulation, and personalized support. Leaders exhibiting transformational qualities are inclined to adopt advanced technologies and practices. Developing a perspective that views a shifting environment as an opportunity encourages employees or team members to pursue innovation. Charisma, intellectual encouragement, and empowering influence are defining traits of transformational leadership. In creating a collaborative climate, transformational leaders encourage employees to rethink their perspectives while fostering a shared vision.

In addition, transformational leadership plays a critical role in managing safety within construction projects. Its importance lies in guiding the dynamic nature of construction processes, where continuous changes demand adaptive and visionary leadership. Idealised influence represents the charismatic aspect of transformational leadership, where leaders serve as role models, earning the admiration, respect, trust, and emulation from their subordinates [1].

The construction industry continues to expand to meet growing societal demands however; this growth is accompanied by increased waste generation, posing significant risks to both the environment and public health. In contrast, methodologies like Lean Construction (LC) offer effective strategies for minimizing waste. Although LC has been tailored for the infrastructure industry, its implements and standards are frequently misapplied. Furthermore, a lack of staff training and familiarity with the methodology often results in suboptimal outcomes. The last planner system, although recognised as a valuable tool, is often misused due to various shortcomings, including a lack of proper observation, misalignment with project execution methods, insufficient planning, and failures in analysing constraints. As a result, research highlights that implementing LC site methodology enhances project management by accelerating execution and minimising delays California's high-speed rail projects faced major set-offs, including delays in schedules and budgeting, mainly due to inefficient coordination and ineffective management practices. By implementing transformative leadership, the project team emphasizes uniform vision and fostering innovation, along with lean methods such as the Last Planner System (LPS) and Kanban. These strategic improvements reduced project delays by 15% and total costs by 10%. This demonstrated the specific benefits of management failures and lean

management approaches. The lean idea originated in the 1930s, following the Analysis of processes in Toyota factories. It has been widely applied in industrial and production processes through various approaches and Instruments, such as 5S, SMEN, QFD, TPM, Kanban, and Poka-Yoke, leading to streamlined production. Continued application of these methods over time results in constant progress and increase of production processes [2].

LC methodologies has gained popularity as a method for project delivery, prompting many organisations to embark on their own execution journeys. Successful adoption often hinges on effective training in lean tools and the staff's ability to adapt their behaviours to this new project delivery approach [3]. While training is recognised as crucial for a lean transformation, equally important is the need for transformational leaderships to modify their practices, behaviours, and mindsets to support the change. Several project management approaches, such as LC, lean project management, and value engineering, have come up to enhance construction performance. LC, in particular, offers a fresh management approach aimed at boosting productivity, reducing waste, and increasing profitability within the construction sector. The parallels between construction methods and construction make lean production theory highly relevant to the industry. As a result, LC has become single of the fastest-growing patterns in the field. Currently, various construction contractors from various countries have begun implementing LC, driven by optimistic expectations of achieving improved results in their ongoing projects. Applying lean management standards in the infrastructure sector can enhance both profitability and project quality, all while ensuring timely completion[4].

Sustainable project delivery management involves designing, monitoring, and analyzing projects while overseeing delivery and support processes, with a focus on environmentally resilient, sociable, and economic characteristics throughout the project lifecycle. Its goal is to deliver stakeholder benefits through crystal-clear, reasonable, and ethical practices, alongside proactive stakeholder engagement. Achieving project sustainability relies on the involved participation and collaboration of the project team and all stakeholders included in the project's programs and portfolios. Moreover, this approach offers additional advantages, including improved construction efficiency, the use of more eco-friendly assets, and a strengthened corporate reputation for environmentally friendly practices. The traditional paradigm, which focused solely on the three aims of effectiveness, cost, and schedule, has gradually evolved into a recent pattern centered on sustainable design construction projects. The shift towards sustainability represents a new paradigm, where sustainable aims are integrated into decision-making at every stage of the facility's lifecycle within the structure plan and construction organization. In this study, sustainable project management refers to the integration of environmental, social and economic considerations in planning, implementation and delivery of civil engineering. The aim is to minimize negative effects (e.g. waste, resource ravens) and at the same time maximize the long-term benefits of stakeholders, municipalities and the environment that are consistent with the sustainable structure principles described in the literature.. Therefore, it is essential for recent project managers to embrace a transformational leadership approach that balances the environmental, public, and economic dimensions of eco-friendly development [5].

2 Literature Review

According to Table 1, the delivery of civil engineering projects is much improved when transformational leadership is combined with lean approaches. By putting an emphasis on creativity, effectiveness, and team empowerment, these methods not only improve project management and provide long-term advantages, but when combined, they also maximize results and project performance overall.

Table 1. Previous Review Studies

Review Technique	Study Focus	Reviewed Studies	Ref
Systematic Review	Transformational Leadership in Civil Engineering	125	[1]
	Lean Methodologies in Civil Engineering	67	[2]
Comprehensive Review	Project Management in Civil Engineering	501	[3]
Bibliometric Analysis	Transformational Leadership in Project Management	31	[4]
Systematic Review	Lean Methodology in Sustainable Project Management	58	[5]

1. Transformational Leadership & Lean Methodology

According to previous studies, transformational leadership is essential in building projects. The United States and Australia are cited as major contributors in a survey of 125 papers from WoS and Scopus, despite the lack of international cooperation [6]. As important subjects for further research, themes including safety, team dynamics, and transformative leadership stand out. New trends and areas for further research are revealed by keyword analysis. These insights support the development of project management competencies and better leadership techniques [7].

By reviewing 67 articles about the advantages of LC in connection to waste production and environmental issues in the construction sector, this study closes the gap. It uses information from South African specialists to assess how LC affects output and resource efficiency [8]. The results from paper highlight improved cost-effectiveness, waste reduction, and effective material management as major benefits [9].

2. Transformational leadership & Lean Methodology in Sustainable Project Management

Over the past ten years, there has been a notable growth in interest in off-site building, which has led to an increase in scholarly research. Though some literature studies are available, none has employed a methodical methodology to conduct a full analysis of the topic. This study fills the gap by conducting the first bibliometric analysis of offsite construction research, examining 501 high-ranking construction journal articles using science-mapping techniques. The study identifies publishing trends, key sub-fields, citation patterns, leading institutions, researchers, and their interactions. Findings reveal a focus on product research over operations and management, limited collaboration across sub-fields, and a need for greater exchange of ideas to advance future research [10].

The construction industry faces significant hurdles in addressing global issues such as poverty and climate change. This study investigates the need for strong leadership in integrating sustainability through a systematic review of 31 publications. The results indicate that transformational leadership is the most successful strategy for sustainable construction, even though there is not a single, all-encompassing method. This information can be used by project managers to guide the implementation of sustainable practices and promote better results [11].

Methodologies for project management specify organized strategies for collaboration and communication. Agile emerged as a result of the waterfall's widespread adoption but limitations in handling complexity, whereas lean six sigma blends Lean and six sigma concepts [12]. This study addresses cause-and-effect links and data gaps by using fuzzy cognitive mapping to examine the success elements of various approaches. The results specify important and decisive information for project management in intense, technologically advanced marketplaces [13].

3 Methodology

The integration of sustainable project delivery into construction project management is examined in this research using bibliometric analysis and a thorough literature assessment. In this study, Scopus and Web of Science were used as the main databases for bibliographic analysis. Extensive reporting on experts selected literature in engineering, management and interdisciplinary disciplines related to civil engineering, transformation management, lean methods and sustainable project management

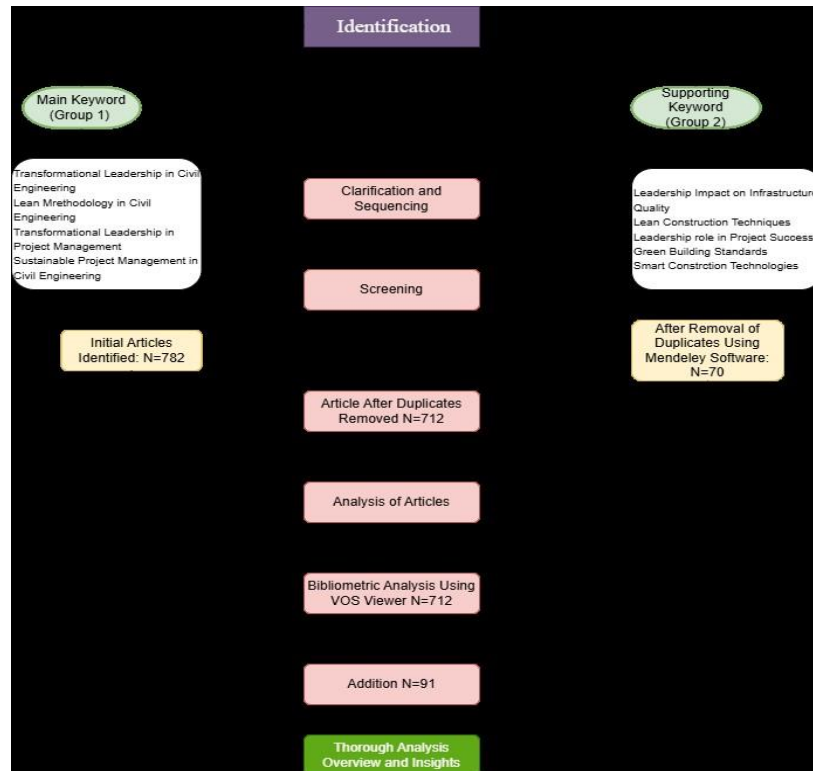


Figure 1: Study Methodology

3. Keyword Selection for Sustainable Project Management in Civil Engineering

The research offers a contemporary viewpoint on subjects like transformational leadership, lean methodology, transformational leadership in project management, and sustainable project management. A two-phase method was used to choose the keywords. Four key terms were found in the first stage: "Lean Methodology in Civil Engineering," "Transformational Leadership in Civil Engineering," "Transformational Leadership in Project Management," and "Sustainable Project Management in Civil Engineering."

These were categorized as "Main Keywords" or "Group 1."

The following concepts were extended into more specific keywords in the second stage:

"Leadership Impact on Infrastructure Quality," "Lean Construction Techniques," "Leadership's Role in Project Success," "Green Building Standards," and "Smart Construction Technologies." According to their labels, these were "Group 2" or "Supporting Keywords." To improve their relevance, terminology like "Sustainable Construction" was changed to incorporate synonyms and ideas that are closely linked, including

"Structure" and "Lean Project Management."

In addition, the Group 2 keywords were divided into four smaller groups, which stood for transformational leadership, lean methodology, transformational leadership in project management, and sustainable project management, respectively: Group 2A, Group 2B, Group 3C, and Group 4D.

4. Article screening

The first step was to use primary keywords to find relevant articles. Nevertheless, the study was useless due to the existence of duplicate records. Mendeley software was used to remove redundancies and remedy this. The streamlined collection of articles was then carefully examined for new keyword research suggestions. Studies that looked at how lean methodology and transformational leadership affected civil engineering project management were included in the final selection.

5. Visualization and Analysis of Bibliometric Data using VOS Viewer

This study uses bibliometric analysis and VOS viewer software to map the literature on transformational leadership and lean methodology in civil engineering project management. Through the analysis of bibliographic data, VOS viewer uses cross-referencing and co-occurrence mapping to identify important research themes, significant publications, and new trends. In addition to other advanced technologies in the construction industry, this study offers a thorough grasp of the connections between transformational leadership, lean methodology, sustainable project delivery, and project management by utilizing VOS viewer's analytical capabilities.

4 Results & Discussion

6. Integration of Transformational Leadership in Civil Engineering

The analysis with VOS viewer found strong patterns and clusters indicating transformational leadership integration with Civil Engineering. Keywords like "Driving project success through leadership," "Transformational Leadership Practices," and "Smart construction project leadership," regularly appear alongside "Civil Engineering," indicating the increasing importance of transformational leadership in the infrastructure sector. An Indonesian industry assessment that covered emerging regions and major cities like Jakarta, Surabaya, and Medan examined how transformational leadership affected team performance in building projects. Enhancing team performance in construction projects requires the implementation of transformational leadership. Leaders who inspire, foster creativity, and establish a positive atmosphere are more likely to accomplish exceptional project outcomes. Through the alignment of personal growth with organizational objectives, this leadership style tackles construction issues and promotes long-term success. Many industries agree that transformational leadership improves team performance by focusing on inspiration, growth, and motivation. The significance of transformative leadership in improving construction project performance and efficiency is highlighted by the studies that utilized driving project success through leadership [14].

Driving project success through leadership: For projects to be more efficient overall, transformational leadership is essential. Employees are inspired and motivated by a transformative leader who helps them achieve both their personal and organizational goals. Research suggests that maintaining consistent motivation increases the possibility of project success by 90%, while a lack of drive nearly inevitably results in project failure [15].

Transformational Leadership Practices: Transformational leadership practices can significantly improve the overall structure of SMEs when applied effectively, as shown by the results observed in Turkey's construction industry. According to recent surveys, approximately 13 years is the average lifespan of SMEs, and 50% of newly founded businesses fail within the first five years. Furthermore, SMEs that survive frequently have difficulty growing and continue to operate as small businesses [16]. Effective leadership is essential to maximizing financial and HR achieving sustained growth. According to research, SMEs gain a great deal from transformational leadership through improved organizational structure, company development, corporate image, task delegation, and recruitment procedures. In addition to being essential for SMEs, these contributions also show significant value for larger businesses [17].

Smart construction project leadership: The project manager is primarily in charge of overseeing the execution of the project and managing it overall, which calls for highly skilled individuals. Among leadership philosophies, TL is unique in that it emphasizes leaders' moral conduct and team-focused attention to improving project performance. Bass underlined that TL is crucial in the fast-paced construction industry of today because it allows subordinates to go beyond expectations. Both superiors and subordinates see transformational leaders as more efficient and suitable

for project management positions. This emphasizes how important TL is to the success of organizations and projects. The impact of TL on project success has been the subject of numerous empirical research in recent years. The majority of this research has shown that TL has a major role in enhancing project results. This shows how crucial TL is to getting good project outcomes [18].

7. Lean Methodologies in Sustainable Project Management

Applying lean construction to sustainable building patterns and clusters shows the integration of lean methodologies with project management. Keywords like "Kanban in Project Management," "5S Methodology in Project Management," and "Lean Project Scheduling," regularly appear alongside "Project Management," indicating the increasing importance of lean methodologies in the green building sector. Li and Zhao first exposed the Chinese construction industry to lean construction. This integration has addressed numerous common issues and increased the rigor of green building project delivery methods. According to Hawken and others, lean concepts can cut resource usage by as much as 90%. Thus, integrating green building methods with lean construction principles improves project efficiency and propels the advancement of environmentally friendly building methods [19].

Fundamentally, lean construction promotes improved construction quality and a longer building service life by adhering to the concepts of Total Quality Management (TQM) and standardized production. Because it gradually reduces material use, extending a construction's lifecycle is a smart strategy. Second, the sustainability of construction projects is improved by lean construction, which focuses on removing waste, particularly inefficiencies in time and output. Lean construction guarantees that these projects may be completed without raising expenses, even though the initial price of sustainable initiatives frequently presents a major obstacle. Thirdly, lean construction incorporates both planning and building from a flow perspective to control schedules. The workflow of construction projects can be planned and managed with the Lean Production System (LPS) tool. The effectiveness of sustainable project delivery is also increased by lean construction, which encourages cooperation among project participants and enhances communication and information exchange [20].

Kanban in Project Management: A lean approach that originated in the automobile industry, kanban was created to pull components and materials through the value stream just in time. The materials control card utilized in this pull method is called "Kanban," which means "card" or "sign" in Japanese. It guarantees efficient inventory control and streamlined manufacturing procedures.

Several public sector organizations in the UK construction industry, such as housing associations, local authorities, Registered Social Landlords (RSLs), and Arm's Length Management Organizations (ALMOs), have adopted the use of lean construction principles, especially for improving public housing stocks. The 'Kanban' technique and other lean processes have been shown to be successful in cutting down on waste, speeding up product delivery, and improving customer value. These procedures guarantee work continuity, which further increases process efficiency [21].

Industry participants have noted that implementing lean methodologies has greatly benefited them, in particular Small and Medium-sized Enterprises (SMEs). In example, the Kanban approach boosts labor productivity by guaranteeing that construction teams have the materials they need on hand promptly, expediting project completion, and improving overall effectiveness [22].

5S Methodology in Project Management: Using lean techniques, like the 5S system, is a practical way to reduce fatalities and injuries in construction workplaces. A lean technique called the 5S process is intended to reveal hidden issues and arrange workspaces methodically in order to increase productivity and cut down on waste. Enhancing productivity, cutting waste, encouraging continuous improvement, streamlining work processes, and above all advancing worker safety and health are its main goals. Enhancing the safety and health of workers continues to be the top priority of the 5S methodology among these objectives, indicating its vital role in establishing safer building workplaces [23].

Lean Project Scheduling: Due to their inherent complexity, construction projects need careful planning and scheduling in order to be completed successfully. By cutting waste and streamlining procedures, lean concepts provide a revolutionary way to improve the effectiveness of scheduling and planning construction projects. Value stream

mapping, for example, can be used to identify waste areas during the planning and scheduling phases, allowing for focused process improvements. Project managers may show how important lean methods are to contemporary construction management by incorporating these ideas into their work and completing projects on schedule, within budget, and in line with client expectations [24].

8. Role of Transformational Leadership in Project Management

Applying transformational leadership to construction industry patterns and clusters shows the integration of transformational leadership with project management. Key- words like "Motivating Teams," "Developing Future Leaders," and "Sustainable Success," regularly appear alongside "Project Management," indicating the increasing importance of transformational leadership in the construction sector. In construction projects, transformational leadership is essential for improving team performance. Since work motivation has been shown to effectively mediate this link, creating an inspiring work environment helps close the gap between leadership practices and worker performance. Through a clear vision and a commitment to personal growth, transformational leaders inspire and encourage intrinsic motivation, which boosts output and enhances project results overall. Moreover, transformational leadership's attributes actively promote creativity and innovation in the industry. Leaders who encourage inventive thinking and give them the freedom to be innovative foster an atmosphere where teams can come up with practical answers to project problems. The influence of transformative leadership in construction projects goes beyond inspiration and creativity. It also affects important elements like service quality, market orientation, and the general work atmosphere, which makes it a crucial strategy for long-term project success [25].

Motivating Teams: Workplace motivation stems from the necessity and anticipation of tasks, along with various elements that enhance team engagement. Leadership qualities in managers play a crucial role in recognising and addressing employees' expectations, shaping the overall organisational culture. Among the numerous responsibilities of a leader, fostering motivation within a team remains both the most essential and the most intricate [26]. This complexity arises due to the ever-evolving nature of motivational factors. Key drivers of employee motivation include the fulfilment of professional needs, equitable workplace treatment, effort recognition, structured development initiatives, and well-designed reward and appreciation policies.

Developing Future Leaders: Aspiring leaders must possess the capability to craft a compelling strategic vision that guides and motivates the organisation. Cultivating an environment that encourages innovation, embraces transformational leadership, and navigates change efficiently is equally essential. Research findings from surveys and questionnaires emphasize the necessity of adaptability, conflict resolution skills, and team-building expertise in leadership development. Studies further underscore the value of self-improvement and lifelong learning as fundamental traits of effective leaders. Proficiency in leveraging technology and digital advancements also plays a crucial role in shaping future leadership success [27].

Sustainable Success: In the modern business landscape, strategically overseeing the entire project portfolio is crucial for sustaining long-term success and maintaining a competitive edge. The initial phase of projects serves as a catalyst for innovation, where opportunities emerge, concepts take shape, and the groundwork for future portfolio and organisational success is established. Achieving lasting growth, however, depends on the ability to identify and proactively manage portfolio opportunities. Detecting both present and future gaps at an early stage is essential to maximising potential and ensuring strategic alignment [28].

9. VOS viewer analyzation

This research utilises VOSviewer, an advanced tool designed for creating data-driven visual maps by analysing relationships between nodes. Applying keyword co-occurrence analysis, key terms were extracted from relevant literature to detect recurring themes within titles and abstracts, providing deeper insights into topic associations. As illustrated in Figure 2, Network visualisation display a cluster that indicates that the the field that have more reoccurrence and connected are sustainability, lean construction, sustainable development and climate change

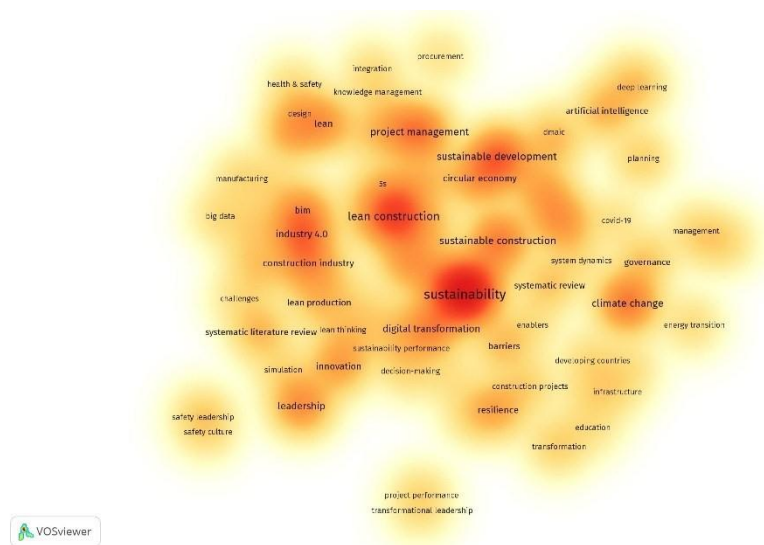


Figure 4. Density visualisation

5 Conclusion and Future recommendations

Incorporating transformational leadership with lean methodologies in civil engineering is vital for improving project sustainability, operational efficiency, and management effectiveness. Establishing a culture centered on innovation, motivation, and continuous improvement enables leaders to elevate organisational performance while adhering to sustainable construction principles. Lean methodologies, which prioritize waste minimisation and process optimisation, further enhance resource utilisation and overall project success. The combined impact of these approaches leads to higher productivity, cost reductions, and greater environmental accountability in civil engineering projects. Despite these advantages, obstacles such as resistance to change, inadequate leadership training, and flawed implementation strategies must be overcome to maximise their effectiveness. Advancing research in this field should focus on integrating digital transformation tools with lean principles and transformational leadership frameworks. Furthermore, implementing industry-wide training initiatives will be essential in strengthening leadership capabilities and fostering lean methodology adoption. Refining these strategies over time will drive the industry toward more resilient, economical, and sustainable construction practices.

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Predicting Individual Well-Being with Machine Learning Using Social Media Language

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Abstract. This study examined the use of social media language in predicting individuals' wellbeing through machine learning methods. Text data obtained from social media platforms was evaluated as a valuable data source for predicting individual well-being. The most successful model used in the study, Random Forest, achieved an accuracy rate of 97.02% in predicting individual well-being. The high performance of the model highlights the effectiveness of social media language as a tool for passive assessment of individuals' mental and emotional states. Evaluation results, including metrics such as precision, recall, and F1-score, revealed consistent classification performance across all classes. The findings suggest that well-being prediction based on social media language can offer an innovative solution for real-time monitoring of psychological states and the development of preventive mental health applications. This study not only provides strong evidence for predicting individual well-being through digital footprints but also emphasizes the potential of machine learning techniques in this field. For future studies, it is recommended to expand datasets to include a wider range of diverse platforms.

Keywords: Social Media Analysis, Machine Learning, Random Forest, Prediction of well-being, Data Analysis

Introduction

The widespread use of social media has led to the generation of an immense amount of user-generated content, providing valuable insights into individuals' thoughts, emotions, and behaviors. Researchers have increasingly turned to social media as a data source for understanding various aspects of human life, including individual wellbeing. Language used on platforms like Twitter, Facebook, and Instagram often reflects users' psychological states, making it a rich resource for predicting mental health and overall well-being[1]. This study explores the use of Random Forest (RF), a powerful machine learning algorithm, to predict individual well-being based on social media language. Random Forest has gained significant attention for its efficiency and accuracy in handling structured and unstructured data, making it an ideal choice for this task. By leveraging

linguistic features extracted from social media posts, this research aims to build predictive models that can assess well-being with high precision[2]. The primary goals of this research are twofold: first, to investigate the relationship between social media language and individual well-being; and second, to evaluate the effectiveness of Random Forest in predicting well-being compared to traditional methods. The findings of this study could contribute to the development of tools for early detection of mental health issues and personalized interventions, ultimately promoting better mental health outcomes.

Related Works

The prediction of individual well-being through social media language has gained significant attention in recent years, as the proliferation of user-generated content provides a unique opportunity to study psychological and behavioral patterns at scale. Prior research in this domain has primarily focused on leveraging linguistic features, sentiment analysis, and machine learning techniques to model well-being[3].

One of the foundational studies in this field was conducted by Schwartz et al., who demonstrated the potential of using social media language to infer psychological traits and well-being[4]. By employing lexical analysis and machine learning, they identified correlations between specific linguistic features and measures of subjective wellbeing. Similarly, De Choudhury et al. explored how language on platforms like Twitter could predict mental health states such as depression, emphasizing the predictive power of sentiment, word frequency, and activity patterns[5].

More recently, advancements in natural language processing (NLP) and machine learning have improved the accuracy and scalability of such predictions. Techniques like word embeddings (e.g., Word2Vec, GloVe) and transformer-based models (e.g., BERT) have been used to capture the semantic richness of social media text. For example, Zeberga et al. applied deep learning models to predict well-being metrics from social media posts, achieving notable success in capturing nuanced relationships between language use and psychological outcomes[6].

In addition to traditional and deep learning approaches, gradient boosting algorithms, such as Random Forest, have emerged as powerful tools for prediction tasks due to their efficiency and robustness in handling heterogeneous data. RF has been applied in various domains, including health informatics, due to its ability to model complex interactions and its resistance to overfitting[7]. However, its application to predicting well-being using social media language remains relatively underexplored. This study builds upon the existing literature by focusing on the application of RF to predict individual well-being from social media language. While previous work has predominantly utilized linear models or deep learning techniques, this research investigates whether RF can provide a competitive edge in terms of accuracy and interpretability[8]. Furthermore, the study explores the integration of linguistic, behavioral, and temporal features, contributing to a more comprehensive understanding of the predictors of well-being in the context of social media.

Methodology

To predict individual well-being using social media language, this study employs a systematic methodology comprising data collection, preprocessing, feature extraction, model training, and evaluation. The primary goal is to develop an accurate predictive model using Random Forest while integrating linguistic, behavioral, and temporal features extracted from social media posts.

Dataset

To investigate the connection between social media usage patterns and emotional well-being, the "Social Media Usage and Emotional Well-Being" dataset was developed. This dataset includes details on users' emotional states and interactions on social media networks. Publicly accessible social media posts gathered from sites like Facebook, Instagram, Reddit, and Twitter make up the dataset. User-generated text, timestamps, and meta-data (likes, shares, and comments) are all included in the data. The dataset offers statistics and metrics regarding users' demographics, social media usage abilities, and emotional health. This dataset can be used in academic studies, policy development efforts, corporate marketing strategies, and application development fields. This dataset is accessible on Kaggle platform. Users can download the dataset to conduct their own analyses and share their findings. The indicators and their explanations included in this dataset are shown in Table 1.

Table 1. The indicators and their explanations included in this dataset

Features	Description
User_ID	The user's unique identification
Age	User age
Gender	The user's gender (male, female, or nonbinary).
Platform	Use of social media platforms, such as Facebook, LinkedIn, Instagram, Snapchat, Whatsapp, and Telegram.
Daily_Usage_Time (minutes)	Minutes spent on the platform each day.
Posts_Per_Day	The quantity of posts created each day
Likes_Received_Per_Day	Daily count of likes received
Comments_Received_Per_Day	Daily count of comments received
Messages_Sent_Per_Day	The quantity of texts sent each day
Dominant_Emotion	Throughout the day, the user's primary emotional state (such as happiness, sadness, anger, anxiety, boredom, or neutrality)

Data Preprocessing

This dataset includes many features for analyzing the relationship between social media usage and emotional well-being. Preparing the dataset for meaningful analysis requires a proper preprocessing process. Applying preprocessing techniques commonly used in the literature and best suited for this dataset will positively enhance the model's performance. Data preprocessing ensures that the raw text and metadata are clean and suitable for analysis.

Data exploration and understanding is a critical step conducted at the initial stage of machine learning projects, aiming to comprehend the structure, features, and potential issues of the dataset. This process is essential for making the data preparation and modeling steps more effective. The data exploration process began by loading the dataset into a data analysis environment (e.g., Python, R). The number of non-null values and data types for each column are shown in Table 2.

Table 2. The number of non-null values and data types for each column

No	Column	Non-Null Count	Data Type
0	User_ID	1001	object
1	Age	1001	object
2	Gender	1000	object
3	Platform	1000	object
4 5	Daily_Usage_Time (minutes)		
6 7	Posts_Per_Day	1000	float64
8 9	Likes_Received_Per_Day	1000	float64
	Comments_Received_Per_Day	1000	float64
	Messages_Sent_Per_Day	1000	object
	Dominant_Emotion		

To understand the dimensions and basic structure of the dataset, the number of rows and columns was identified. The data type of each column (numerical, categorical, text) was examined. It was determined whether the dataset contained missing values, and if so, the proportion of these values was calculated. Basic statistics for each column were extracted to gain general insights about the data. Visualization techniques were used to understand the data distribution, and the distributions of variables were analyzed. Outliers in the data, which could negatively impact the performance of machine learning models, were detected. Relationships and correlations between variables were analyzed, and a correlation matrix was generated for detailed analysis[9]. Potentially erroneous data (e.g., illogical values, such as negative values in an age column) were identified during the data cleaning process. Categorical columns were converted into numerical values using techniques like label encoding or one-hot encoding. For machine learning models, an analysis of the dependent variable was conducted, and the class distribution was checked for imbalances[10]. The findings obtained during this stage were documented. This process is critical for proper data preparation and a successful modeling process. The gender distribution of posts on social media platforms is shown in Fig. 1.

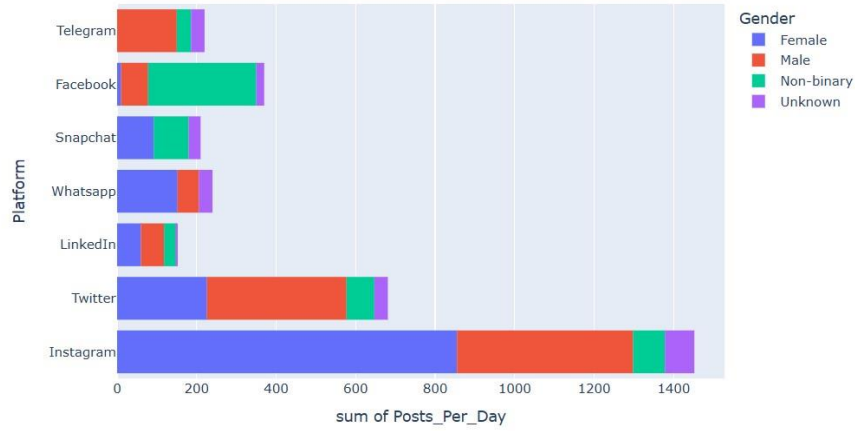


Fig. 1. Distribution of posts on social media platforms

Text cleaning is a preprocessing step performed to make raw text data more suitable for machine learning models. By removing noise and irrelevant information from the text, cleaning helps models produce more meaningful and accurate results from the data. Removal of stopwords, URLs, hashtags, emojis, and special characters to standardize the input text. For tasks involving textual data in machine learning and natural language processing (NLP), text cleaning is an essential preprocessing step[11]. By eliminating noise, inconsistencies, and unnecessary information, the objective is to make the remaining raw text data understandable and structured for analysis or modeling. Text cleaning transforms the text into a simplified, meaningful, and structured form for analysis. This process enhances the accuracy of text data and improves the performance of machine learning models.

In machine learning projects, missing data is a frequent problem that can have a big impact on model performance and accuracy. In order to make the dataset more useable, handling missing data entails identifying the underlying reason of the missing values and applying the proper strategies to fix them.

Detecting missing data is the first step in the process. The columns with missing values and the extent of their prevalence in the dataset were identified. Visualization tools were used to understand the patterns of missing data. There can be various reasons for missing data. For example, the absence might be unrelated to the variable itself but related to other variables, or the data might be missing completely at random. Understanding the cause of missing data determines the strategy to handle it. Removing missing data is the simplest method that can be applied. However, this should be done cautiously, as it might lead to class imbalance issues. This method is generally used when the proportion of missing data is very low or the missing values do not carry significant information.

Filling missing data based on the available data is another commonly used method[12]. In this study, missing data were filled using the median method. For numerical data, missing values were replaced with the column's mean, while for categorical columns, the most frequently occurring value was used. After filling the missing values, it is important to verify how these changes impacted the dataset. In this study, the consistency of the dataset's statistical properties was checked. The strategies applied for handling missing data in this study are shown in Table 3. Processing

missing data enhances the accuracy and reliability of machine learning models. The choice of method depends on the structure of the dataset, the extent of missing data, and the modeling objectives. When managed correctly, missing data ceases to be an issue for machine learning projects.

Table 3. The strategies applied for handling missing data

Condition	Applied Method
Missing data rate is low (< 5%)	Delete a row or column
Missing data imputed at random	Filling with mean, median, and mode
High rate of missing data (> 30%)	Filling using median
If missing data carries important information	Making deficiencies a separate category
If the algorithm can work directly with incomplete data	Leave without action

Random Forest

A well-liked machine learning approach for classification and regression issues is Random Forest. It functions by merging several decision trees and is essentially an ensemble learning technique. In order to generate predictions, Random Forest uses the average (for regression) or majority vote (for classification) of the predictions produced by individual decision trees. By merging the output of several models, it seeks to improve performance[13]. Random Forest employs an ensemble technique called Bagging (Bootstrap Aggregating). Several independently trained decision trees are combined in the method. A random subset of the dataset is used to train each tree. Furthermore, rather than utilizing every feature in the dataset, a random subset of characteristics is chosen for each decision tree. This helps avoid overfitting and broadens the model's diversity[14].

The bootstrap resampling technique is used in the Random Forest algorithm to generate random subsets from the training dataset. Since sampling is done with replacement, some samples may be chosen more than once. For instance, if a dataset has 1,000 samples, each subset may contain 1,000 randomly chosen samples. Every subset is used to train a separate decision tree. Instead of using the entire set of features, each tree utilizes a random subset of them (for example, if there are 10 characteristics, each tree may use only 4 features). Every tree predicts its class[15].

Random Forest uses random sampling and feature subset selection to increase model diversity and reduce overfitting. The combination of decision trees balances the errors of individual trees, enhancing the model's generalization capability. Since decision trees are trained independently, Random Forest is well-suited for parallel processing. It can also identify which features are more important to the model. Random Forest can be used for both classification and regression problems. Irrelevant features do not significantly impact the model's performance[13]. In some cases, it can handle missing data effectively. Additionally, it can process numerical, categorical, and mixed data types simultaneously. Despite its advantages, Random Forest also has some disadvantages. Training a large number of trees can be time-consuming, especially for large datasets. It may also require high memory usage when dealing with many trees and large datasets.

Results and Discussions

Evaluation Metrics and Parameters

Social media sentiment analysis aims to classify the sentiment in texts (positive, negative, neutral). Random Forest is a powerful machine learning model capable of solving classification and regression problems using multiple decision trees. When using Random Forest for social media sentiment prediction, employing various evaluation metrics and optimizing hyperparameters is essential to train and evaluate the model accurately.

Classification issues are frequent in social media sentiment prediction. Consequently, the most commonly used metrics for machine learning models are Accuracy, Precision, Recall, and F1-Score were employed in this study. The proportion of accurately anticipated observations to all observations is known as accuracy. It is employed in the assessment of overall performance. The ratio of genuine positives to all data that the model predicts would be positive is known as precision. When high accuracy for the positive sentiment class is essential, it is employed. The proportion of accurately predicted positive classes to all actual positive classes is known as recall. In order to capture the negative sentiment class, it is crucial. Precision and Recall are balanced by the F1-Score, which is the harmonic mean of the two. As is frequently the case in sentiment prediction tasks, it is an effective performance metric for datasets that are unbalanced, such as those with a higher prevalence of negative sentiment. The formulas for evaluation metrics are shown below.

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \quad (1)$$

$$Precision = \frac{TP}{TP+FP} \quad (2)$$

$$Recall = \frac{TP}{TP+FN} \quad (3)$$

$$F1 \text{ Score} = \frac{2 * Precision * Recall}{Precision + Recall} \quad (4)$$

The Random Forest model's performance can be enhanced by optimizing its hyperparameters. The Random Forest algorithm's `n_estimators` parameter, which establishes the number of trees in the forest, is one of its most crucial parameters. While raising this figure strengthens the model, it also raises the computational expense. Higher numbers can be evaluated for larger datasets, but generally speaking, a figure between 100 and 500 is appropriate. Each decision tree's maximum depth is specified by the `max_depth` parameter. The learning capacity and overfitting risk are impacted by the tree's depth. Overfitting can be avoided by limiting the depth. The ideal depth is usually achieved with values in the range of 10 to 30.

The bare minimum of samples needed to further split a node is indicated by the `min_samples_split` option. Greater values assist avoid overfitting and result in less complicated models. Usually, tests are conducted on numbers ranging from 2 to 10. The bare minimum of samples needed to build a leaf node is specified by the `min_samples_leaf` option. The model performs better when more data are needed for each leaf. The `max_features` option determines how many features should be used for each tree. This has an impact on the model's accuracy and variety. The best results are frequently obtained with `sqrt` or `log2`. Table 4 displays the parameters that were optimized for this investigation along with their respective values.

Table 4. Optimized Hyper-parameters

Hyper-parameter	Value
n_estimators	[100, 200, 300]
max_depth	[10, 20, 30, None]
min_samples_split	[2, 5, 10]
min_samples_leaf	[1, 2, 4]
max_features	['sqrt', 'log2']
optimizer	adam
loss	categorical_crossentropy
activation	softmax
epoch	300

Results

In this study, individual well-being was predicted using machine learning techniques based on social media language. The dataset, freely obtained from the Kaggle platform, was trained with various machine learning models. Random Forest, Gradient Boosting, Logistic Regression, SVM, KNN, and Naïve Bayes models were applied using the same dataset and parameters.

The results were measured and evaluated using accuracy, precision, recall, and F1 score metrics. Among these six models, the highest accuracy rate was achieved with the Random Forest model. The overall accuracy rate of the Random Forest model was 97.02%. This reflects the robustness of the Random Forest model for the given task. For the emotions anger, anxiety, boredom, happiness, neutral, and sadness, the Random Forest model achieved accuracy rates of 98%, 98%, 94%, 99%, 98%, and 96%, respectively. Value of evaluation metrics are shown in Figure 5.

Table 5. Value for Randomof Evaluation metrics
Forest

	Accuracy	Precision	Recall	F1-Score
~~Class~~				
Anger	98%	99%	100%	99%
Anxiety	98%	99%	98%	98%
Boredam	94%	96%	%94	95%
Happiness	99%	100%	100%	100%
Neutral	98%	99%	96%	97%
Sadness	96%	97%	98%	97%

The accuracy values for the other five models were as follows: Gradient Boosting - 96.40%, Logistic Regression - 85.71%, SVM - 88.94%, KNN - 94.82%, and Naïve Bayes - 86.15%. The accuracy values of all models are shown in Fig. 2. The Random Forest model achieved the highest accuracy of 97.02%, indicating that it is the most effective model for predicting individual well-being using social media language. Gradient Boosting follows closely with an accuracy of 96.4%, demonstrating that boosting techniques perform almost as well as Random Forest. K-Nearest Neighbors (KNN) achieved a decent accuracy of 94.82%, showing that a non-parametric approach also performs well but lags behind ensemble methods. Support Vector Machine (SVM) and Naïve Bayes models achieved accuracies of 88.94% and 86.15%, respectively. Logistic Regression had the lowest accuracy of 85.71%, possibly due to its sim-

plicity and linear assumptions. Ensemble techniques like Random Forest and Gradient Boosting significantly outperform other models, likely due to their ability to reduce overfitting and handle complex data relationships. KNN's high accuracy (94.82%) suggests that the data structure and distances between points are well-defined, but it is not as robust as ensemble models in capturing intricate patterns. The lowest accuracy implies that the relationships in the data are non-linear and cannot be effectively modeled using logistic regression.

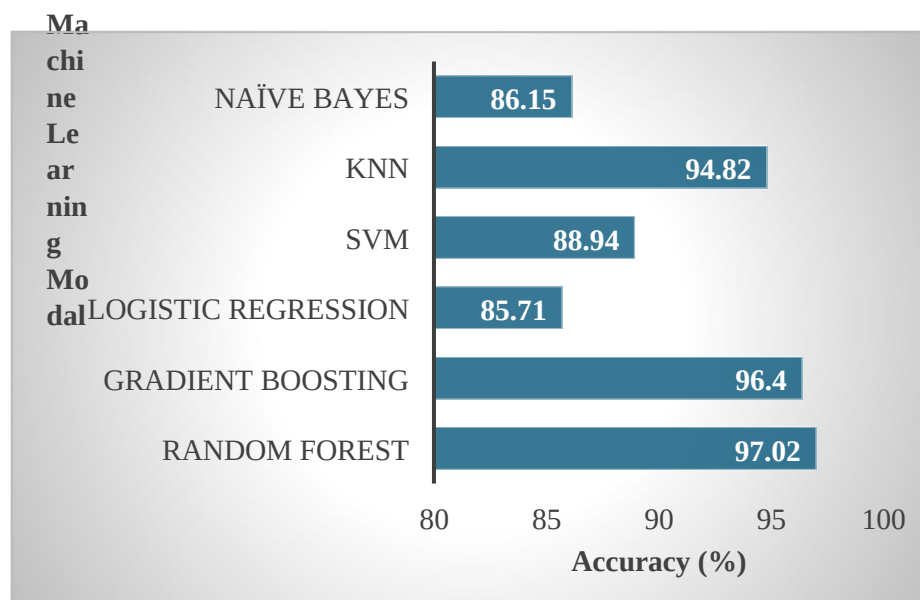


Fig. 2. The accuracy values of all models

Conclusion

This study explored the prediction of individual well-being using social media language, detailing the results based on the performance of machine learning models, the scientific and societal contributions of the findings, methodological challenges, and limitations. The analysis of the results revealed a strong correlation between positive content sharing and individual well-being. It was observed that social media data can be used for passive and real-time measurement, instead of traditional methods (such as surveys and face-to-face interviews). This provides an opportunity to assess individuals' well-being quickly and at a low cost. This study demonstrates that social media platforms can be utilized to monitor individuals' mental health. Such algorithms could be especially useful for developing early warning systems in clinical applications. The Random Forest model provides highly reliable predictions for individual well-being using social media language. With an overall accuracy of 97.02%, the model is robust and well-suited for this task. Minor adjustments to enhance precision and recall for specific classes could further improve the model's effectiveness.

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Saudi National Authority Applying AI in Education Case Study Architecture Program

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Abstract. In November 2023, the Saudi Authority began implementing Artificial Intelligence (AI) across various disciplines, including Architectural Engineering. This research aims to examine the effects of AI usage in architecture schools, with a particular focus on design studios, the specific phases of design involved, and the degree of integration. The methodology employs AI programs across three key design steps: the primary research phase, the form phase, and the rendering phase. A survey was distributed to Design 6 students to gather their responses regarding the use of AI in architectural design. Selected case studies from students' work were analyzed to illustrate the research findings. Survey results revealed that students successfully incorporated AI into their primary research by 99%, into building forms by 74%, and into rendering by 91.6%. The research concludes that AI should be utilized in primary research and analysis, building forms, and rendering, with oversight from instructors. Additionally, architecture students should receive training through courses, workshops, webinars, and competitions to enhance their understanding and application of AI in their field.

Keywords: Saudi commission, artificial intelligence in architecture, application of AI in primary research, AI in developing building form, AI in Rendering.

1 Introduction and Literature Review

The Royal Order No established the National Center for AI. (A/471) dated 29/12/1440 AH and is organizationally linked to the Saudi Data & AI Authority. NCAI drives the national AI priorities in collaboration with its partners in the public and private sectors to support national research projects, strengthening research and innovation in the field of AI in the Saudi Kingdom, supporting the field with the needed capabilities for innovation, in addition to developing solutions that serve the national priorities in various sectors, and elevating the level of national cadres in data science, AI, and their supporting technologies. Limited literature was found in the field of artificial intelligence (AI) in architecture from 2022 to 2024. These were classified into five research focus areas.

1.1 Saudi Data & AI Authority (SDAIA)

The Saudi Data & AI Authority (SDAIA) is the competent authority in the Kingdom that is concerned with data and AI, including big data. [1].

1.2 SDAIA Academy

SDAIA Academy is one of the Saudi Data & AI Authority (SDAIA) initiatives, which aims to support and develop national competencies in data and artificial intelligence data [1].

1.3 AI in Higher Education

SDAIA offers many courses. Dr. Hanan discussed a webinar on ‘ Saudi National Authority to Apply AI and its Applications.’ Many courses are provided in AI science, such as Data Science Engineering, AI Engineering, AI in Architecture Engineering, Data Science, Data Analysis, AI, and administration [2].

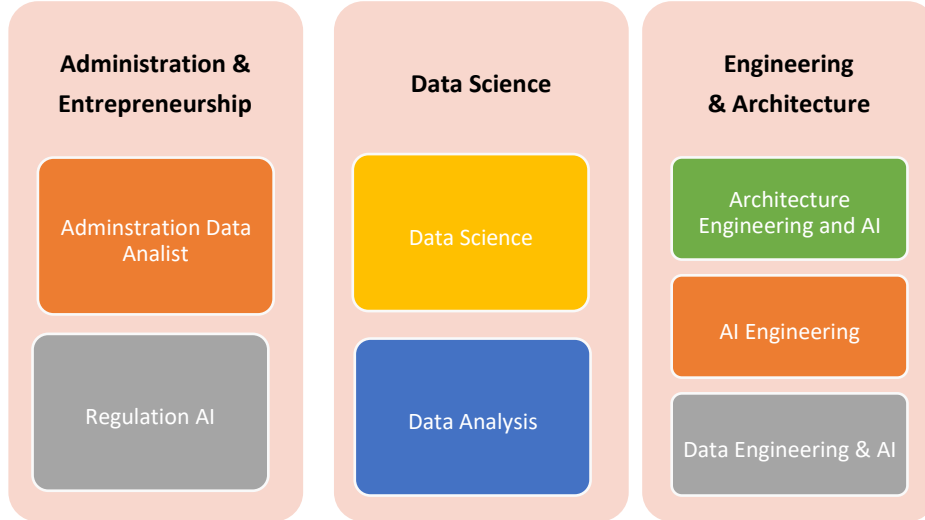


Fig. 1: shows AI fields in SADAIA and AI Specialization [3].

In addition, Dr. Hiba discussed the webinar on ‘ Using AI in Problem Solving in Architecture.’ The webinar was presented by Naseej Academy and explained three examples

- Zoom AI Companion and AI Summery could be activated by the meeting host.
- Bing Chat experience from Microsoft, which is used by some universities.
- IBM Watson Education teaches the students according to their special needs.
- chat box: most of the university's websites use the chat box to contact the students
- Planning and Strategies
- SIS, students Information System, use of its information in analysis and problems solving
- LMS, a Learning and Management System, uses its information in analysis and problem-solving.

1.4 The Future of Architecture

The International Union of Architects (UIA) launched an online forum to discuss the future of architecture in the 21st century. [4] The forum concluded that the focus is on the capacity of architectural education to respond to these challenges while creating conditions for students and educators to engage as active citizens in their communities.

1.5 AI in Research and Education

[8] Discussed a research paper on the first application of AI in Design Studio 6 in the last semester, 2023-2024-2, focusing on the design process in developing design concepts, building form, sustainability, and rendering. The research outcomes showed less percentage in color and rendering application and development. [9] The research outcome is the main challenge; human-centered AI needs training to manage every user's expectations and input and be adaptable to unpredictable situations. [10] Dr Shahinaz presented a webinar at a conference that discussed using AI in education as reflecting the SDG number 4 quality of education, such as Language Learning. In education, there are applications, LMS, SIS, Virtual Reality (VR), and Augmented Reality (AR). Ethical con-

cerns related to AI-powered decision-making were also discussed. [11] discussed in his research paper case study a model 3D used in the design process and developed by using AI and Chat GPT several times through discovering, defining, and delivering exceptional cases to create the outcome of the research each step between 3 times to nine times to reach a good result. [12] highlighted the importance of creating research capability and capacity through innovation and knowledge involving the students in research and data collection using new technologies and computer programs. [13] This study underscores the promising potential of AI in the architectural domain, serving both as an educational tool and a creative design tool. The outcome of the research stresses the need for a more personalized approach in the development and utilization of AI design. Also, [14] discussed new methods of human signs, such as noise from one person or noise from social speech to be added to AI, and designers might use AI as a more-than-human agent in the design process. In addition, [15] this research paper searched and answered the question: Does Artificial Intelligence have the Possibility of Taking Over Designers' Jobs in the Future? The answer is No. AI could help architects and designers to develop their designs. In addition, [16], the researcher highlighted AI as a creative assistant for designers. The designer should create the model, Planning interaction, and problem-solving, the interaction with AI should be multiple, and the outcome will be excellent. In addition, [17] published a book and discussed in this book Artificial intelligence in the field of architecture, with a focus on AI in form, context, and model.

In addition [5] Chair of the Art and Design Commission, the program focuses on community engagement through workshops, Awards for excellent projects, forums, learning Café, cities and across the Kingdoms, Training programs, Summer Training, Architecture criticism workshops, and Urban transformation. Also, [6] It was stated that universities and schools should embed changes, flexibility, and adaptation as part of their curriculum structure, design studio practices, and learning and teaching processes. She defined AI in three stages: Machine learning, machine intelligence such as computers, and machine consciousness. [7] Discussed UNSDG goal number 17, encouraging the NGOs to collaborate with the education sector to sign agreements to improve students' skills to achieve sustainability goals.

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1.6 AI in Building Form

Pena highlighted the importance of using AI in innovative forms and ideas [18]. For interior and exterior design, the latter combines the strengths of the different platforms [19]. In addition, [20] discussed in this paper applying AI in interior design helps designers in problem-solving; the research introduces a model that allows it to infer and adapt to designers' goals, reasoning, and capabilities. Also, [21] This research focuses on introducing AI literature review in its application in Architecture and introduces three 3D generative models and foundation models, highlighting their recent developments and main application scenarios. Then, the paper explains how the abovementioned models could be utilized in architecture.

1.7 AI in 3D Rendering

[22] and [23] discussed using AI in interior and exterior 3D shots with different backgrounds.

In addition, [24] discussed that AI in Architecture is becoming crucial, and providing more in-depth imaging depends on the keywords provided to the AI box. This tool provides one step to the future image. Hypothesis

- 1) To train the students in Artificial intelligence and new technology.
- 2) To be able to use AI in research
- 3) To be able to use AI in building form development.
- 4) To be able to use AI in rendering

2. Method

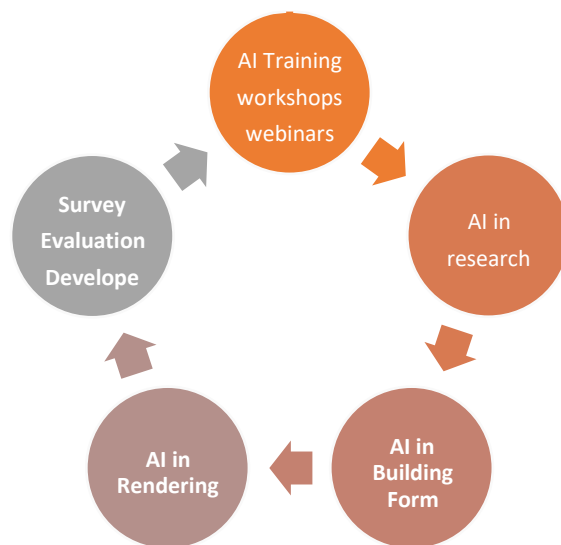


Fig. 2: Shows the research process plan

The research methodology has four steps. Many AI tools were used in the concept phase of Architecture Design Studio 6 from 1991 to 2010, and new tools were generated from 2011 to 2020 [25].

Table 1. Show the AI programs applied by the students

Case study No.	AI program	Advantages	Disadvantages
1	http://promelai.com/website is a rendering concept.	Different development concepts.	AI changes its form.
2	Mnml.com	Midjourney	Develop the form Need training
3	Develop the form	Need training	
4	LooX.AI.com.	Fast, form development. Image or sketch - realistic Need to set up. photo system, limited Fantasia color.	credit points,
5	Chat Box	Use this website to answer student's questions for 24 hours Help to develop writing quality Help to provide the students with the case study	It is not working Need to be re-viewed By Human
6	Chat GPT	Help in statistics Help in Analysis	

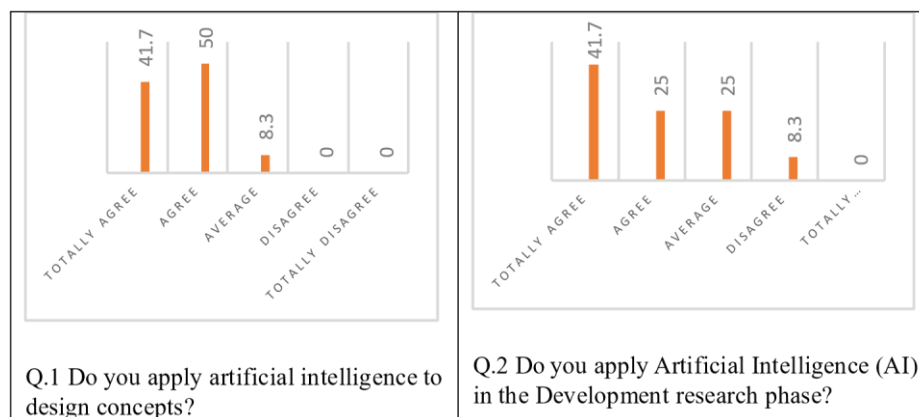
2) Applying the AI program in four areas: training the students, research phase, form development, and Rendering phase.

3) Distribute a survey to the Architecture Design Studio 6 students to register their responses to using AI in their design project 6 in their research, form development, and Rendering phases. The survey was designed using Google Forms and distributed to all the students by email. The total number of students was 15. All the students answered the survey, and the response was 100%.

4) Three case studies from students' work in studio D6 were selected to reflect the research work.

3. Results

3.1 The results from the survey



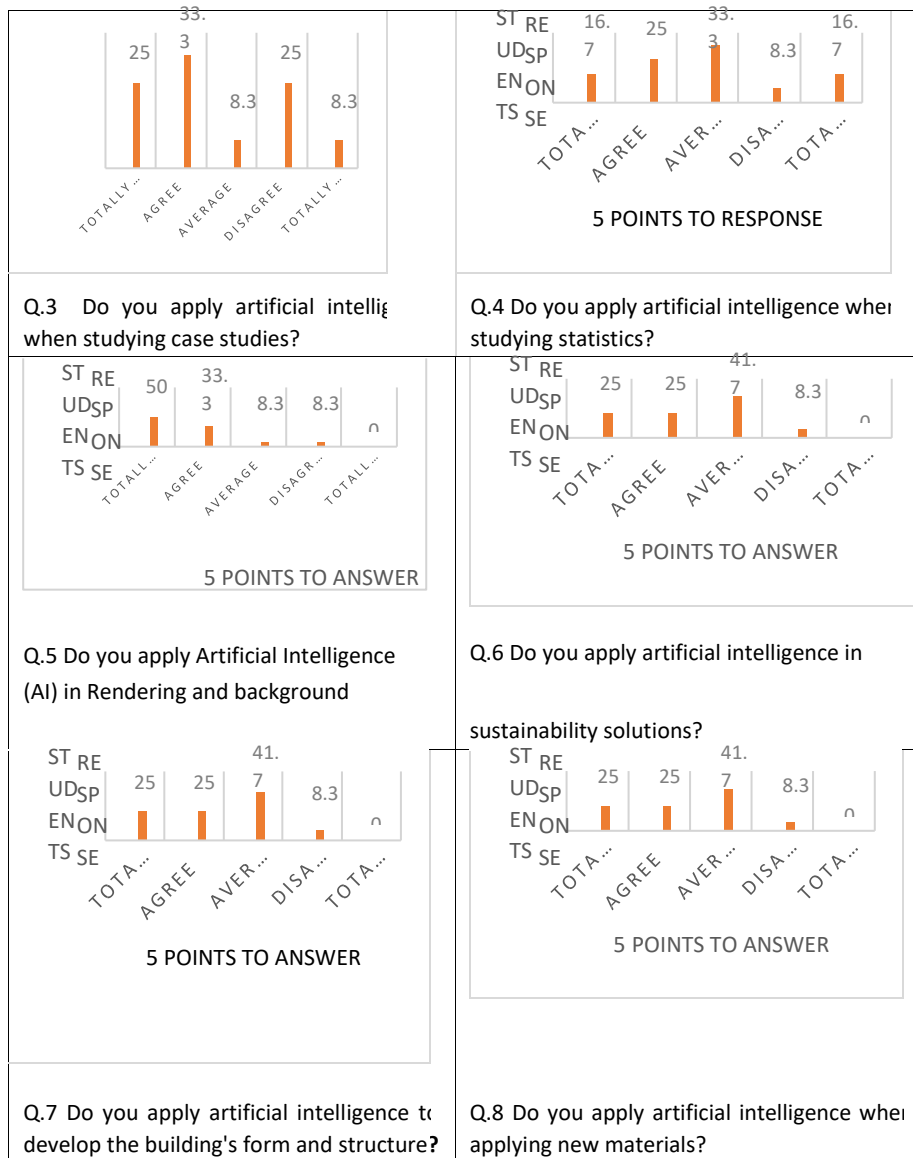


Fig. 3: The survey results (analyzed by author_

4. Discussion

4.1 discuss the survey results

The survey was distributed in May 2024, and the total respondents were 20 female students. 20/20 answered the survey questions. The results showed students applied (AI) in developing their design process in concept, as shown in Figure 2. Here, the research agreed with [16] (that AI) was a useful tool used to develop design processes. In the first question 100% of the students answered that they applied AI in concept development and those students had no idea how to use AI programs, they were involved in groups, helping them to apply AI, and helping them to improve their skills. In the second question, third, and fourth questions, more than half of the students agreed that (AI) helped them to develop the research about site analysis applied by 99.9%, data analysis and statistics used by 75% of the studies analysis applied by 66.6%, AI gave them more visualization of the project site. Here, the research met with ([7], who highlighted the importance of creating research capability and capacity through innovation and knowledge involving the students in research and data collection using new technologies and computer programs. In the fifth question, 91% of the students used AI in rendering, it gives quick background images, skyline, and sunset about the project. Here, the research met with [20] AI is used to create interior and exterior 3D images, with the latter combining the strengths of the different platforms. In addition, in question six,

91% of the students agreed that they applied AI to sustainability solutions. The AI gave them solutions such as adding green roofs, terraces, reflected glass in elevations, and green terraces, as shown in case studies of plants and trees in the outdoor environment. Also, in the seven questions, 75% of the students applied AI to develop building forms and structures here the research agreed with (Ploennigs, 2023) In combining the strengths of the different platforms. In question eight, 92% of the students applied AI to find new building materials in the elevations. Question 9 was an open question, and the students were asked about their experience with applying AI in the design D6. They said it was a useful experience to come up with new and unique ideas and think outside of the box. One student said It helps me to develop more work in a short time. Another student said that, in my experience, using artificial intelligence (AI) in projects, including D6, has significantly enhanced efficiency and outcomes. One student said: The D6 project leveraged AI for various tasks such as data analysis, predictive modeling, and process automation. In addition, one student said, for instance, we utilized machine learning algorithms to analyze large datasets, extracting valuable insights that informed our decision-making processes. Predictive models were developed to forecast trends and identify potential risks, allowing us to proactively address issues before they become problematic. Additionally, AI-driven automation streamlined repetitive tasks, freeing up team members to focus on more strategic activities. This not only improved productivity but also ensured higher accuracy and consistency in our output and ease of developing the design idea through AI programs. Question ten was open, and the students were asked about the programs they used. And they answered that they used Chat box, Chat GPT, Midjourney, Prome, and Mnml.com. Finally, the use of AI still needs training to be applied in all design studios, now in this semester it was officially applied in design D6, and we need to extend the experience to all design studios, improve design skills, and increase the student learning outcomes ILOs

4.2 Discuss the case studies

The project is National Culture Center and Knowledge Exchange, considered a multidisciplinary public space, considered a hub of intellectual exchange, exploration, and enrichment, serving as a destination for those seeking to understand a different culture, play a significant role and landmark in the city, locally in Saudi Arabia such culture center as King Fahad Culture Center, in Riyadh, and Jameel Square in Jeddah, while internally. Example: Jaber Al Ahmad Culture Center. This Art and Culture center includes a large space theater with 3500 m², a small area theater with 2500 m², a cinema with 2000 m², multi-proposed halls used as art halls and seminar rooms, workshops halls, and artificial intelligence hall, a library, and restaurant and administration and, Historical Museum.

The first case study

The first case study concept, designed as a sculptural form, emerged from the linear intersection of pedestrian paths within the cultural district and sprouted a network of preaches. Gradually, developed, into a growing organism, spread as the earth's geological layers, addressed climatic change with curved layers. AI was applied to develop the building form, shown in Figure 7, AI-generated 12 different shots helped to create the building form; the main AI program used was “Prome”. 9 generated shots by AI in the following Figure 4

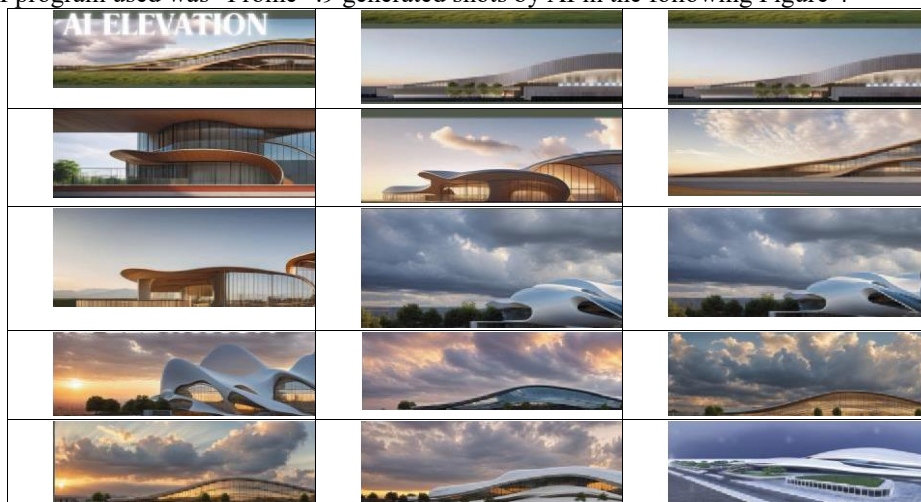


Fig. 4 The AI shots were generated in case study one by using the Prome AI program. (Designed by the student 1).

The second case study

The design concept is abstract from Najd style and door motifs, Particularly concentric circles resembling the sun, blending heritage with modernity. applied local building materials such as Riyadh stone, and sustainability was used in the reflected glass and green roof and green landscape. The building form was developed using sketches and AI, giving different geometrical forms. As shown in the following figure. Three shots of concept development and three shots in rendering a total of six shots by AI using Midjourney and Chat GPT AI programs. Six shots were generated in the following Figure 5.

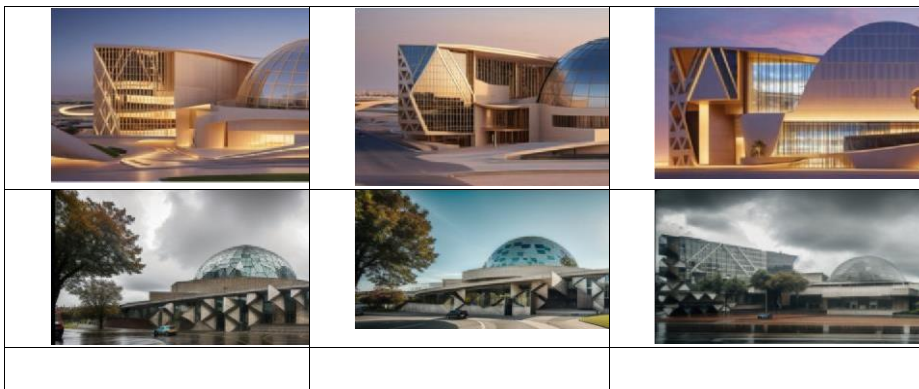


Fig.5.: The AI shots were generated in case study two by using the Midjourney AI program.

(Designed by student 2)

The third case study

The concept extracted from the Najd style was to design two courtyards and all the functions and spaces surrounding the two courtyards, then reflect the Sulmani style in a new way and modern design by applying the triangle windows with reflected glass and sky lighting. The AI used in the research phase in Chatbox helped in some information about site analysis and data analysis. Also, in the design development phase, the student started by drawing sketches about the concept, then inserted the sketches in AI, and Prome AI was applied to develop the design concept. Building form and rendering. 9 shots were generated in the following Figure 6

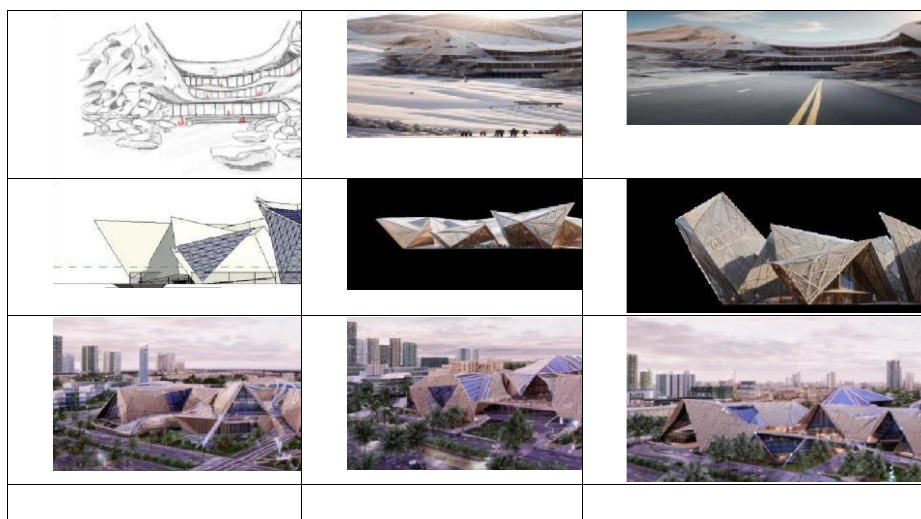


Fig. 6. The AI shots were generated in case study three by using the Prome AI program.

(Designed by student 3).

Challenges facing Applying AI tools in architecture

- Not all the students know about AI programs
- To solve this problem, the teacher divided the students into small groups to learn the programs in pairs
- The need to repeat the input with different keywords to have better results
- More shots should be provided from 4 to 12 to have different solutions in elevations, form, backgrounds
- limitations associated with AI adoption in architecture education.
- ethical considerations
- cost factors to downloading the AI programs
- the need for continuous learning and adaptation and training and workshops in the AI program

Explanation of AI tools

The students used different AI tools to design and write the exercise. Table 1 lists the names of these programs and the advantages and disadvantages of each program.

- Advantages include the fast, innovative AI tool, which gives more solutions to develop the concept and form. Render shots and sustainability • Disadvantages include the need for training, it works for 24 hours if it's free
- The process starts by downloading the program and then uploading the sketches or photos, writing the keywords, writing the number of shots, choosing the theme, then starting
- In A few seconds, the AI will give you the result
- You could repeat the process with more keywords to have better results

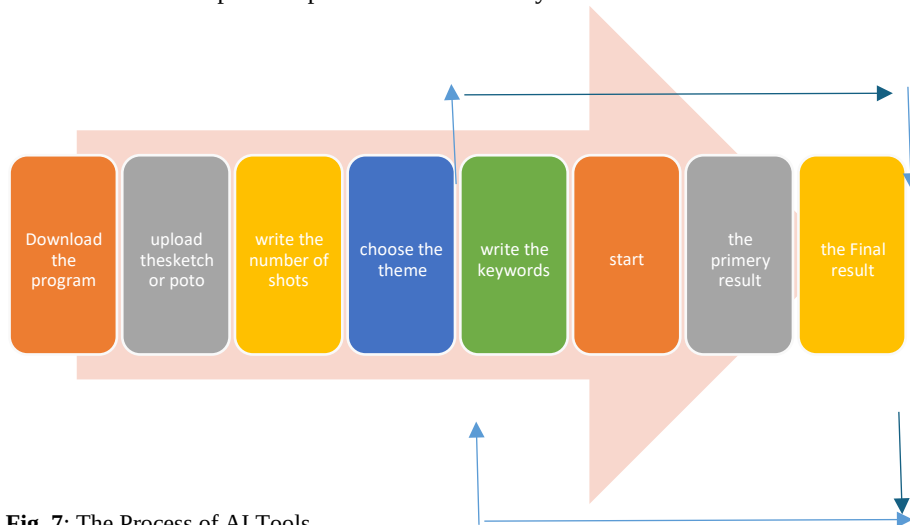


Fig. 7: The Process of AI Tools.

By comparing the results of this research with the results of [8] shown in Table 2, I recognize that the achievement percentage of doing research is increased to 99 %, in concept increased to 100%, building form increased to 74%, rendering increased to 91%, coloring is not applied in this project, sustainability increased to 91.7%, material, and structure increased to 91.6%, generally the student's performance and applying AI is increasing the ILOs and developing their project up to 91.6%.

5. Conclusion

The novelty of this research lies in applying Artificial Intelligence throughout the architectural design process. AI was utilized to develop the primary research, building form, and rendering on Design Studio 6. The research methodology applies to AI programs in different design project stages. Additionally, a survey was distributed to

record the students' responses to AI. The outcomes show that the students applied AI in primary research 99 % in the development of building form 74%, and in rendering, 91% of the students applied AI in developing design processes to achieve the ILOs. This research responds to SADAIA, the Saudi National Authority in AI and intelligent systems in different sectors, including education. The AI assists students in primary research in excellent ways, such as case studies and site analysis. The research recommends applying AI in developing building forms; more than fifty percent of the students apply AI in developing building forms after they draw sketches in the primary design. The research recommends using AI in rendering, providing different backgrounds in 3D, and giving quick images about the design. Comparing the results of this research with those [8] in Table 2, it was found that applying AI in developing design processes increases the CLOs of the course. This research highlighted the importance of students' training in applying AI to different programs to develop design processes in Architecture colleges at all levels. The research encourages Knowledge transfer through workshops, webinars, and competitions internally and externally with other universities.

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Design Thinking for Sustainable Solutions: Developing a Carbon Footprint Tracker

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Abstract. The rising impact of climate change has a need of immediate action to decrease greenhouse gas emissions. Carbon footprint trackers are tools designed to monitor and manage greenhouse gas emissions produced by individuals, companies, or even entire industries. This paper lays the basis for our project and includes a detailed study of carbon footprint tracking systems with their basic frameworks and features. Our main focus is to make people aware of how their basic actions-such as driving cars and reckless production of goods, can have an irreversible environmental impact. This will assist people in making informed decisions and contribute to a sustainable future. We also aim to gamify our app/website's interface, enabling a user-friendly experience and increasing the number of users. For the hardware part of the solution, we use a recycled plastic outer casing, contributing to our goal not only in thought- but in action.

Keywords: Carbon footprint, sustainability, digital tools, environmental impact..

1 Introduction

Climate change is one of the biggest challenges of our time. With the ozone layer depleting, arctic glaciers melting, and our generation's awareness of climate change decreasing, tracking carbon emissions is essential to comprehend the environmental impact associated with our activities. Climate change not only influences the environment, but it indirectly has an affect on us as a society. As carbon emissions accumulate in the atmosphere, they trap heat and contribute to global warming. This leads to rising temperatures and altered weather patterns. Frequent and severe weather events are inevitable, devastating communities and entire ecosystems.

Additionally, increased carbon emissions are a major factor in air pollution, posing health risks to populations, particularly in urban areas. Poor air quality is linked with acute respiratory diseases, affecting vulnerable groups and increasing the mortality rate.

The economic impact is also significant. Climate change disrupts agriculture, damages infrastructure, and therefore increases disaster recovery costs. With India being a developing country, people below the poverty line- such as farmers and daily wage laborers are impacted heavily due to the unsupervised emissions of carbon. Furthermore, as ecosystems are stressed, loss of biodiversity accelerates, threatening species extinction and destabilized food chains.

The topic of tackling carbon emissions is one broad notion. Our main aim is to spread awareness among people, especially older generations, on how their indiscriminate use of vehicles and fuel has an irreversible and negative impact on the environment. To tackle any problem, the first step is for the public to understand it's use and the root of the problem. People may argue that the older generations are usually more aware and responsible when it comes to the use of resources, but there is a monetary drive behind it. We want to convert this fiscal drive to save money and resources to a mindful and responsible one.

By systematic measurement of these emissions, stakeholders are able to make knowledgeable choices, pinpoint opportunities for enhancement, and implement effective reduction strategies. This data not only promotes accountability but also drives the transition towards sustainable practices, contributing to broader efforts to combat climate change.

These issues are too intricate to be addressed by a basic app or website. The severity of carbon emissions is often underestimated by people around the world. Utilizing our tracker is the initial step toward achieving a sustainable future. By raising awareness about the impact of individual actions on the environment and society, we can foster a sense of responsibility that encourages sustainable practices. This might be the beginning of a movement to undo the damage and harm humans have done to the environment and the planet.

This document offers a comprehensive overview insight into the thinking, materials required, insights, procedure, functioning, and the final goal of our project. The primary objective of carbon footprint tracking is to quantify and monitor the emission of greenhouse gases produced by individuals, to identify problems in the current way of usage and to provide goals and targets to promote sustainable development in the future.

2. Literature review

The global effort to combat climate change has initiated the development of tools to measure and reduce carbon emissions. Among these, carbon footprint calculators have emerged as accessible and educational resources for individuals and organizations alike.

Ann Marie Ajufo and Girish (2021) explained in their research paper how transportation serves as a significant factor in global environmental challenges, releasing millions of tons of harmful gases into the atmosphere every year. This rise in transportation usage has led to significant environmental problems, including the thinning of the ozone layer, the pollution of the air, and, most critically, the rise in global temperatures and shifts in climate patterns. Among all transportation modes, road transportation is particularly damaging, emitting large amounts of greenhouse gases directly into the atmosphere. These emissions are expected to grow substantially over time. To address this issue, tracking and monitoring transportation-based emissions is important to reduce greenhouse gas emissions worldwide. Carbon footprint calculators are a useful tool for this purpose. However, most existing calculators either focus broadly on emissions or require tedious manual input, making them less appealing for regular use. To bridge this gap, the authors introduced TCTracker, a mobile app/website designed to automate carbon footprint tracking specifically for personal transportation. This app/website leverages GPS functionality and built-in AI features to simplify the process. The study assessed the tool's acceptance using the Technology Acceptance Model (TAM), involving 40 users who evaluated four key factors: convenience, usefulness, perceived enjoyment, and intent to use. The findings revealed that convenience and perceived usefulness received the highest ratings, demonstrating not only the acceptance of the tool but also its potential to sustain user interest in tracking carbon footprints. By making the process simpler and more effective, TCTracker shows promise as a valuable solution for encouraging environmentally conscious behavior in transportation.

Annada Dash, Piyusha Patel (et.al 2024) wrote in their research, climate change is a major threat to our planet, and individual carbon footprints play a big part in the crisis. Although more people are growing to become aware of the problem, many still find it hard to track and decrease their impact on the environment because the tools available are often complicated or inaccessible. To address this gap, the researchers introduced EcoTrack, a user-friendly mobile app/website designed to help individuals monitor and reduce their carbon footprint. Unlike most tools, EcoTrack provides a comprehensive solution by tracking daily activities like travel, food consumption, and app/website usage. The app/website includes a carbon footprint calculator, a visual tracker to monitor progress, and a chatbot offering personalized advice for leading a more sustainable lifestyle. What makes EcoTrack stand out is its focus on education and motivation. It offers a resource page filled with practical tips and information about sustainability, along with a rewards system to encourage users to adopt eco-friendly habits. By integrating AI-powered recommendations and a user-centered design, the app/website doesn't just help people understand their impact—it actively inspires long-term behavior change. During initial testing, EcoTrack showed great potential to raise awareness and motivate users to make greener choices in their everyday lives. With its simple design and engaging features, the app/website brings sustainable living within reach, empowering individuals to take meaningful steps toward a healthier planet.

As John Mulrow, Katherine Machaj, and Sybil Derrible (et.al 2019) explained in their research paper, "The carbon footprint has become a widely used concept for communicating both the causes of climate change and the many opportunities to reduce greenhouse gas emissions". Many organizations have created online carbon footprint calculators, often with a great deal of input categories and user customization. This study critically examines the state of online carbon footprint calculators that target the individual through carbon emissions. This online carbon footprint calculator gives how much amount of carbon emissions are occurring. This calculator was made with the use of guidance from the footprint calculator literature and reviews of common calculator features and architecture concerning their interactions with online carbon footprint calculators. By comparing and conducting surveys, the most essential carbon calculator features are home energy and transportation input, explanations for flight categories, advice for lowering emissions, and to have emission values shown for each category calculated. Through these findings and the development of the radar plots, the best examples of carbon calculators studied are Carbon Footprint Ltd., Carbon Independent, and Cool Climate Network. In this context, calculators could easily move beyond simply calculating carbon emissions, combining measurement of economic, social and environmental metrics.

Shaoqing Shi, Jianhua Yin (2021) explain about how global crises and extreme climate events have appeared to become major hurdles for countries' socio-economic development. It has become imperative to identify feasible scientific carbon emission measuring tools that aim to ensure sustainable development. It is also helpful for scholars to connect different levels of carbon consumption with a unified theme so that their research has a common reference basis. The advantages of carbon footprint tracking support the adoption of unified goals and encourage stakeholders to make informed decisions, therefore necessitating the need to review and categorize carbon emissions. This study reviews the development of carbon footprint research based on bibliometrics and knowledge maps.

After nearly 30 years of development, carbon footprint research has achieved results in many fields. This improvement has also resulted in cooperation on the global level. These fair and reasonable mechanisms have claimed that

'CLIMATE BENEFITS' are highly expected. On the other hand, unbalanced development between regions and countries is a major problem for current carbon footprint research. Climate change is a common enemy to mankind and measures must be adopted by the human race as a whole to negate the negative impacts of it. The writers provide solutions for the improvement of international mechanisms such as 'THE PARIS AGREEMENT' and extensive international cooperation amidst developed and developing countries and within developing countries.

Annada Dash and Piyusha Patel (et.al 2024) emphasized the need for a user-friendly interface for the app/website. Their methods of research and implementation resonate closely with our ideas and aims.

3. Methodology

3.1 The Idea

Our research included various approaches, including the use of the internet and one-to-one interactions, providing us with an overall analysis of the problem statement. We understood the basic operations a carbon footprint tracker must perform, its effectiveness, and how user-friendly interfaces are the major incorporations in successful carbon footprint trackers. The negative effects of climate change and increasing carbon emissions also played a major role in our choice to take it up as our project, and it is a small role we would like to play towards a sustainable future.

3.2 What?

Climate change is a great challenge for our time, with the carbon footprint playing an important role in this global crisis. The carbon footprint refers to the total emissions by greenhouses, primarily carbon dioxide (CO₂) and methane (CH₄), released from human activities such as driving cars, heating homes, and manufacturing goods. As these emissions continue to rise, they accumulate in the atmosphere, trapping heat and disrupting the planet's natural balance. Urgent action is needed to mitigate these effects and transition to sustainable practices.

3.3. So What?

The first step of our implementation was identifying the results of carbon emissions on our surroundings. We identified three main consequences, the first being increased levels of global warming. Although this is a problem that the whole world faces, it is often ignored. The second major impact is the disruption of ecosystems. Due to high amounts of carbon being emitted in the atmosphere, entire ecosystems are disturbed from the base up. This has adverse effects on the ecological balance of the planet, indirectly affecting us as a human society. The third impact was climate change, and although all three impacts are interconnected, they have different causes and results, all pointing to imminent danger for future generations.

3.4. NOW WHAT?

We aim to develop an app/website that is easy to use with a user-friendly interface so that people are encouraged to measure their carbon footprint and make informed decisions. This may seem to be of no use, but once a person knows how their actions impact the environment, it drives them to make small changes in their approach.

3.5. COMPONENTS

- ESP-32, to measure CO₂ emissions in urban areas.
- Jumper wires are used to connect remote electric circuits.
- Breadboard, is utilized to build temporary circuits.
- Li-ion battery, power source
- Battery holder
- Resistors
- DHT-11, digital temperature & humidity sensor.
- CCS-811, measures the CO₂ & TVOC (Total volatile organic compounds).
- Pushbuttons
- Led lights

3.6. DECISION MATRIX

We coordinated our ideas with 4 categories, complexity, efficiency, and potential shown in table.1. We then proceeded to rank each of our ideas on basis of the scores awarded for them. On this basis, user-friendly interfaces ranked in the top spot. The decision matrix was based on the ideas provided by each of our team members. We decided on incorporating all 4 ideas in our project to maximize efficiency and minimize waste.

Table.1 Decision matrix

3.7. Sketches

Criteria	Maximum score	1. Recycled plastic	2. User friendly interfaces.	3. Carbon-free daily routine tips	4. Gamification
Cost	5	3	2	2	2
Complexity	5	4	5	4	5
Efficiency	5	4	5	4	4
Potential	5	5	5	5	5
Score:	100	80	85	75	80

We then proceeded to make sketches by hand based on our ideas. These sketches are a basic idea of what we think our final prototype will look like how we planned to execute it with basic knowledge and minimal experience. Our first idea (Fig.1) was to use a recycled plastic outer casing to minimize environmental waste and play a part in sustainable development. Although it may not make a huge change in the measure of waste generated on the global level, it's a small part that we would like to play towards a greener future.

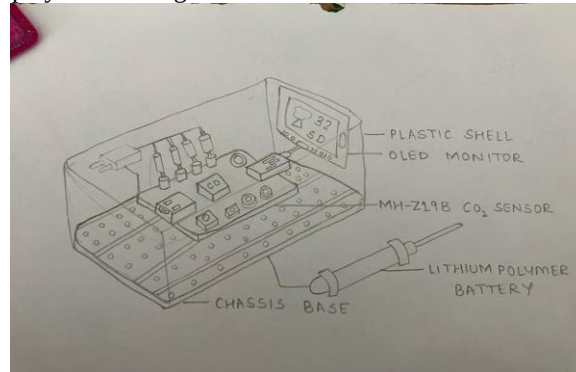


Fig.1 IDEA 1-Recycled plastic outer casing

Our second idea (Fig.2) was to make our app/website user-friendly. We wanted to tackle the problem of boring interfaces by incorporating a graphical representation and questionnaires that would encourage users to use our app/website.

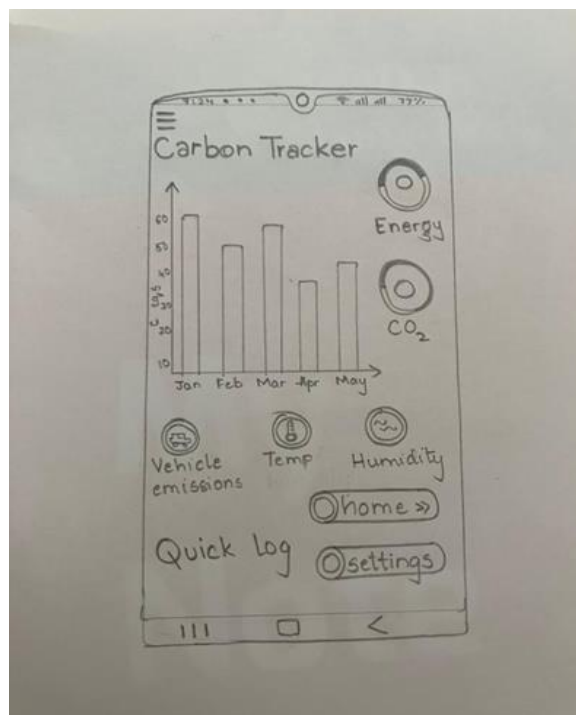


Fig.2 IDEA 2-User friendly interfaces

The third idea (Fig.3) was to provide personalized tips to the user on recommendations to reduce their carbon emissions. These tips are tailored to each user on the basis readings provided by them and help them to become more aware of their legacy to the environment. These tips give the user a roadmap to reduce their impact on their surroundings.

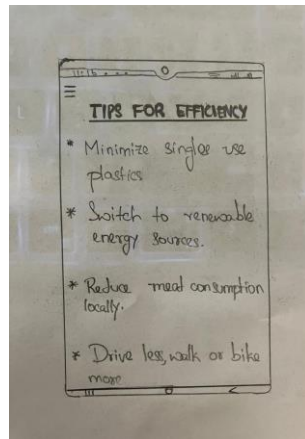


Fig.3 IDEA 3- Carbon-free daily routine tips

The fourth idea(Fig.4) included using references from apps like Duolingo, to gamify the interface and make it easy to navigate, with leaderboards and extra points to invite friends.

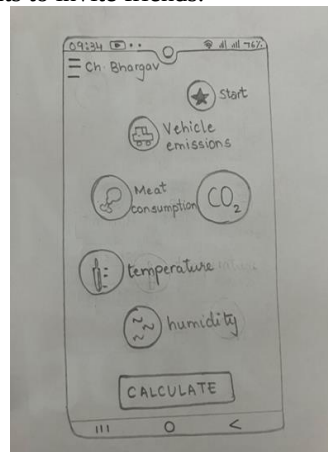


Fig.4 IDEA 4-Gamification

We finally decided make use of a combination of Idea 1 and Idea 4 to construct our final prototype(Fig.5). A tracker with a recycled plastic casing, programmed with an app/website which will be gamified with various aspects such as leaderboards that will encourage users to be constantly aware of their emissions. This device is aimed to be portable, so that the user can measure carbon emissions in chosen places, such as homes as well as the environment.

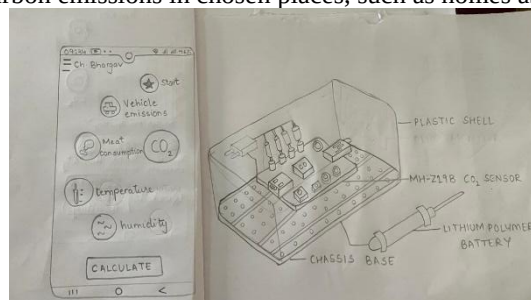


Fig.5 Final Prototype Sketch

4. Results and Discussion

The Carbon Footprint Tracker (Fig.6) works with a website, calculating and estimating the amount of carbon emissions produced by the individual. It empowers people to make decisions while keeping the environment in mind, leading to a smoother transition towards a sustainable future. We are currently working on the development of our website and its integrated use with our sensor. Our recent developments include the formation of a basic interface and we aim to be able to use the software seamlessly with the hardware part.

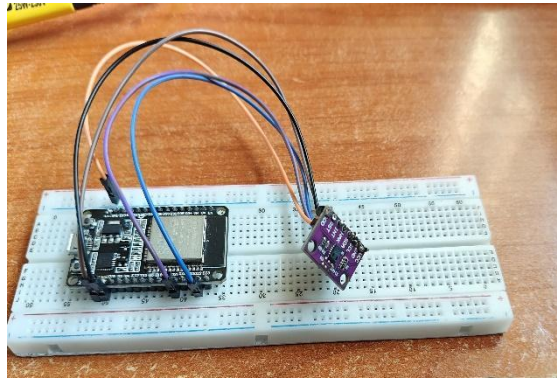


Fig.6 Final prototype

The tracker contains an ESP 32 to measure CO2 emissions and a CCS 811 tracker. These are programmed using the Arduino software. The software continuously reads data from the sensor and provides near accurate readings.

- An Automated Personal Carbon Footprint Calculator for Estimating Carbon Emissions from Transportation Use

By Ann Marie Ajufo and Girish Bekaroo

- EcoTrack-A Mobile Application for Real-Time Carbon Footprint Tracking and Sustainable Living

By Annada Dash and Piyusha Patil

- Global research on carbon footprint: A scientometric review

By Shaoqing Shi, Jianhua Yin

- The state of carbon footprint calculators: An evaluation of calculator design and user interaction features

By John Mulrow, Katherine Machaj, Joshua Deanes,

Sybil Derrible

We aim to develop a fully functional app or website and add more sensors to make the tracking efficient and accurate. We also aim to improve the code and the interface by using advanced programming languages. The use of sensors helps the user to get accurate readings to calibrate user experience.

5. Conclusion

The transition towards sustainable living is inevitable. One small step can have a huge impact on the perceived notions of climate change globally. We hope that our legacy towards a greener planet resonates with people, leading to a global trend to 'GO GREEN'.

The use of the app/website not only gives an estimate of the carbon footprint, but it also invokes a sense of responsibility in the minds of people. When future generations grow in an environment where people actually care about the planet, sustainability is a by-product. The bigger impact of the product is one that influences people globally.

The Carbon Footprint tracker is an intuitive app/website that helps users measure and reduce their carbon emissions. It tracks daily activities like transport, energy use and consumption, providing real-time data and personalized insights. With actionable recommendations and progress tracking, it empowers users to set sustainability goals and make eco-friendly life choices.

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Evaluation of User Acceptance In Public Service Application Using Combination of UTAUT and Privacy Calculus Theory

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Abstract— This study aims to further explore the Unified Theory of Acceptance and Use of Technology (UTAUT) extended with the privacy calculus model while incorporating the role of government regulations to evaluate the acceptance of Identitas Kependudukan Digital (IKD) applications as a public service application. Various previous studies have explored the integration of the UTAUT construct with privacy calculus models; however, only a few have incorporated government regulatory constructs into existing frameworks. The results of the study, which employed a quantitative method, and involved 417 respondents and applied the partial least squares structural equation modeling (PLS-SEM) technique, highlight significant findings, concluding that the constructs of Performance Expectancy, Social Influence, and Government Regulation have a significant positive influence on Behavioral Intention. On the other hand, the key factors inhibiting the intention to use the IKD application are Perceived Risk and Privacy Concern. Notably, the social influence factor played a significant role, which not only enhanced the level of trust, but also encouraged the use of IKD application.

Keywords— Public Service, Digital Identity, UTAUT, Privacy Calculus, e-Government, Digitalization

I. INTRODUCTION

Technology has been able to change how governments interact with society by providing opportunities for more efficient and transparent services. The adoption of e-government and digital transformation has been carried out as an effort by the government to meet the demands for better services. In Indonesia, this has been regulated in various ways, the latest of which is through Presidential Regulation Number 82 of 2023. One of the objectives of government regulation is to accelerate the digital transformation process to realize a high-performance public service bureaucracy and strengthen the aspects of cybersecurity and information security. In addition to regulating integration and interoperability for the integration of national digital services, the regulation also regulates various prioritized public application services that are prioritized [1].

One of the priority applications outlined in residential regulations is digital population administration services. In connection with this, the government launched an innovation program in the form of a mobile application called Identitas Kependudukan Digital (IKD). The IKD can later be a means for residents to prove their identity online, especially when they are going to access various services that require identity, both government and private [2].

In general, an IKD is an application that contains electronic information to represent civil administration documents and reverse data that displays personal data as the identity concerned electronically. The IKD can also act as a digital wallet [3], which can contain several other population and civil documents, as stipulated in Article 17 of Permendagri No. 72 of 2022, including resident biodata, family cards, population certificates, civil registration documents, and other documents, as stipulated by the provisions of laws and regulations. This digital identity can later be a means for residents to prove their iden-

tity online, especially when accessing various services that require both government and private identity [2].

Based on data from February 22, 2024, the number of activations reached 8,186,961 inhabitants since it was first launched in 2022. The number of activations is quite low compared to the total of 202,851,038 residents who have been eligible to activate the IKD [3].

This study aims to gain further insight into the factors influencing public acceptance, identify the challenges faced by the community, and determine the elements that can promote the adoption of the technology, including factors related to data privacy, as this application stores personal information. Issues of trust, security, and privacy have been identified as primary obstacles to successful integration, interoperability, and information sharing in the implementation of e-government[4].

II. BACKGROUND THEORY

This study used the Unified Theory of Acceptance and Use of Technology (UTAUT) combined with the elements of Privacy Calculus as its model.

A. Unified Theory of Acceptance and Use of Technology (UTAUT)

The Unified Theory of Acceptance and Use of Technology (UTAUT) proposed by Venkatesh combines the main principles of 8 (eight) pre-existing technology acceptance methods: the Theory of Reasoned Action (TPA), Social Cognitive Theory, Technology Acceptance Model (TAM), Theory of Planned Behavior (TPB), Model of PC Utilization, Motivational Model, Innovation Diffusion Theory and CTAM-TPB Research Model [5].

UTAUT is useful for understanding how technology can be accepted in the context of public services by looking at 4 (four) main constructs in the acceptance of technology. The four main constructs of this model are performance expectancy, effort expectancy, social influence, and facilitating condition[5]. In general, there are open opportunities to connect UTAUT with e-government services [6] by providing a framework for evaluating the factors influencing the adoption of technology [5].

B. Privacy Calculus Theory

Privacy Calculus Theory is a theoretical framework that attempts to explain how individuals consider the benefits and risks associated with disclosing or providing their personal information. This theory assumes that individuals make rational decisions based on their perception of the benefits derived from disclosing personal information [7].

Privacy calculus shows that citizens' intentions to use services are influenced by considerations (calculations) of perceived benefits and privacy risks [7]. Theoretically, the construction of the privacy calculus builder consists of perceived risk, risk reference, benefit reference, perceived benefits, probability of the risk, and perceived privacy risk, which are factors that play an important role in every case that requires the active role of the community in the use of e-government services [8].

The privacy calculus approach has been widely used to examine privacy-related relationships. Other research also revealed that the privacy factor has a significant effect on user acceptance of technology [9]. This model is expected to provide recommendations to relevant stakeholders to increase the use and public acceptance of IKD applications.

This study also involved government policy and regulatory variables. Several studies have revealed a significant influence of privacy settings and policies on consumer convenience and consumers' desire to share personal information [10]. Several other studies on the relationship between government regulations, especially privacy regulations, have had a significant impact [11]. For example, regulations have also increased the desire to use and adopt mobile banking applications in China [12].

III. METHODOLOGY

The methodology used in this study is shown in Figure 1, and the variables are defined in Table 1.

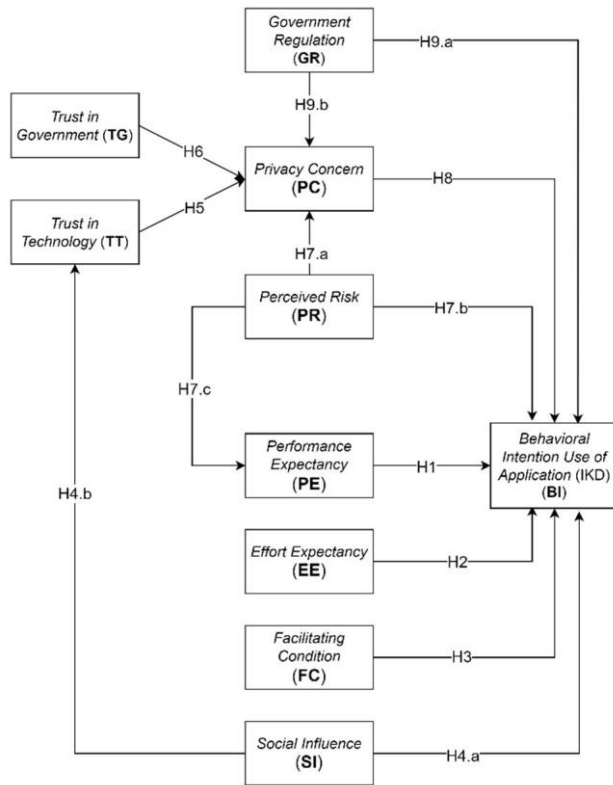


Fig 1. Research Methodology

TABLE I. VARIABLE DEFINITION

Variable	Definition	Reference
Performance Expectancy	The belief is that individuals/communities benefit from using the application of this technology such as through convenience and fast service process.	[5], [13], [14], [15]
Effort Expectancy	Individual/community beliefs or perceptions influence how easily they adopt and use technology applications.	[5], [13], [14], [15]
Facilitating Condition	Individuals' beliefs/perceptions about the ease of access, availability of resources, infrastructure, and technical assistance, influence decisions to use/adopt technology.	[5], [13], [14]
Social Influence	Individuals' beliefs/perceptions that the social environment	[5], [13], [14], [15]

	(community, friends, family) can influence decisions in using technology.	
Trust in Government	Beliefs/perceptions of individuals/communities towards the government or regulators.	[7], [13], [14], [15]
Trust in Technology	Individual/community trust in the technology used.	[13], [14], [15]
Privacy Concern	Individuals' belief in the possibility of loss of privacy due to the disclosure of personal data.	[13], [14], [15]
Perceived Risk	Individual confidence in the existence of problems or risks that will arise due to the disclosure of personal data.	[13], [14], [15]
Government Regulation	Individuals believe that there are policies and regulations in place to protect and control user security and privacy.	[11], [12]
Behavioral Intention Use of Application	Belief or desire to use a technological system or application.	[5]

A. Hypothesis

The hypotheses of this study were as follows:

- UTAUT
- H1: Performance expectancy is positively correlated with behavioral intention.
- H2: Effort expectancy is positively correlated with behavioral intention.
- H3: Facilitating conditions are positively correlated with behavioral intentions.
- H4a: Social influence positively correlates with behavioral intention
- H4b: Social influence is positively correlated with behavioral intention.
- Privacy Calculus Theory
- H5: Trust in technology reduces privacy concern related to behavioral intentions.
- H6: Trust in government reduces privacy concern related to behavioral intention
- H7a: Perceived risk positively correlates with the variable of privacy concern
- H7b: Perceived risk negatively correlated with behavioral intention variables
- H7c: Perceived risk negatively correlated with performance expectancy variables
- H8: Privacy concern have a negative influence on behavioral intention
- H9a: Government regulation has a positive influence on behavioral intention
- H9b: Government regulation has a negative influence on privacy concern

B. Data Preparation

The data collection mechanism uses a questionnaire with an instrument adopted from previous research [11], [12], [13], [14], [15] to test the hypothesis using a Likert scale of 5 (five) points.

Furthermore, in determining the number of samples to be used in the study, it refers to several factors: (i) the total budget required for the survey, (ii) the cost of a single unit survey, and the taking of all necessary measurements, and (iii) the accuracy required to draw key conclusions from the survey data [16].

Given the unknown distribution of users and to overcome the challenge of budget constraints, this study uses a cluster sampling method using provincial clusters to ensure diverse geographical representations. Cluster sampling is an effective method for managing surveys in large and dispersed populations [17].

The criteria for respondents to be used as samples in this study are as follows: a) Indonesian citizens who have activated an IKD application; b) age 18 – 50 years; c) have a gadget/smartphone.

C. Data Processing Methods

In this study, both validity and reliability tests were conducted. The validity test included two main types: convergent validity and discriminatory validity. Convergent validity was assessed using two coefficients: Composite Reliability (CR) and Average Variance Extracted (AVE).

For convergent validity, the loading factor of each indicator is associated with the latent variable (LV). In general, a loading factor is considered valid if it exceeds the limit of 0.7. If there is a loading factor below 0.4, the item does not need to be used, and if the item has a loading factor between 0.4-0.7, then the removal of the item can be done if it improves the CR and AVE above the threshold. Additionally, the AVE of the latent variable must be greater than 0.5 to be considered valid [13].

Furthermore, it is necessary to conduct a discrimination validity test to analyze whether each construct is different from other constructions [14]. To test the validity of discrimination in evaluating the relationships between constructs in structural models, cross-loadings, the heterotrait-monotrait ratio of correlations (HTMT), the ratios, and the Fornell–Larcker criterion can be used [14].

The last stage is to conduct a hypothesis test to determine whether the hypothesis can be declared accepted by conducting an Inner Model Fit Evaluation by running several stages of testing, namely, the coefficient of determination (R²) and path coefficients [18].

The R-square (R²) value is used to measure how much variation in the dependent variable can be explained by the independent variable, with an R² value above 0.100 [19]. In addition to the R² value, it is important to consider the significance of the path coefficient in the model [18].

Each path coefficient refers to a hypothesis. Each hypothesis is tested by calculating the P-value, which correlates with the path of the coefficient; if the P-value is below a certain threshold of 0.5, then it is assumed that the hypothesis is acceptable, and vice versa [20].

In this research, data processing will be carried out using Structural Equation Modeling (SEM) with partial least squares (PLS-SEM). Data analysis will use the SmartPLS 4 application.

IV. RESULT AND DISCUSSIONS

This study included 417 respondents from six provinces in Indonesia. The data was collected using a third-party online survey company with a cluster random survey. Table II shows that each indicator had an outer loading value greater than 0.7, which was derived from the PLS-SEM algorithm, confirming adequate indicator reliability in the measurement model. Additionally, the AVE values in Table II were all greater than 0.5, indicating sufficient convergent validity. [21].

Subsequently, internal consistency testing was conducted by examining the Cronbach's alpha and composite reliability values. Reliability assessment is based on a composite reliability value greater than 0.7 and a Cronbach's alpha value greater than 0.6 [21]. According to Table II, all composite reliability values exceeded 0.8, and the Cronbach's alpha values were above 0.7. Thus, all variables in this study were deemed reliable.

Furthermore, based on Table III, the square root of AVE for each dimension shows the highest value for its corresponding construct, indicating that the model meets discriminant validity according to the Fornell-Larcker criterion. Even though some correlations are negative, discriminant validity is still satisfied as long as the square root of AVE is greater than the absolute value of the correlation.

TABLE II. CONSTRUCT RELIABILITY AND VALIDITY

Var	Item	Outer Loading	CA	CR	AVE
BI	BI1 There is an intention to use the IKD Application in the future	0.903	0.892	0.933	0.823
	BI2 There is a desire to try the IKD application	0.916			
	BI3 There is an intention to recommend to other parties about the IKD application	0.902			
EE	EE1 The IKD activation process is easy	0.879	0.844	0.906	0.763
	EE2 IKD features are easy to understand and use	0.884			
	EE3 The IKD installation process is simple	0.856			
FC	FC1 There is adequate technical support available	0.871	0.856	0.912	0.776
	FC2 The IKD application has the necessary resources	0.901			
	FC3 The use of IKD is quick and easily accessible	0.872			
GR	GR1 The government has regulations and policies related to privacy	0.796	0.813	0.890	0.729
	GR2 The regulations are sufficient to protect IKD users from potential issues that may arise.	0.895			
	GR3 The government has an effective mechanism for monitoring privacy violations	0.868			
PC	PC1 There is a risk of data being misused by parties with access to the data sources	0.862	0.789	0.876	0.703
	PC2 There are concerns about data breaches	0.870			
	PC3 There is a risk of data alteration without the data owner's consent	0.781			
PE	PE1 The use of IKD can make the population service process faster	0.874	0.847	0.907	0.765
	PE2 The IKD application allows population services without the need for physical documents	0.860			
	PE3 The IKD application facilitates the storage of population data	0.889			
PR	PR1 Using IKD may result in a loss of control (edit, delete, insert) of personal data	0.831	0.756	0.860	0.672
	PR2 There are potential negative effects associated with using IKD	0.831			
	PR3 There is a vulnerability when using IKD (if the device is lost, etc.)	0.797			
SI	SI1 The use of IKD is influenced by factors of the social environment (family, friends, etc)	0.814	0.803	0.884	0.718
	SI2 The community has carried out the use of IKD at large	0.864			
	SI3 The government encourages the use of IKD	0.863			
TG	TG1 IKD is a reliable solution for good population services launched by the government	0.900	0.828	0.897	0.744
	TG2 If issues arise, the government will assist IKD users	0.878			
	TG3 The government will not misuse personal data	0.807			
TT	TT1 IKD has a good level of data security	0.913	0.889	0.931	0.819
	TT2 IKD has a reliable technology infrastructure	0.928			
	TT3 IKD is an application that is capable of processing data transactions quickly	0.874			

TABLE III. FORNELL-LARCKER CRITERION

	BI	EE	FC	GR	PC	PE	PR	SI	TG	TT
BI	0.897									
EE	0.660	0.873								
FC	0.662	0.732	0.881							
GR	0.583	0.545	0.549	0.854						
PC	-0.580	-0.382	-0.371	-0.418	0.839					
PE	0.648	0.722	0.714	0.523	-0.386	0.875				
PR	-0.565	-0.433	-0.429	-0.411	0.521	-0.394	0.820			
SI	0.754	0.635	0.661	0.559	-0.585	0.631	-0.509	0.841		
TG	0.515	0.518	0.541	0.479	-0.341	0.548	-0.344	0.555	0.863	
TT	0.496	0.496	0.533	0.484	-0.374	0.487	-0.378	0.515	0.734	0.905

TABLE IV. HETEROTRAIT-

	HETEROTRAIT (HTMT)									
	BI	EE	FC	GR	PC	PE	PR	SI	TG	TT
BI										
EE	0.767									
FC	0.763	0.861								
GR	0.688	0.658	0.658							
PC	0.688	0.465	0.451	0.517						
PE	0.749	0.852	0.836	0.630	0.469					
PR	0.692	0.541	0.533	0.523	0.677	0.490				
SI	0.900	0.776	0.800	0.691	0.735	0.765	0.654			
TG	0.603	0.620	0.643	0.591	0.413	0.649	0.442	0.680		
TT	0.560	0.571	0.608	0.568	0.443	0.562	0.463	0.610	0.862	



Additionally, to ensure the validity of discrimination, as shown in the results of the Heterotrait-Monotrait Ratio (HTM) analysis in Table IV, the majority of the construction pairs were below the threshold of 0.90 [21]. This indicated that the construction of these constructs had sufficient discriminatory validity. This result provides a level of confidence that each variable is measured to ensure that each construct is different from the rest of the construct in the model so that each variable represents a unique concept.

TABLE V. R-SQUARED (R^2)

	R^2	R^2_{adjusted}
BI	0.691	0.685
PC	0.335	0.328
PE	0.156	0.153
TT	0.265	0.264

Furthermore, in the evaluation of the R-squared value, the R-squared value (R^2) is used to assess the influence of certain independent variables on dependent variables. There are three categories of grouping on the R^2 value, namely 0.75, 0.50, and 0.25, which are categorized as strong, moderate, and weak, respectively.

The results based on Table V show that the research model has a good ability to explain the Behavioral Intention (BI) variable, with an R^2 value of 0.691 and an adjusted R^2 of 0.685. This indicates that approximately 69.1% of the variance in Behavioral Intention can be explained by independent variables, such as Performance Expectancy (PE), Effort Expectancy (EE), Facilitating Condition (FC), Social Influence (SI), Privacy Concern (PC), Perceived Risk (PR), and Government Regulation (GR).

TABLE VI. DIRECT EFFECT EVALUATION

	Original Sample (O)	T Statistics (O/STDEV)	P Values
EE -> BI	0.124	2.183	0.015
FC -> BI	0.110	1.810	0.035
GR -> BI	0.097	2.308	0.011
GR -> PC	-0.187	3.197	0.001
PC -> BI	-0.148	4.189	0.000
PE -> BI	0.117	2.182	0.015
PR -> BI	-0.139	4.430	0.000
PR -> PC	0.390	9.604	0.000
PR -> PE	-0.394	8.820	0.000
SI -> BI	0.317	6.962	0.000
SI -> TT	0.515	10.245	0.000
TG -> PC	-0.037	0.571	0.284
TT -> PC	-0.108	1.492	0.068

Based on the results of the analysis in Table VI, it can be observed that the UTAUT model shows that Performance Expectancy (PE) has a significant positive influence on Behavioral Intention (BI) with a coefficient

of 0.117. This indicates that the higher the user's expectations of the performance of the system or technology, the greater is their intention to use it. This relationship is supported by a T-statistic of 2.182 and P-value of 0.015, which indicates significance (H1). Effort Expectancy (EE) also had a positive influence on Behavioral Intention, with a coefficient of 0.124, indicating that ease of use of technology contributed to an increase in user intention to use it (H2). This relationship was statistically significant, with a T-statistic of 2.183 and a P-value of 0.015. These results are consistent with those of previous studies in which Performance Expectancy (PE) and Effort Expectancy (EE) have a significant impact on Behavioral Intention (BI) [13], [14]

In addition, the Facilitating Condition (FC), which reflects the availability of resources or support to use technology, showed a positive influence on Behavioral Intention, with a coefficient of 0.110, T-statistic of 1.810, and P-value of 0.035 (H3). The results of this study are slightly different from those of previous studies [13], [14], where Facilitating Condition (FC) does not have a significant impact.

Meanwhile, Social Influence (SI) has a greater impact on Behavioral Intention, with a coefficient of 0.317. T-statistic of 6.962 and a P-value of 0.000 show a very significant relationship (H4). This is in line with the results of previous studies [13] although other studies have shown different results [14]. This suggests that influences from a social environment or group, such as friends or colleagues, significantly encourage user intent to use the technology.

In addition, related to privacy calculus, which has an impact on behavioral intentions, Social Influence also has a very strong influence on trust (TT), with a coefficient of 0.515, T-statistic 10.245, and P-value 0.000 (H4b). This shows that people are more likely to trust the IKD application if there are people closest to them who have used the IKD application. These results are in line with previous research showing that social factors play an important and critical role in building trust in technology [13], [14].

Moreover, the influence of Trust in Technology (TT) on Privacy Concern (PC) was slightly negative, with a coefficient of -0.108, T-statistic 1.492, and P-value of 0.068, which showed a relationship close to significant but not strong enough (H5). The influence of Trust in Government (TG) on Privacy Concern was also slightly negative, with a coefficient of -0.037, T-statistic 0.571, and P-value 0.284, which means it was not statistically significant (H6). Although the relationship is generally negative, this result is slightly different from those of previous studies [15] where Trust in Technology and Trust in Government have a significant impact on Privacy Concern.

In contrast, Perceived Risk (PR) has a very significant positive influence on Privacy Concern, with a coefficient of 0.390, T-statistic 9.604, and P-value 0.000. This shows that the higher the risk perception, the greater is the user's concern for privacy (H7a). These results are quite consistent with previous studies [13], [14]. This reflects that the perception of high privacy risks may increase concerns about the potential misuse of personal data.

Perceived Risk also had a significant negative influence on Behavioral Intention, with a coefficient of -0.139, T-statistic 4.430, and P-value 0.000, indicating that perceived risk can reduce users' intention to use technology (H7b). Previous research [13], [14] has explored the relationship between Perceived Risk and Actual Use Behavior. Similarly, this current study extends those findings by supporting the negative influence of Behavioral Intention.

In addition, Perceived Risk negatively impacted Performance Expectancy, with a coefficient of -0.394, having a T-statistic of 8.820, remained statistically significant, with a P-value of 0.000 (H7c). This result is also in line with previous research [13], [14], where the public may override the risk aspect if they perceive the convenience and usability of the IKD application, making the privacy aspect seem less important.

Privacy Concern (PC) itself has a significant negative influence on Behavioral Intention, with a coefficient of 0.148, T-statistic 4.189, and p-value 0.000. This suggests that users' concerns about privacy can lower

their intention to use technology (H8). These results strongly support those of previous studies [15], which showed a significant negative correlation with Behavioral Intention. Because IKD stores highly sensitive personal data, the level of public concern about data misuse can affect people's desire to use IKD.

On the other hand, Government Regulation (GR) contributes positively to Behavioral Intention with a coefficient of 0.097, T-statistic 2,308, and P-value 0.011, which means that government regulation can increase users' intention to use technology (H9a). This result is in line with previous research in China [12] on the use of Mobile Banking Services. In this regard, good Government Regulation (GR), especially related to privacy, can increase the desire to use applications. This can also occur if the terms of use of the IKD application are regulated by clear Government Regulations.

In addition, Government Regulation also has a significant negative influence on Privacy Concerns, with a coefficient of -0.187, T-statistic 3.197, and P-value 0.001, indicating that the existence of good regulation can reduce users' concerns about privacy (H9b). This is in line with previous research [11] where travelers in the UK felt more protected by privacy regulations. Regarding IKD, the most likely reason is that people feel reassured as long as the government can issue good regulations to protect privacy.

V. CONCLUSIONS

One of the major limitations of this study is the potential for low-quality data resulting from the use of an online survey method. This approach carries the risk of respondents providing answers that may not accurately reflect their true opinions, potentially influenced by factors such as fatigue, lack of engagement, or insufficient understanding of the questions. To address this limitation, future research could adopt a mixed-methods approach by integrating quantitative surveys with qualitative techniques, such as in-depth interviews or observations. This would not only enhance data reliability but also provide deeper insights and a better understanding of the contextual factors surrounding privacy and technology acceptance.

Overall, these research shows that factors such as Performance Expectancy, Social influence, and Government Regulation significantly influence behavioral intention, while Perceived Risk and Privacy Concerns tend to be inhibitors. Trust has a weak and less significant impact on privacy concerns, but social influence plays an important role in building trust and driving user intent. These relationships highlight the complexity of understanding the factors that influence the use of technology, especially in the context of behavioral intentions and privacy concerns.

In future research, one notable finding that requires further exploration is the relatively insignificant level of trust -both in Technology and in Government- compared to Privacy Concern, as observed in this study. Additionally, researchers should examine the relationship between trust and regulations, which was not covered in this study. Specifically, it is important to investigate whether regulations influence trust levels, which in turn may impact the degree of Privacy Concern and Behavioral Intention.

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Diverse Search, Unified Strategy: Analyzing Seo Success Across Google, Bing, And Yahoo

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Abstract. In today's digital and dynamic landscape, mastering Search Engine Optimization (SEO) techniques is crucial for any business seeking online visibility and acquire organic traffic. Google holds the lions share in search engine market, but platforms like Yahoo, Bing also continue to attract millions of users. Each of these engines possess unique algorithms, ranking systems, and user bases. A comprehensive analysis of SEO strategies across major platforms, to achieve success on every platform and identifying unified strategies that can be applied across all platforms. The study employs a multi-methods approach, quantitative data analysis of search rankings, traffic patterns, and user behavior with qualitative insights from SEO experts. Quality content, keyword optimization, technical SEO factors are significant areas of investigation. This study reveals some engine specific preferences such as Bing's focus on social signals and Yahoo's preference for certain content types, there are also overachieving principles—like the importance of mobile-friendliness, page load speed—that are universally effective. This study also emphasizes on significance of emerging trends such as growing importance of voice search and AI-driven software, which are shaping the future of SEO across platforms.

Keywords: Search Engine Optimization, Website Traffic, Back linking.

1. Introduction

Search engine optimization (SEO) has become an indispensable component of digital marketing strategies in the contemporary online landscape. As businesses strive to increase their visibility and attract more users, understanding the intricacies of how search engines rank and display content is paramount. While Google commands the lion's share of the global search market, platforms like Bing and Yahoo continue to play a significant role, particularly in certain demographics and regions. Each search engine employs unique algorithms and ranking factors, presenting both opportunities and challenges for digital marketers aiming to optimize their online presence. Despite the dominance of Google, businesses cannot afford to overlook Bing and Yahoo, as these search engines collectively account for a substantial portion of the market. Ignoring these platforms can result in missed opportunities for traffic, conversions, and brand exposure. Furthermore, each search engine caters to different user behaviours and preferences, which means that a one-size-fits-all approach to SEO may not be effective. This research seeks to bridge the gap between platform-specific optimization and a unified approach to SEO. By conducting a comparative analysis of Google, Bing, and Yahoo, this study aims to uncover the distinct and overlapping strategies that drive SEO success across these platforms. Many existing studies provide valuable insights on platform specific approaches to enhance performance of a website's ranking, our study aims to find holistic methods that could be used for all the

search engines. We also discuss how some techniques work in some search engines but are not of the same significance in others.

2. Literature review

The study focuses on how Page Ranking Algorithms are used by search engines such as Google, Bing, Yahoo, MSN, and others to show users relevant websites. It examines the SEO performance of various search engines and describes SEO as a methodology used to improve website rankings. The advantages, restrictions, difficulties, and business uses of SEO are also covered in the study. The necessity of SEO for improving website exposure, the duration of SEO efforts, and the utilization of different technologies to help with SEO duties are all emphasized in the conclusion. It also emphasizes how important SEO has become for operating a successful online business in view of the vast and expanding internet user base.[1]

The role of SEO strategies in raising website ranks in search results is covered in the abstract. It emphasizes how new strategies are introduced by the internet's constant evolution, even while some SEO tactics remain constant. The goal of the study is to ascertain whether different SEO tactics actually improve website ranks and traffic by examining a particular website that was developed to evaluate these strategies. Testing and confirming results are part of their search process, and the last phase includes conclusions and suggestions for more action.[2]

With the rapid proliferation of websites and online technologies, the web has progressed from the early "document-based" online 1.0 to the "social and mobile" Web 2.0 and now to the "semantic" Web 3.0. Search engines are essential middlemen in the broad digital world, assisting users in finding information among the almost 2 billion websites that exist today. SEO professionals create techniques to raise site ranks since search engines are always improving search results through algorithmic refinement, but their standards are still unclear. By making adjustments to a website's look, code, and content, search engine optimization (SEO) seeks to increase user experience and visibility while also improving search engine rankings. In contrast to Black Hat SEO tactics, which seek to unethically manipulate search engine rankings, this paper focuses on White Hat SEO strategies, which support high-quality content and moral behavior.[3]

This study looks into how SEO techniques might be used to improve university websites. It focuses on optimizing elements including external links, page content, keyword placement, and website design. Because it is easily accessible and pertinent to the author's work, the School of Continuing Education at Ocean University of China is used as a case study in this study. The use of SEO strategies is described in full in the article, along with enhancements to header texts, titles, descriptions, and overall content in addition to keyword integration and structural changes to web pages. The study shows that the website saw enhanced visibility, better search engine ranks, and a stronger brand presence as a result of implementing these SEO tactics. Effective SEO techniques can greatly increase a website's visibility and add to its overall success, according to the report.[4]

This essay emphasizes how important search engine optimization (SEO) is for raising website ranks and increasing user page views. It covers fundamental SEO concepts and tactics as well as the several ways search engines optimize their results. The efficiency of several SEO techniques is compared throughout the study. The significance of cutting-edge SEO technology in improving user engagement and search engine performance is emphasized in the conclusion. Through an analysis of page ranking variables like content quality and link structure, the study

offers insights into how SEO may be used to increase website visibility and competition in the digital space.[5]

This paper investigates the ways in which regional geography and culture—specifically in Jordan—affect search engine rankings for websites. It investigates how utilizing social and cultural terms along with other regionally relevant keywords affects a website's visibility in Jordanian search engines like Google.jo. The research finds the most popular local keywords and examines how they affect website rankings. Search engine ranks for Arabic and English inquiries are greatly increased by incorporating culturally relevant terms, according to tests conducted on 45 Jordanian websites.[6]

What factors affect search engine rankings and how can web content authors increase the exposure of their sites are the two primary questions this course aims to answer. It highlights three essential SEO lessons: working with other content providers, including keywords into site content, and conducting keyword analysis with an eye toward competition and audience. The class places a strong emphasis on applying these concepts gradually and keeping up with changing search engine optimization techniques and algorithms. It recommends a phased strategy for SEO and provides case studies to back up the efficacy of these tactics. It does, however, caution that SEO is dynamic and that ongoing adaptation is required for long-term success due to factors including the expanding impact of social media and modifications to ranking algorithms.[7]

The "All in Title Query Result Analysis" method of SEO is a novel approach that this article presents. It helps find low-competition keywords that can rank well without requiring a lot of off-page treatment. The study shows, by examining 36 months of Google Analytics data, that keywords found using this method perform better than those recommended by well-known keyword programs. This method helps digital marketers get faster results and save money on off-site SEO, especially for startups. The results show that, although utilizing the "allintitle" operation to locate relevant keywords can be difficult at times, it frequently yields higher success rates when compared to alternative approaches.[8]

In order to better understand the factors that impact search engine optimization (SEO), this article employs a reverse engineering technique to analyze 200,000 web pages. It looks at components including HTML, URL structure, and PageRank based on the top 20 Google search results. According to the study, there are five essential SEO components that constantly affect website rankings. It is suggested that concentrating on these components is essential for successful SEO. In order to maintain steady performance in the face of algorithm changes, the article highlights the significance of giving user needs equal weight with search rankings. Subsequent investigations will examine supplementary SEO elements to augment website optimization.[9]

The importance of Search Engine Optimization (SEO) in boosting a business's online visibility and revenue is examined in this essay. It looks at SEO from a management standpoint, highlighting how important it is to getting top search engine ranks and boosting business profits. Given the surge in smartphone internet usage, the study—which is based on secondary data—highlights the significance of combining SEO with mobile marketing. It promotes Whitehat SEO techniques to raise the visibility and revenue of websites. The study comes to the conclusion that improved search engine results, more website traffic, and long-term business success all depend on efficient SEO, which includes keyword research and proper SEO techniques.[10] The paper gives an overview of SEO tactics and how they positively impact the websites' online traffic and exposure. It states that the goal of SEO is to improve a website's relevance to

user queries in order to push it up to the top of search results. The limits of usual search engine as it depends more in syntactical correctness rather than the user intent. The Semantic Web, which seeks to more precisely represent data using well-defined vocabularies, is also introduced in this work. Engine quality can be enhanced by things like query logs such as query sent, results clicked, and their rankings. The efficacy of engine is enhanced greatly. The PageRank algorithm has been modified to more precisely weight inbound links, and design principles have been used to organize the framework of the search application. The study highlights how crucial it is to examine user-query interactions in order to enhance search engine relevancy and performance.[11]

The inconvenience of choosing from a Meta-search engine. With growing volume of information availability, its essential that the queries of user are catered to properly. This author employs genetic algorithms to assess the “fitness” of search engine—its degree of relevance to user query. This aims to cut down the amount of time spent searching less relevance of search engines. The suggested algorithms perform better in terms of temporal complexity and yields faster when determining the most pertinent search engine. It's recommended that future research investigate various heuristic techniques for additional optimization and tackle temporal complexity problem.[12]

In rapidly expanding field of information technology, Search Engine Optimization plays a role of great significance. To improve website visibility, we can equip our website with content richness, website structure, backlink quality, and keyword selection. In this paper we go through we can see the technical approaches and information on search engine ranking algorithms. Ongoing modification and regular updates play a key role maintaining a high ranking.[13]

This page studies the four primary Search Engine Optimization (SEO) strategies on Page Interest and SEO Effectiveness: structure, keyword, content, and link optimization. It finds the, aim elements effecting SEO by studying 116 websites using a third-party tool. The study shows that Page Size, 404 Error Page Customization, and Overall Links have a big impact on Page Interest and SEO efficacy. User navigation and site credibility is boosted by 404 pages and larger page widths promote user engagement and engine crawling. Addition of links also increases traffic without any hindrance to user traffic. The reliance on skin-care brands and Baidu engine limits the results; larger sample of evaluation leads to more results.[14]

Improvisation of page's visibility through online marketing using SEO tactics. Increased search engine ranking and visibility for a business have a positive effect on bandwidth, visit time, and hit count. This is more affordable and accessible than Pay-Per-Click (PPC) advertising, especially for small businesses and startups. In order to effectively increase audience, reach, the research advises using SEO strategies. It also suggested that future studies investigate the synergistic effects of SEO and SNS.[15]

Integration of Ai in SEO techniques is examined this peace of literature, mainly focusing on three techniques – statistical models, fuzzy logic, and evolutionary composition. It examines a number of AI-powered SEO prototypes and tools, including as Polidoxa, Fuzzy Inference Systems, commercial software like SPSS Clementine and SearchDex Hyperloop, and methods like K-Nearest Neighbor and Support Vector Machines. It highlights the issues brought on by search engines' and SEO businesses' usage of secret algorithms. AI plays a significant role in data analysis to improve website design and optimization.[17]

Google indexes more than 35 trillion online pages hence, this study concentrates on optimization for google and increase website exposure. One of the on-site strategies to improve websites ex-

posure is accurate headline generation and off-site is backlinking. SEO positively and significantly improves the exposure of the website in a browser. By putting these strategies into practice, a website can improve its visibility, rank higher, and compete more effectively with other websites.[18]

3. Methodology

3.1 Data Collection

Secondary sources: This study is primarily based on secondary credible sources. Secondary data collection from academic journals, industry reports, white papers, and articles. These sources provide us with various Search Engine Algorithms, existing SEO techniques, and case studies related to SEO performance across platforms like Google, Yahoo and Bing.

Selection of Search Engines: We selected search engines Google, Bing, and Yahoo due to their significant market share and influence in digital marketing landscape. This selection allows us to conduct a comprehensive comparison of cross platform SEO practices and different algorithms used.

Keywords and Website Selection: Set of keywords that are of high relevance in their respective industries such as technology, wealth, health and retail. Websites that rank of these keywords are analyzed to understand their relevance and impact in implementing SEO strategies. These keywords are selected on basis of search volume, competition level, and relevance to the study.

Tools and software: Several tools are used for the analysis of SEO metrics such as keyword rankings, backlinks, page load speeds, and others. Tools like Google Analytics, SEMrush, Moz, and Ahrefs were employed to gather quantitative data on the performance of websites across different search engines.

3.2. Data Analysis

Comparative Analysis: data collected was subjected to comparative analysis across platforms Google, Yahoo, Bing to evaluate the effectiveness of SEO strategies. Organic traffic, bounce rate, conversion rate, and average session duration are one Key Performance Indicators (KPIs), these are measured to evaluate measure the success of SEO practices.

Statistical Analysis: content analysis was performed to assess the quality of different SEO practices and search engine rankings. Regression analysis was performed to determine the impact of specific factors like keyword density, backlink quality, and page load speed on the rankings.

Content Analysis: A qualitative analysis of the content was conducted to assess the quality of on-page SEO elements like meta tags, heads, and content structure. This analysis was aimed to identify the best practices that contribute to increasing the rankings of pages across different search engines.

Evaluation of SEO Techniques: Black hat, grey hat, and white hat SEO techniques are evaluated. The effectiveness, ethical implications, and long-term sustainability of these techniques were analyzed.

Gap Analysis: discrepancies between current SEO practices and optimal strategies are analyzed. This was instrumental in providing recommendations for businesses to improve their SEO performance

3.3 Ethical Considerations

This study strictly adhered to ethical practices by ensuring all data used was publicly available and was not a breach of privacy. All sources of information were appropriately cited, and no proprietary or confidential data was used.

3.4 Limitations

This research is primarily based on secondary data. Hence it may not capture most recent changes in search engine algorithms. Additionally, the focus on only three search engines may limit the generalizability of the findings to other platforms.

4. Results and Discussion

Survey Results:

Which aspects of Search Engine Optimization (SEO) are crucial for improving a website's ranking on search engines?

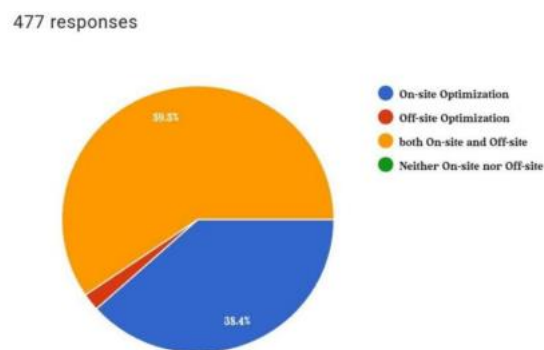


Fig.1. crucial aspect of SEO to improve its ranking on SERP.

Shown in fig.1, 83% of respondents selected On-site Optimization (red slice) as the technique involved in creating accurate headlines and improving website structure. 8.4% of respondents chose Content Optimization (green slice). A small blue slice represents Off-site Optimization, though the exact percentage isn't provided, indicating it's less than 8.4%. A yellow slice represents Black Hat SEO, but the percentage is very small, likely under 5%. We can conclude that both off-site and on-site SEO techniques are essential for string performance of a website.

Which of the following SEO techniques involves creating accurate headlines and improving website structure?

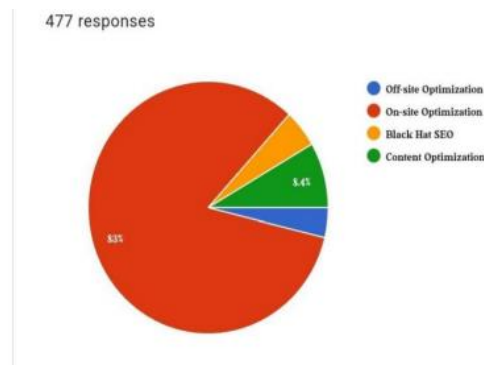


Fig.2. SEO techniques to improve website structure.

Shown in fig.2, Pie chart that shows the results of a survey asking how off-site optimization primarily improves a website's SEO. The chart shows that 83.6% of respondents believe that off-site optimization primarily improves SEO through back linking from other websites. The remaining 16.4% of respondents are divided between "By optimizing website structure" (7.3%), "By reducing website content" (9%), and "By minimizing page size" (7.3%). On-site SEO techniques provide with more structure and make user navigation easier. It enhances the presentability and engagement when compared to others.

What is the primary benefit of applying SEO techniques to a website?

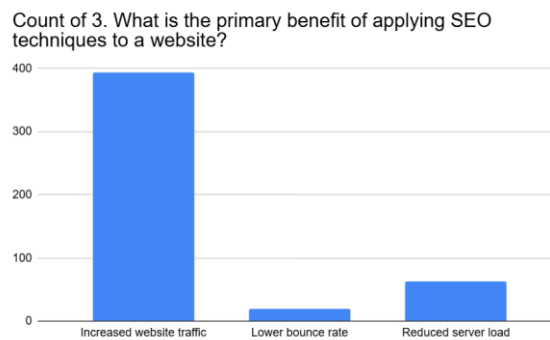


Fig.3. Benefits of applying SEO.

Shown in fig.3, Higher ranking in search engine results: 83.6%. Lower page views: Not specified. Increased costs: Not specified. Reduced website visibility: 12.2%. Increased ranking of a website creates better visibility and more user engagement as users tend to use the links that appear at the top more often than not. Looking in a business and economic point of view it is crucial that we consider the online presence of our business and make it more prominent to attract and retain users.

According to the discussed papers, which SEO technique is considered the most sustainable and long-term?

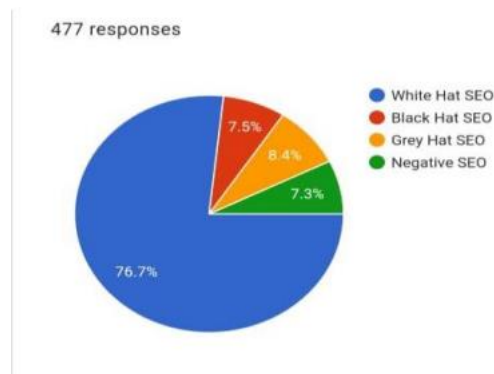


Fig.4. Sustainable and long-term SEO techniques.

Shown in fig.4, The chart is divided into four sections representing different advantages: Lower cost: The largest section, comprising 78.4% of the responses. Immediate results: Occupies 12.6% of the chart. Temporary visibility: Represents a smaller portion with 5.7% of the responses. Higher conversion rates: The smallest section, with 3.3% of the responses. White hat techniques are more reliable in long run as they focus on user engagement as well as retainment. Although black hat and grey hat techniques provide huge surge of ranking or a short period of time it is not effective in long run. This could be due to many reasons such as risk of penalties, violation of search engine guidelines, lack of trust and constantly altering algorithms.

What role does keyword selection play in search engine optimization?

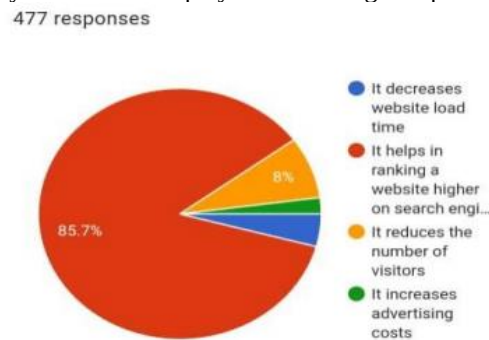


Fig.5. Role of keyword selection.

Shown in fig.5, The chart shows that 83.6% of respondents believe that off-site optimization primarily improves SEO through backlinking from other websites. The remaining 16.4% of respondents are divided between "By optimizing website structure" (7.3%), "By reducing website content" (9%), and "By minimizing page size" (7.3%). Keywords indicate the relevance of a user's requirements. The more keywords match with our requests, the more effective results for our search. Key words have great prominence in search engines like Bing and Yahoo.

Which of the following is a potential outcome of using effective SEO techniques on a website?

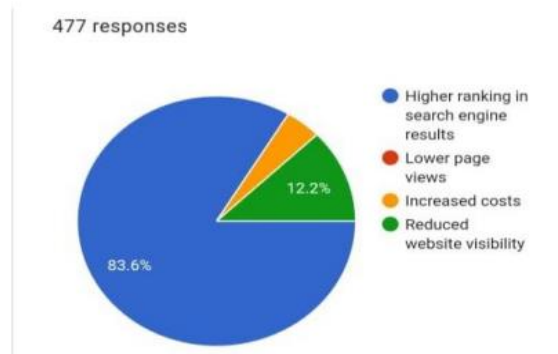


Fig.6. Potential outcomes for effective SEO techniques.

Shown in fig.6, The chart shows the following outcomes and their corresponding percentages: Higher ranking in search engine results: 83.6% Lower page views: Not specified Increased costs: Not specified Reduced website visibility: 12.2%. on optimal use of SEO techniques, we can get a high ranking of our website. This will increase user engagement and user base. Constantly maintaining the ranking will build a sense of trust and reputation that sustains a strong user base.

What is a common challenge in applying artificial intelligence to SEO, according to the information provided?

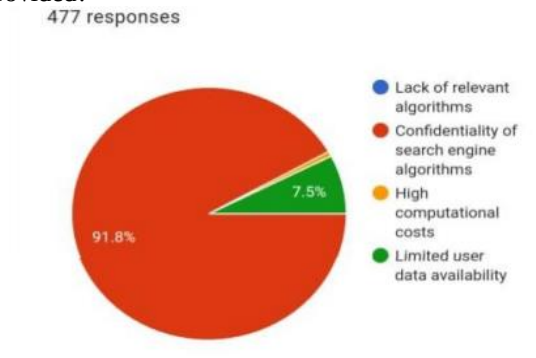


Fig.7. Applying AI to SEO.

Shown in fig7, the chart shows that the confidentiality of search engine algorithms is the most significant challenge, accounting for 91.8% of the responses. Other challenges include: Lack of relevant algorithms: 7.5%. High computational costs: 0.4%. Limited user data availability: 0.3%. The chart visually emphasizes the dominance of confidentiality of search engine algorithms as the primary challenge in applying AI to SEO. Although this is a main concern currently, but enhancing AI techniques could provide better security.

How does off-site optimization primarily improve a website's SEO?

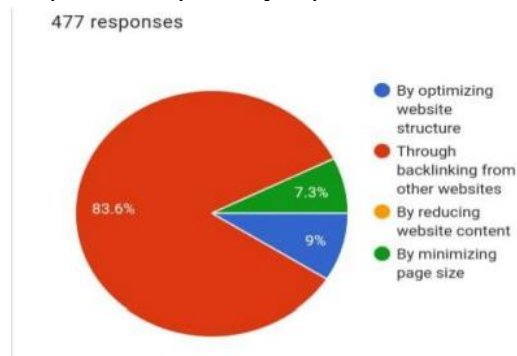


Fig.8. Improvement by off-site optimization.

Shown in fig.8, The chart shows that 83.6% of respondents believe that off- site optimization primarily improves SEO through backlinking from other websites. The remaining 16.4% of respondents are divided between "By optimizing website structure" (7.3%), "By reducing website content" (9%), and "By minimizing page size" (7.3%).

Which search engine is most frequently mentioned as a focus for SEO strategies?

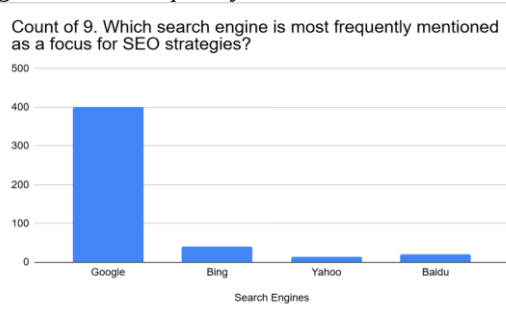


Fig.9. Most Frequently mentioned search engine for SEO strategies.

Shown in fig.9, Google is the overwhelming leader with 84.1%of mentions. Yahoo comes in second with 8.6%of mentions. Bing follows with 4.2% of mentions. Baidu has the smallest sharewith3.1% of mentions. The chart visually emphasizes the dominance of Google as the primary search engine considered in SEO strategies based on the survey data. Given the wide spread user base of Google, it only makes sense to prioritize the optimizing for it.

What are some advantages of SEO over Pay-Per-Click(PPC) advertising, as discussed?

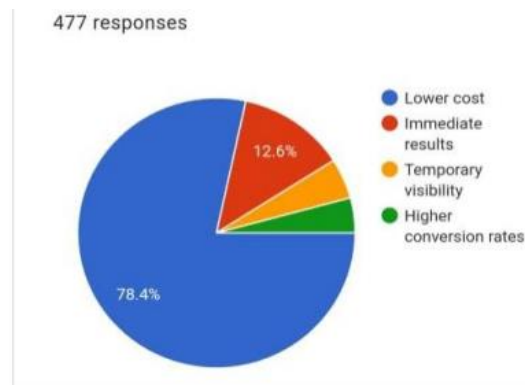


Fig.10. Advantages of SEO over PPC advertising.

Shown in fig10, the chart is divided into four sections representing different advantages: Lower cost: The largest section, comprising 78.4% of the responses. Immediate results: Occupies 12.6% of the chart. Temporary visibility: Represents a smaller portion with 5.7% of the responses. Higher conversion rates: The smallest section, with 3.3% of the responses. The chart visually emphasizes the significance of lower cost as the primary advantage of SEO over PPC advertising according to the survey respondents. Although its low cost for the website owner it is not something a user would prefer.

5. Conclusion

This paper provides us an insight on various Search Engine Optimization (SEO) strategies across Google, Bing, and Yahoo, highlighting the importance of adapting techniques to each platforms' specific algorithms. While universal practices like keyword optimization, backlink quality, and page speed are crucial, search engines differ in how they prioritize these factors. Google emphasizes user experience and content quality, whereas Bing and Yahoo may place more weight on keyword density and social signals. This could be attributed to Google's advanced algorithms that are well versed in identifying quality content. This only improves the quality of each search. On the other hand, Bing and Yahoo also identify good quality content the rely comparatively more on metrics such as keywords and social signals. The study underscores the need for businesses to tailor their SEO efforts to unique requirements of each search engine to achieve better visibility and attract more traffic. Additionally, the ethical implications on SEO were considered, with white hat SEO techniques proving to be more sustainable and safer than black hat or grey hat methods, which carry significant risks. The gap analysis revealed areas where current SEO strategies could be improved, especially by considering the dynamic nature of search engine algorithm. Although SEO is a critical component of digital marketing, staying informed and adaptable is essential. Future research should explore the integration of merging technologies like AI into SEO practices and their impact. Further studies will delve deeper using primary sources of data analyzing then to get a more granular understanding of user behavior, content engagement, and platform dynamics. Unlike this study that gives a more generalized overview of patterns and trends, focus of future research could include more detailed analysis using case studies of individual websites, comparing them over multiple platforms. This could yield more targeted exploration of the subject.

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The Role of Ethics and Professionalism in Engineering Education

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Abstract. The integration of ethics and professionalism into engineering education is an essential requirement for producing competent engineers with a strong ethical background. This paper examines the application of ethical and professional principles into engineering curricula and their significance in preparing students for workplace challenges. The study evaluates the advantages and limitations of the present teaching methods through a survey conducted among the engineering students and faculties using Google Forms. A closed and open-ended question survey will be used to assess awareness, understanding, and implementation of ethical and professional principles. Results reveal that students know ethics are necessary but gaps do exist in what is taught. Specifically, areas of improvement can be found regarding real-world applications and decision-making. Faculty recommendations include realistic case scenarios and more industry partnerships as a means of improving ethical competency. The study emphasizes the necessity of structured strategies to develop ethical and professional skills among engineering students. These insights contribute to improving engineering education by informing faculty, scholars, and policy-makers on refining curriculum design to address ethical challenges in modern engineering

Keywords: Engineering ethics, professionalism, curriculum, ethical decision-making, industry integration

1 Introduction

A range of cognition and learning is acquired in engineering education to create future professionals for dealing with multifaceted issues in different professions. More importantly, as the advances in technology keep evolving in each and every industry, it becomes even more important that students embrace the codes of ethics and professionalism in engineering practices. Ethical competence is not only core to engineering practitioners but also instrumental in attaining long-term sustainability. Ethical choices by engineers have implications for sustainable development, conservation of the environment, and public welfare. Some of the problems that engineers face refer to their ethical codes and duties that go beyond technical specifications. Hence, it is relevant to know how prepared engineering programmes make their students to address these challenges in using their skills as well as hands to improve the nation and the world in general.

The research discussed in this paper is based on the following research problem: Is the current engineering education effective in equipping learners with ethical and professional competencies for career practice? As these two components are formally acknowledged as essentials in engineering education, there seems to be a scarcity of empirical data that critique the implementation of ethics and professionalism in engineering curricula. This leads to a gap in questions about whether engineers graduating from these universities are ready to make ethical decisions when they are practicing their professions.

The importance of the present investigation resides in its opportunity to contribute to the improvements of the curriculum and methods adopted for engineering courses. Through quantitative analysis of the responses to a survey questions, the present study will compare the current state of ethics and professionalism education and training from the participating students' and faculties' perceptions. Those findings could inform better approaches which might be used to incorporate ethics and professionalism within engineering curriculum, in an effort to create sound technical engineers with a sense of ethical responsibility. The goal of this research is twofold: the first is to provide an evaluation of the current state of ethics and professionalism education in engineering curricula and second is to indicate the avenues for improvement. This is done by a cross-sectional study performed in an engineering college, with the aid of Google Form to get responses from the targeted participants.

Through the survey method one is able to get broad feedback on the level of awareness, understanding and practice of ethical principles and professional standards. Based on the survey findings of the current study, it will be possible to offer practical suggestions on how ethics and professionalism can be mainstreamed in the teaching of engineering. The procedure involved in the survey is explained so as to justify and support the results that can assist in future educational practices.

2. Literature review

(Colby and Sullivan 2008) This paper aims to establish how undergraduate engineering programs in the United States of America help in the growth of students' ethical understanding through case studies from seven universities. It evaluates ethical course strength as well as the areas of inefficiency by comparing the extent to which these courses meet the professional code of ethics and responsibility. In addition, research identifies some specific goals for their instruction in morality, in addition to indicating ways in which the effectiveness of these approaches can be increased. The differences between International and Domestic courses. The gap analysis and unique aspects. Nevertheless, this paper gives a detailed examination of the ethics education in various engineering schools in the U.S., while its major source of information is, therefore, observational case studies as well as recommendations of the existent programs. This is unlike the current study which involves the conduct of surveys within a single institution with a view of determining gaps regarding ethics and professionalism that need to be addressed in that particular given learning institution. Concentrating on only one location allows for a more differentiated manner of assessment with the subsequent recommendations that are applicable to this college or university context.

(Loui 2005) The purpose of this paper is to identify how students in the undergraduate engineering program understand their professional self and the effect the course in engineering ethics has on this understanding. This is a disappointing revelation because the study reveals that most of what students understand about professionalism they learn from their families and co-workers and not from the technical courses they undertake. Ethics courses of comparison such as those that use real-life cases and those that are diverse are beneficial to the students in the following ways: The study strengthens the students' confidence in ethical decision making. Although this paper examines the effect that ethics courses have on the development of students' professional identity, and underlines the significance of personal experience in terms of the formation of an individual professional identity, the emphasis is on students' opinion and the relevance of the courses. The current study however employs a survey based approach in a single institution to examine the impact of integrating ethics and professionalism at the curriculum. It is intended to supply systematic advice in light of such data from that particular context, thus presenting a more fine-grained analysis of the role of ethics education in professional training.

(Hamad et al. 2013) This paper conducts a critical survey of engineering ethics, with reference to the programmatic elements of being an ethical engineer, as well as the substance and delivery of ethics instruction, and the evaluation of ethics education. It focuses on the assessment of moral judgment development among

the engineering students using the Defining Issues Test (DIT) and the Engineering and Science Issues Test (ESIT). The review emphasises on the fact that there is limited amount of literature available on engineering ethics as compared to other disciplines such as medical sciences and biology. In the first one, the process of gap analysis is described, as well as some unique features of the chosen topic are mentioned. Although this paper provides a current status of the engineering ethics and the assessment tools, it provides only an outline assessment and conventional assessment tools. The present research, therefore, employs a survey technique to assess the current status of and the extent to which ethics teaching is incorporated into engineering in the given institution. This approach is localized to assess the strengths and weaknesses and possible suggestions when it comes to offering ethics and professionalism instructions relevant to the institution's environment.

(Zhu and Clancy 2023) This paper argues against the dominant liberal individualistic model of engineering ethics education that integrates an agent-based model of moral reasoning grounded on Western ethical theories. This approach, the argument goes, fails to account for the relational and role constellations of engineering work. Introducing the Confucian role ethics, the paper put forward a role approach to the teaching of ethical, based on understanding the moral responsibilities arising from the engineer's roles and relationships within communities. However, this paper raises objections to the individualistic approach in ethics and proposes the role-based perspective based on Confucian values ; at the same time it is confined to the level of theoretical and philosophical changes in ethics education . While the present study measures the extent of ethics education's effectiveness in a real setting using a self-administered questionnaire conducted in one organisation. It is designed to examine certain areas of the existing curriculum to offer evidence-based suggestions about the integration of the issues of ethics and professionalism; therefore, it offers a more research-oriented and context-sensitive approach.

(Leifler et al. 2020) This paper proposes an approach of teaching both ethics and sustainability in addition to academic skills and techniques within a single curriculum in computer science education. Conventionally, it demonstrates the difficulty of integrating such elements into the computer science curricula and shows that offering these as components of a single subject, viz., 'Professionalism in Computer Science', helps increase students' interest and enthusiasm. The approach adopted involves, flipped classroom, educational games and formative and summative assessments on the students' skills and attitude towards such classes through questionnaires and course feedback forms. Even though in this paper I aim at discussing the ways in which ethics, sustainability, and academic skills should be integrated in computer science education, the approach is appropriate solely for computer science discipline and employs a particular method. The current study, on the other hand, aims at the scholarship of teaching and learning of ethics and professionalism in a broader engineering context using survey method in one institution. Its purpose is to deliver more precise evaluation of how efficiently these components are currently being taught, and provide specific recommendations concerning their further enhancement in each institution, avoiding general call for integrated models of teaching and learning combinations, but pointing at undisclosed conventions' deficiencies in existing curriculum.

(Koehn 1991) In this paper, I present the concept for a seminar – Ethics and Professionalism in Engineering – aimed at acquainting students with the engineer, the engineer's function in society, and the engineer's responsibilities in terms of ethics and professionalism. The course complies with the guidelines set out by ABET and includes such topics of study as safety measures in construction, ethics of nuclear energy, and the case study of the Challenger tragedy. From the assessments conducted on the seminar, the students' perception of the topics as interesting and relevant to their exiting or planned professional lives is positive. The gap analysis and the special aspects of the proposed study Although this paper outlines a seminar and considers the issues related to its structure and the reactions of students, it is, in essence, devoted to the question of the seminar's design. The current study, however, targets the evaluation of the extent or level of ethics and professionalism integration in a specific engineering curriculum with survey results being used as the evaluation parameter. It sets out to learn potential omissions in the current curriculum and give specific suggestions on

how ethics can be taught better at an institutional level rather than depicting what one type of a course in ethics looks like.

(Zhu and Clancy 2023) Arguing against the conventional western and individualistic approaches towards engineering ethics education and adoption of the moral reasoning along with two of the most prevalent ethical theories, namely deontology and consequentialism. Critiques by Toulmin have it that this approach fails to address relational and role-based aspects of engineering practice. Through Confucian role ethics, the paper proffers a role-oriented method that calls for duties of engineers pulled from their roles and responsibilities in communal affiliation that will be helpful for the promotion of engineering ethics education. In planning to execute our strategies, there will be a few activities that are specific to each of these strategies: Although this paper offers changes to ethical education in theoretical level and suggests the role-base approach based on Confucian ethic, this paper itself is more concerned with philosophical viewpoint and its application. On the other hand, the current study aims at evaluating the extent of a survey-based practical use of ethics and professionalism integration into the engineering curriculum of the current institution. It is to discover deficiencies of the subject and to provide practical, evidence-based strategies to the officials of the institution, which should present a more practical approach to the evaluation of ethics education than the approaches used in the paper.

(Mitcham and Nan 2015) Engineering ethics can therefore be said to have evolved from being a concern of engineers during the early years of the 20th century up to the start of the second world war, to being a discipline under philosophical scrutiny especially in Germany and the US but equally from other parts of the world such as Denmark, the Netherlands, China and the influence of Americans. The paper opines that engineering ethics scholars should adopt political philosophy in their subsequent work, as Aristotle has in combining ethics and politics. Recommendation for applied implementations and assessment of effectiveness in certain educational contexts are not a part of this paper as this paper offers a historical background and philosophical underpinnings of engineering ethics but it does not critique current best practices. Unlike the activities of the current study, which concern with assessing the level of ethics and professionalism integration within a specific engineering curriculum employment of the survey questionnaire, as well as with providing the specific recommendations for the improvement of the ethics teaching at the certain institution, it is an academic research that does not aim at delivering the general conclusions on the topic. That is why this approach can be considered as more practical and based on the available data as opposed to more historical and philosophical stance of the paper.

(Génova, González, and Fraga 2007) This paper focuses on the practical and theoretical drawbacks of keeping naïve consequentialism for software engineers in terms of moral decision-making concerning software systems since the latter are highly ramified and uncertain. It approves a moderate ethical theory known as moderate deontologism which asserts to both rule and consequence ethics as well as human dignity. The paper also proposes the extension of this approach with virtue ethics to more effectively frame the education of responsible software professionals. In planning for the implementation of ethical principles in software engineering, this paper offers a balance of analysis of similarities and differences relative to other professions and prescriptions for action, yet this paper is unique to software engineering. However, the current work assesses the About engineering ethic and professionalism within the broader context of an engineering programme and embraces a survey analysis technique. It is meant to establish the missing and/or insufficiently explored aspects of the implementation of reforms in current practices and give an institution-specific advice on the improvement of this process, thus providing a realistic working understanding of what is lacking in ethics education in engineering rather than a boutique theory specific to one or another engineering specialty.

(Herkert and Vincent Viscomi 1991) This paper fills the gap which has been observed in engineering curricula of not giving adequate attention to issues of technology in social, political, economic, ethical, and legal aspects. It challenges the use of selective humanities and social sciences courses for such cross-linking and

offers a remedy in the form of a mandatory course known as ‘Engineering Professionalism and Ethics’ at Lafayette College. This course encompasses engineers and their responsibilities at the societal level, economic systems, ethics, safety and risk, responsibility and law. Comparison between Existing and Proposed Analysis Specificities Despite the presentation of the topic of this paper with regard to an effectively educating course that can effectively bridge the gap between the goals of Engineering and the rest of society with regard to curriculum development, this paper is predominantly centered on the course description and content. However, in the present study, authors employ survey method in order to measure how appropriate it is for an institution of engineering to integrate ethics and professionalism into its curriculum. It is to seek for pragmatic areas of deficiency and to make specific suggestions as to improvements in the teaching of ethics and professionalism; the proposal is likely to provide a more quantitative measures of the efficacy of the curriculum than simply a description of a new course.

(Huang et al. 2020) This paper explores the diverse challenges and opportunities presented by the integration of artificial intelligence (AI) into educational settings. It provides an in-depth analysis of how AI can transform traditional teaching practices by offering personalized learning experiences, automating routine administrative tasks, and providing real-time feedback to both students and educators. The paper highlights AI's potential to address systemic issues in education, such as promoting equity and access by offering scalable, customized solutions. However, it also discusses significant challenges, including concerns about data privacy, the risk of reinforcing existing biases through algorithmic decisions, and the need for robust infrastructure and comprehensive teacher training. The authors emphasize the necessity for ethical guidelines and regulatory frameworks to ensure that AI technologies are implemented responsibly and effectively in educational environments.

(Stieb 2011) This paper argues out against the principles that the engineering professionalism as put forward by Engineering Societies like the NSPE as being one that should benefit humanity. This requirement, it says, is an unwarranted provocation that impinges on the freedom of engineers and brings about politics of influence that strangle research and development. Instead of compulsory service to humanity, the paper calls for a politically correct definition of engineering and professionalism that recognises a code of ethics. A note on Co-Collection and the Unique Method Although a number of engineering societies’ professional demands are criticized in this paper and a politically unbiased definition of this term is offered, this paper’s main concern is philosophical and political aspect of engineering professionalism. On the other hand, the present work employing a survey-based approach to evaluate the extent to which E&P are implemented in the engineering curriculum of focus for the purposes of making recommendations based on the existing research gaps. This provides a less philosophical analysis of curriculum efficacy than a breakdown of professional definitions and specifications.

(Bielefeldt et al. 2016) The purpose of this paper is to review current practices of the incorporation of ethical concerns into service learning courses and other community based co-curricular activities in engineering education. That is to say, most service-learning courses present a median of eight ethical topics; in contrast, the co-curricular activities, namely Engineers Without Borders presented a total of a median of seven. Micro-ethical subjects are more frequently taught in service-learning courses; assessments are also more likely to be present in such courses than co-curricular activities. As for the approaches in embedding and measuring the ethics of the strategies, there are several options described in the study. Consulting and Accountability Apart: A Gap Analysis of SCU Strategic Planning and Appropriate Components Although this paper analyses the manner in which ethics is inculcated through service learning and co-curricular activities such as the frequency of ethical content and evaluation, it does not discuss on ethics professionalism in the required engineering curriculum. This current study therefore employs a survey that establishes the efficiency of ethics and professionalism education within the targeted specific engineering course in order to pinpoint weaknesses and offer more specific suggestions for enhancement. This provides a more targeted consideration of ethics as a formal

subject in schools as opposed to how it might be learned in ‘other’ contexts of community or outside of classroom activities.

(Monteiro, Leite, and Rocha 2019) This paper examines the contemporary dynamics of change in higher learning institutions especially in the engineering discipline where the institutions are shifting from ‘pure’ academicism to serving the economic production sphere. It posits for the inclusion of ethical education as part and parcel of the HEQuest to meet today’s and tomorrow’s challenges. The study aims at determining whether the engineering undergraduate curricula in Portugal provide all the requisite characteristics for ethical education and concludes that only to a minimal extent is present with the programmes not having the comprehensive characteristics recommended for ethical education. Comparison of the current status and the gaps as well as identification of such factors as the nature of the organization, business environment and strategy, and availability and sources of funds. This paper focuses on the importance of ethical education in higher learning institutions and assesses the extent of their implementation in the curricula of engineering courses in Portugal. Though the paper may debate on the responsibility of integrating ethics as an aspect of education as well as the extent of their integration within engineering curricula in Portugal it does this more so in general nodding at the practices rather than a direct analysis. On a stark contrast, the current study drives directly into a survey-based research model to assess the implementation of ethics and professionalism within a particular curriculum of Engineering education and hence focus on providing the specific areas of difficulties which may be faced by that particular institution correspondingly by providing corresponding recommendations. This makes it more precise in the assessment of the curriculum effectiveness and provides tangible solutions for their enhanced effectiveness as opposed to the broad educational environment highlighted in the paper.

(Marcy et al. 2014) From this panel discussion, the following questions do arise: How do engineers come to know these responsibilities and obligations that they are under? If they do act or omit to act in the way that they should, what are some of the consequences that might ensue? It looks at the part played by formal education, continuing education, and work experience in the development of ethical standards in the engineering practice. This panel discussion deals with the moral obligations of engineers and the educational procedures but it is much more concerned with the general, evaluative, aspect of professionalization rather than with actual curricular incorporation. On the other hand, the current study employs a survey to evaluate the application of ethics and professionalism knowledge within the engineering curriculum that is under focus and the major objective of study is to evaluate the strengths and weaknesses of incorporating and applying these aspects in practice, and make recommendations thereon. This brings a more grounded assessment of ethics education within the curriculum as compared to the more discursive approach taken in the panel.

(Hersh 1999) This article points out that till now, engineers have only given optimal technical solutions with no much attention to the ethical consequences of their work in the environmental and social perspective. It opines that engineering ethics has mainly focused on devotion and competency of the engineers and not environmental issues. This paper focuses on the function and relevance of environmental ethics for engineers: it also describes characteristics of an optimal environmental ethics system and gives an idea of how to promote these ethics within the engineering practice. Gap Analysis and Special Features This article aims at postulating a scheme on how environmental ethics can be incorporated into engineering approaches and the criteria for ideal ethical frameworks; however, its main thrust is in outlining broad ethical principles though occasional discussions of educational practices are presented. The present study employs a survey and quantitative analysis to assess the outcome of teaching ethics and professionalism in the given scope of an engineering programme, to determine potential deficiencies and make suggestions for such improvements. This allows for a specific analysis of curriculum integration and its efficiency and can be more useful than a rather vague encouragement of ethical values mentioned in the article.

The results indicate that students who used the AI advising system experienced faster graduation rates, improved academic performance, and greater satisfaction with the advising process. The case study also highlights how the system can identify at-risk students and provide preventive support. Challenges include integrating the system with existing IT infrastructures and ensuring that its recommendations align with university policies. The authors recommend stakeholder involvement and iterative development as best practices for implementing AI in academic advising.

3. Methodology

3.1. Research Design:

The purpose of this research is to examine the role of professionalism and ethics in engineering education with reference to a quantitative approach. Since the research aimed to gather data from a portion of the college engineering students a survey method was employed. Conducted in a poll form, the rationale of the question was to establish the extent to which the students appreciated the importance, coverage, and utility of engineering program in ethics and professionalism.

3.2. Survey Instrument:

As a result, some important decisions were made; it was decided, for example, to compose a non-trivial systematic questionnaire containing both Likert scale and multiple-choice questions. The survey covered a wide range of professionalism and ethics topics, The survey covered a wide range of professionalism and ethics topics, such as which may explain the impression one gets about the curriculum being replete with subjects concerning professionalism and ethical issues .the relevance of the curriculum learnt in school in preparing the pupils for moral issues that they find themselves in today. how often professionalism and ethics are discusses in classes .The effectiveness of the present instructional strategies is another important and widely used measure .From the amalgamation of professionalism and ethics in the job market, the prospects of future.

3.3. Sampling and Data Collection:

Hyderabad Institution Of Technology And Management engineering students were the target respondents of the survey. Thus, 1,156 replies in all were collected. Sampling technique employed was convenience sampling where the participants were, should be students studying in various engineering schools. This survey was open for response for a period of [6 months] and the responses were received electronically using Google Forms.

3.4. Data Analysis:

In analyzing the data collected, uses of the descriptive statistics were made, to establish trends and patterns. To accomplish replies frequencies, each and every top-quality survey item was gauged in frequency distributions and percentages fashion. To establish differences in the opinion that might be occasioned by various demographic factors including the program specialization and year of study comparative studies were conducted. The results were than used to make judgments on the state of professionalism and ethics education as well as identify areas that require development.

3.5. Ethical Considerations and Data Collection:

The survey was constructed to measure validity and reliability in capturing the perceptions of students regarding ethics and professionalism in engineering education. Clarity and consistency were tested through a pilot test with a small sample. Internal consistency and reliability were tested through Cronbach's alpha. Engineering education and ethics experts validated the survey to assess its appropriateness.

4. Results and Discussion

Convenience sampling was employed to gain access to students from different engineering fields, although it will likely produce some bias. To minimize bias, students in various years and specializations were represented. Respondents were not identified to prevent biased answers.

- How important do you believe ethics and professionalism are in the engineering curriculum?

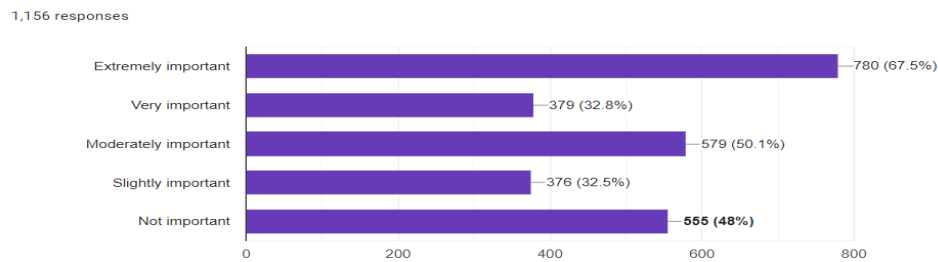


Fig. 1. Describing

the importance of ethics and professionalism are in the engineering curriculum

Another result of the surveys is that the respondents are aware of the high value of ethics' and professionalism in the engineering curriculum. Of 1,156 respondents, 67. 5% (780) regard these topics as "Extremely important," and 32%. When asked about the importance of each of the topics, 8% (379) responded that it is 'Very important,' indicating that a majority of the respondents are open to their inclusion. However, a good percentage of the respondents – 50. At 1% (579), they consider them 'Moderately important.'. 5% (376) regard them as "Slightly important." In fact 48% (555) find them as "Not important showing a sizeable number of people who either do not think they are important or feel that they are over emphasised. This indicates that there might be disparities in the manner in which ethics and professionalism are taught or by how they are received or interpreted in the curriculum

- To what extent do you feel that your engineering education has adequately prepared you to handle ethical issues in professional practice?

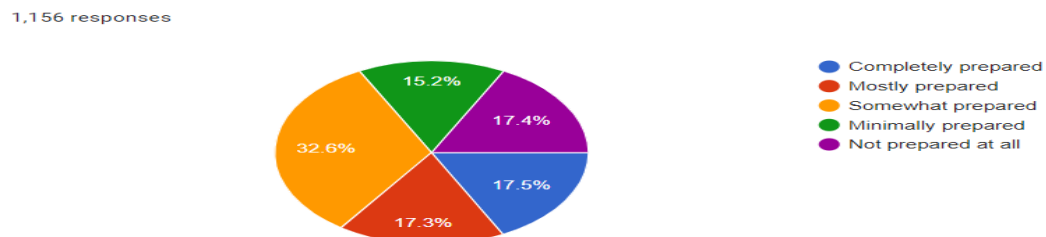


Fig. 2. Describing To what extent do you feel that your engineering education has adequately prepared you to handle ethical issues in professional practice

This table shows a neutral perception of the survey respondents in terms of how engineering education intech ascription prepares students in dealing with ethical matters when in practice. Of the 1,156 respondents, only 17. 5% of them say they are "Completely prepared" whereas 17. 3% are of the opinion that they are "Somewhat prepared." Only 3% argued that they are "Mostly prepared." 6 per cent rated it as 'Somewhat prepared' meaning that a number of students consider themselves as having little ethical training. Additional-

ly, 15. 2% said they are “Minimally prepared” and 17. 4% of the students said they were ‘Not prepared at all’. These findings indicate while some students hold considerable confidence, others perceive that their education does not equip them adequately for ethical issues as they are in real life. This brings the issue of ethics education to high light to denote that it is time to step up efforts in the way students are prepared to face ethical practices in professions.

- Which of the following topics related to ethics and professionalism have been covered in your courses?
(Select all that apply)

1,156 responses



Fig. 3. Describing the topics related to ethics and professionalism have been covered

A brief analysis of survey results pointed to the fact that engineering students receive different levels of coverage of topics under ethics and professionalism. In distribution by gender among the 1,156 respondents, 34 percent. Only 5% of the mentors and mentees stated that “Environmental and, social responsibility” was discussed, which was the most reported on topic. ”Legal implications of engineering” came second with 30. 7% while the trainer gave least emphasis on “Professional codes of ethics” which was mentioned 17. 2%, “Safety and risk assessment” 17. 4%. Notably, none of the respondents mentioned ‘Case studies on ethical dilemmas’ or selected ‘None of the above’ implying that these vital aspects of ethics training may well be overlooked or ignored. This implies that there is a should come up with improved contents of curriculum to include practical cases and improved coverage on ethical issues to ensure students receive adequate training on ethics.

- How frequently are ethics and professionalism discussed in your engineering courses?

1,156 responses

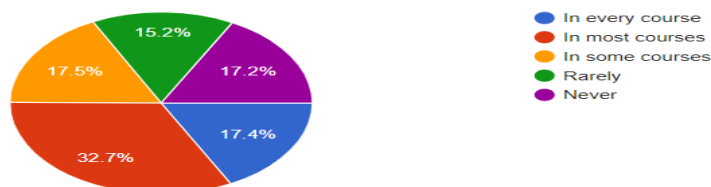


Fig. 4. Describing how frequently are ethics and professionalism discussed in engineering education

From an anonymous online survey that was conducted there was conclusion that perception of the frequency of ethic and professionalism issues regarding to engineering courses differ. From the 1,156 respondents, 32. Seven percent said these topics are discussed “In most courses” and 17. As neither excessively high nor low, 4% of the respondents stated that they are discussed “In every course”, thus meaning that a portion of students is always exposed. However, 17. 5% said they participate in such discussions “In some courses” Two percent stated that organisations pay them “Rarely” or “61” attention. Notably, 17. The worries expressed by the respondents included; the assertion that ‘there is poor coverage ‘, where 2% of the respondents said that ethics and professionalism are “Never” addressed in their classes. Such outcomes mean that despite

ethics and professionalism being provided to ‘many’ students, there is no homogeneity in access and may be even further combined more smoothly with throughout coursework.

- How effective do you think the current methods of teaching ethics and professionalism (lectures, case studies, group discussions, etc.) are?



Fig. 5. Describing how effective the current methods of teaching and professionalism

The respondents’ views on the utility of current approaches for introducing ethics and professionalism in the engineering curricula are quite divided. Among 1,156 respondents, 48.1% (556) regarded the methods as “Very effective,” 49.7% (575) of the students acknowledged them as ‘Effective’, this shows that approximately half of the students are content with the current teaching techniques. However, 34.6% or 400 employees responded “Neutral,” which gives some indication of indifference. More importantly, a large number of respondents had the impression that the teaching methods employed were rather poor, with 50.2% (580) of them rated them as ‘Ineffective.’ It is pretty apparent that more work has to be done when it comes to teaching ethics and professionalism as 32.8% (379) of respondents marked them as “Very ineffective.”

- In your opinion, should ethics and professionalism be a mandatory component of all engineering courses?

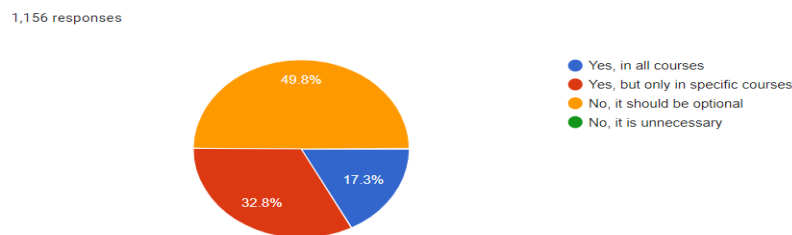


Fig. 6. Describing the is

ethics and professionalism is a mandatory component in engineering course

The survey proved the staff is divided they do or should require Ethics and professionalism in all engineering courses. Among 1,156 respondents, 17.3% of this group think these topics should form part of “all courses” and a slightly bigger 32.8%, endorse them “only in certain subjects,” while the rest—49.8%—said that ethics and professionalism are to be an ‘extra’ meaning that many students do not believe that these subjects must be incorporated into all courses. Almost unanimously, none of the respondents provided the view that ethics and professionalism is ‘useless,’ and while the balance of views might be split on ‘how’ far ethics and professionalism should be entered into the engineering training regime, there seems to be an understanding that it should be done.

- How confident do you feel in applying ethical decision-making in real-world engineering scenarios?

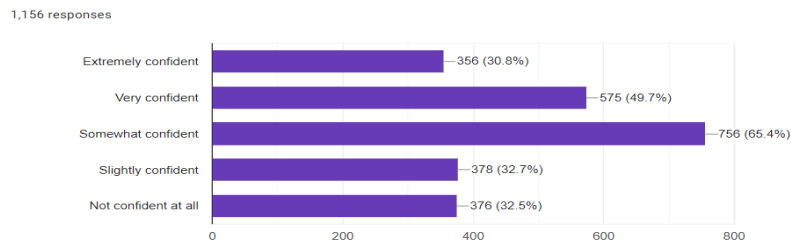


Fig. 7. Describing how confident

do you feel in applying ethical decision-making in real-world engineering scenarios

The topics of the survey revealed moderate to low level of confidence expressed by respondents in using ethical decision making in practical engineering contexts. Of the total 1, 156 respondents, 30. 8% (356) say they are ‘Extremely confident’ and 49. 7% (575) had a self-estimate of “Very confident” and show that a large part of students bear strong confidence in ethical decision making. However, a somewhat larger group 65. 4% (756) claimed to be only ‘Somewhat confident.’ 7% (378) of the respondents are ‘Slightly confident,’ and 32. 5% (376) are Not confident at all While the majority of the students in the study above have some degree of confidence in making ethical decisions, the results above show that there are quite a number of students who remain partially or non-confident in the same.

- Have you encountered any ethical dilemmas during internships, co-op programs, or project work?



Fig.8. Describing the any

ethical dilemmas during internships, co-op programs, or project works

A look at the survey data reveals that a good proportion of students has had to face ethical issues in internships, co-op programs, or project work. Among 1,156 respondents, 47. Reporting the following: In these settings they raised the following; 9% (554) of the respondents said that they experienced ethical challenges. 9% (600) have not. Additionally, 32. Seven per cent (378) of the respondents ticked their answer in the “Not applicable” slot because they did not engage in internships or project work. These results indicate that, of students who engaged in the practical placement, about half have faced ethical concerns and thus, as educators, there must prepare the students for dealing with such issues as they work on their engineering courses.

- What do you think is the primary challenge in teaching ethics and professionalism in engineering education?

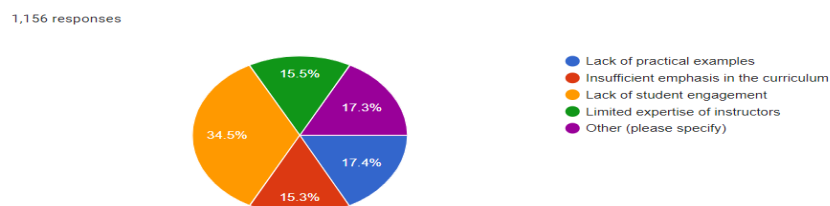


Fig.9.Describing primary

challenge in teaching ethics and professionalism in Engineering education

When analyzing the data obtained from the survey several concerns that affect approaches to teach and practice ethics and professionalism in engineering education are identified. The overall response of the 1,156 participants showed that the most chosen difficulty was the ‘Lack of student engagement,’ which 34 percent of the respondents chose. This presents a view that students are not fully engaged in learning of these topics as they only represent 5% of their total course work. Out of all the responses collected, ‘‘Lack of practical examples’’ was noted to be the deficiency in 17%. As to the last question about changes they have observed in other teachers’ practices, 4% of the participants pointed at the lack of sufficient number of real-life examples as a teaching aid. The next two complaints presented equally – ‘not enough emphasis put into the curriculum’ and ‘instructors lack expertise’, both being 15%. 3% and 15. The gaps found were in the areas of content delivery 5%, and preparation of faculty 5%. Additionally, 17. Three percent selected Other, in which they also named more other unspecified difficulties in teaching ethics and professionalism. These results highlight the directions to improve the ethics training – engaging, applicable and adequately backed-up initiatives.

- Do you believe that incorporating more ethics and professionalism into engineering education would positively influence your future career as an engineer?

1,156 responses

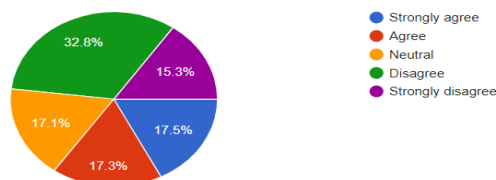


Fig.10. Discussing Ethics and

professionalism into engineering education would positively influence your future career as an engineer

The results of the survey show gaps in the ethical training of students that may prevent them from making decisions that are sustainable. Enhancing ethics education will make engineers better at developing sustainable solutions for industry and society.

The survey shows the respondents’ rather diverse attitudes to the possible consequences of absorption of more ethics and professionalism into engineering curricula. In a total of 1,156 respondents, 17. 17% “Strongly agree” on the statement that if more emphasis is placed on these areas it would have a positive impact on their future careers. 3% “Agree,” A significant number, that is 17. 1% continue to hover at ‘Neutral’, meaning that they retain no clear sided viewpoint neither on positive or negative ramification. Conversely, 32. 8% “Disagree,” and 15. 3% strongly disagree which may be interpreted to mean that a number of students may not see any value to be derived from improvement of ethics and professionalism courses. These varied reactions indicate discrepancies in the views concerning the significance and efficiency of ethics training, which underscores the importance of continued discussion and assessment in order to synchronise the topics presented in ethics education with the respective occupational realities.

5. Conclusion

To fill the gap in the literature as well as to accomplish the objectives of this study, a cross-sectional survey of 1156 students was conducted with reference to ethics and professionalism within engineering education. The findings confirm the high level of agreement with the necessity to address such subjects, at the same time, they expose important disparities concerning the level of students’ readiness for ethical challenges in

their future professions. Although, relatively many of the students acknowledge the importance of ethics, there is a substantial difference in the implementation frequency, and quality between the courses. The present study implies that, despite the fact that the current approaches are quite helpful, there is the potential for development and enhancement of ethics education improvement. In the light of these gaps the following recommendations are made regarding engineering curricula: There should be an enhanced coverage of ethics and professionalism as a subject. The use of multiple instructional models and the raising of the proportion of practical cases can help students improve the ethical lessons learnt. To do this, it is equally important to invest in, for example, developing faculty development, and strategies for increasing students' interest. Such changes affect not only the educational process but also enhance the students' preparedness concerning ethical issues they are likely to confront in their careers.

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Hybrid Frameworks for Improved Solar Energy Prediction

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Abstract. The prediction of solar insolation is critical for enhancing renewable power technologies, although it is still quite difficult owing to the multivariate nature of both meteorological and geographical factors. This study aims to expand on these weaknesses by devising a new hybrid model combining types of machine learning (ML) and deep learning (DL) approaches. Long Short Term Memory (LSTM) and Gated Recurrent Units (GRU) models with attention mechanism and bidirectional structure, among others, are applied in order to capture spatial and temporal correlations. High-dimensional data accuracy is achieved by the thorough data preprocessing steps. The proposed methods are able to outperform traditional techniques in terms of accuracy as well as robustness. In doing so, these findings provide expanded model solutions to address the barriers that aim to progress renewable energy forecasting at the global level. This research contributes to the domain of energy prediction on solar energy forecasting systems.

Keywords: Solar Irradiance • LSTM • GRU • Deep Learning • Renewable Energy Forecasting.

1 Introduction

There is now an unprecedented fossil fuel crisis that has brought global energy policies to a crossroads, and scholars have been steadfastly searching possible solutions[1]. Thus, the renewable sources of energy have been brought under focus and more specifically, the sun energy turned out to be more important than others, For this purpose comprehensive modeling as well as sophisticated algorithms for the prediction of solar irradiance became essential for effective energy management and optimization of solar energy systems concentration factor. However, solar irradiance forecasting is a complicated process that is subject to a host of constantly changing factors of a weather nature, requiring original solutions to improve forecasting skills and accuracy[2]. The prediction of solar energy generation is a complex task that has many facets. Many parameters affecting solar energy such as atmospheric conditions and geographical diversity also make it more stochastic than wind energy generation. These factors necessitate a shift towards more sophisticated methods which can handle high-dimensional data. Therefore, the present work seeks to tackle the issues of solar radiation prediction through the development of a hybrid framework combining cloud cover forecasting via ML and DL techniques. The research study has been carried out for four locations in west Bengal region of India to capture spatial variability in climatic factors[3].The proposed methodology consists of two parts: baseline comparisons using machine learning regression models such as linear regression and random forest regression, while advanced LSTM and GRU networks are used for further analysis to obtain temporal patterns and dependencies. In addition, attention mechanisms and bidirectional models have also been examined to improve the predictive accuracy. It is noted that the performance of each of the models was rigorously evaluated using a set of evaluation measures which includes Mean Squared Error (MSE)[4], Root Mean Squared Error (RMSE) and the coefficient of determination (R^2).This study also makes it possible to understand how deep learning models are better than other conventional ones in estimating solar irradiance forecasting and provides a range of LSTM and GRU networks based modeling [5]. The results confirm the effectiveness of the LSTM model in which the model reports the least RMSE and the highest R^2 scores relative to other models. The lessons learnt from this study are expected to be useful in developing optimum solar energy applications and set the stage for other works in renewable energy forecasting.[6] This research seeks to fill the gap left by previous models and utilize cutting-edge technologies to develop more accurate and more trustful models for predicting solar energies[7]. This, in turn, would help in the global efforts of promoting renewable energy solutions[8].

2 Literature Review

The prediction of solar irradiance is an aspect that has received much attention within scholars owing to the growth of dependency on renewable energy as well as the optimization of solar energy systems. Estimation of solar irradiation at any given location, is however fraught with a number of difficulties which include meteorological conditions, geographical and time factors. Different techniques including ML as well as DL models have been utilized to improve the prediction, each technique having its own merits and demerits[9]. Linear regression, decision trees and random forests, all referred to as traditional Regression-based ML are the most popular methods employed in forecasting due to their low complexity and ease of interpretation. These methods concentrate on finding the linear and the non-linear relationships between a set of input variables and the solar irradiance. They deal poorly with the temporal dependencies and high-dimensional patterns of solar irradiance data[10]. Random forests, for example, integrate

predictions and reduce over fitting, which improves accuracy, but because these models depend on fixed input features, they cannot adapt to changing meteorological parameters[11]. The Recurrent neural networks – RNNs, Long-Short Term Memory networks – LSTMs, and Gated Recurrent Units models – GRU models, among other deep learning models have proven their capability in covering the gaps that the conventional approaches fail to address[12]. The LSTM and GRU models have commendable performance in the capturing and learning of long term dependencies and time-series patterns such as those in solar irradiance. In addition, the models are improved by the use of attention mechanisms and bidirectional architectures that enable them to pay attention to key features and utilize contextual information. Research has shown that prediction accuracy generated by DL models is better than the one produced by classical ML methods, particularly when the data is high dimensional and involves multi-sited data. With regard to the achievements that have made strides in DL, there still exist research gaps. To begin with, DL models have been shown to be effective in specifically big data predictive analytics, however the complexity involved in their computations combined with the resources needed to run them effectively, have emerged as a challenge for scalar use of these models. Developing small sized models with outstanding performance at low computational cost would be important[13]. Additionally, many of the studies conducted concentrate on single site rather than emphasizing the linkages and relationships that exist spatially between several sites. The model may enhance the scope of understanding of the solar energy potential of regions through the incorporation of multiple and regional site data. Lastly, in the attention mechanisms, there is an improvement, however, the connection of such with hybrid models that utilize both linear and non-linear models has not been adequately addressed[14].

Baas stated, ‘In addition, MSE and RMSE are sufficient indicators for performance evaluation of forecasting techniques. While these metrics are effective, they give only limited perspective on the understanding and suitability of the models in different atmospheric conditions. It would be useful to add in the evaluation process certain metrics that would measure the robustness and the versatility of the model across different climates[15]. The first two gaps could easily be filled playing with existing tools and a bit of innovation[16]. The last gap will only open more accurate, scalable, and interpretable forecasting so it is highly advisable to explore it. Closing these gaps would assist in providing the necessary support to the transition into sustainable energy globally. Because more work will have to be done in a multidimensional context to make hybrid models work in practice and establish advanced metrics[17].

3 Methodology

This study seeks to improve the precision of solar irradiance forecasting by applying new Machine Learning (ML) and Deep Learning (DL) methods. This technique adopts a sequential framework from data preprocessing to feature engineering, model training, evaluation, and comparison so that an optimal solar energy prediction system is achieved. The focus is to apply cutting-edge time-series forecasting techniques, especially Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU) networks to accurately model the complex solar irradiance data dependencies and patterns. Moreover, hybrid model super-ensemble techniques are investigated to improve the predictive performance further. Raw datasets often contain discrepancies, absent data, and distinct scales of ordinal variables that can hinder model performance. Consequently, data cleansing is vital for the construction of useful predictive models. In addition, normalization is used to convert nu-

meric values within a particular range (for example, 0 to 1) so that the large magnitude features do not overpower lower ones. This step is necessary to ensure balanced feature magnitudes for the model inputs. Moreover, standardization transforms features into a normal range where the average (μ) is equal to 0 and the standard deviation (σ) is set at one. As a result, the efficiency and stability of neural network training is enhanced. The standardization procedure can be represented mathematically shown in equation (1).

$$X' = \frac{X - \mu}{\sigma} \quad (1)$$

where X' is the standardized feature, X is the original feature value, μ is the mean of the dataset, and (σ) is the standard deviation.

The described transformation guarantees that the dataset is uniformly scaled, thus eliminating the bias from features that possess vastly different magnitudes. Besides transforming numbers, location identifiers, weather conditions and seasons can be treated as qualitative characteristics and assigned numeric values using the one-hot encoding method. The method helps to prevent the model from incorrectly using the numbers as labels, as every categorical variable is provided with a unique binary vector. The one-hot encoding process turns categorical values into a binary matrix with an instance on each row and a category in each column. This transformation allows deep learning models to use categorical features without putting bias into them. After the data has been preprocessed, the dataset gets divided into training and testing sets for better model evaluation and training. The portion of the dataset that is used to train the LSTM and GRU is referred to as the training set, which consists of 70-80 percent of the dataset. The rest of the 20-30% uses testing to evaluate the model's generalization ability. This way, the model is able to learn meaningful patterns based on historical data and is separately evaluated based on unseen data. The LSTM and GRU models are used because they are best suited to capture sequential dependencies within time-series data. These architectures are well suited for learning complicated temporal dependencies, making them ideal for forecasting solar irradiance when past observations are known to greatly impact future predictions. The dynamics of these models are represented as the input-output relationship which shown in equation (2).

$$Y = f(WX + b) \quad (2)$$

where Y is the output to be predicted, W are the weight parameters, X are the input features, b is the bias, and f is the activation function used to inflict non-linearity. The memory cells in LSTM networks uniquely manage the flow of information using a forget, input, and output gate. The forget gate controls the information that is sent to the output memory and retained, the input gate adds new data, and the output gate provides the added information to the next time interval. This enables the model to remember the important information to be retained while the rest can be overwritten or forgotten, which is achieved through a combination of mathematical computations. In contrast, the GRU architecture simplifies the LSTM structure by combining both the forget and input gates to a single update gate, thus reducing the power needed to compute while remaining effective. GRU networks modify their hidden states based on the use of an update and a reset gate. The control of an update gate manages the portion of the previous information that should be carried to the present step while the reset gate manages the amount of contribution that previously hidden states will add to the candidate activation. The implementation of these mechanisms allows GRU models to efficiently capture long-term dependencies without the complexity that LSTMs require. As a crucial step in the training procedure, the preprocessed dataset is input into the LSTM and GRU models, where their weight parameters are iteratively updated through back propagation, and the network is optimized using stochastic gradient descent (SGD) or an adaptive optimizer like Adam. To accomplish learning, a loss function is defined, which guides the training through Mean Squared Error (MSE)

meant to measure the average of the squared differences between the actual and predicted values. MSE helps to represent the relative error while encouraging large errors to be severely punished. Model accuracy and reliability can also be affected by additional performance evaluation metrics including Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and the R^2 score which help assess these values. As an interpretation of prediction errors, RMSE offers an intuitive metric as values are bound to the same variable unit as the target, and MAE on the other hand, offers a more interpretable metric by calculating the average absolute difference between the actual and predicted values, making it less sensitive to outliers. The R^2 score also provides valuable information for understanding how well the model explains the variance of the data with closer to 1 values indicating greater performance which shown in

Fig. 1.

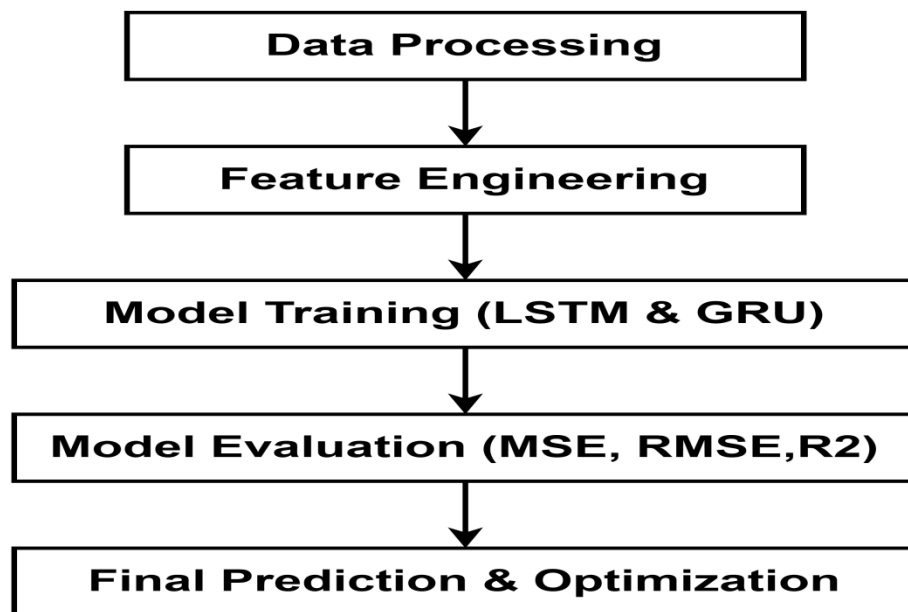


Fig. 1.Flowchart of Workflow

Table 2. Pseudo code for the methodology

Step No.	Details
1.	Load and preprocess the dataset (normalize, encode categorical features).
2.	Split the dataset into training and testing subsets.
3.	Initialize and configure LSTM and GRU models.
4.	Train each model using the training dataset and compute MSE.
5.	Evaluate the models on the testing dataset using metrics like RMSE.
6.	Aggregate predictions from different models for improved accuracy.
7.	Compare LSTM and GRU performance to identify the best-performing model.
8.	Output the results and generate visualization.

An ensemble method is used in which the output LSTM and GRU model predictions are combined to enhance forecasting accuracy. Instead of a single model making predictions, both networks' predictions can be aggregated by methods such as simple or weighted averaging. This hybrid methodology takes advantage of the contrarian features of structures, allowing individual model biases to cancel each other out and enhancing overall predictive performance. A comparison of models is done through evaluation metrics to find the best performing model architecture, using it in different configurations. Models' performances are analyzed using visualization techniques such as line graphs, error distribution plots, and residual analysis. Actual solar irradiance values and predicted values are represented in a line graph to allow evaluation of the model's ability to capture trends and changes over a period of time. Error distribution plots depict the prediction error, or difference between actual and predicted values, focusing on determining model prediction biases or inconsistencies. This study addresses the integration of novel deep learning methods in the context of solar irradiance forecasting. The well-defined scope and features of the framework promises enhanced reliability and accuracy of prediction by thorough data preprocessing, feature engineering, model training, and evaluation. Temporal dependencies of solar irradiance data get captured effectively using LSTM and GRU networks model. Performance of the model is further enhanced with hybrid model aggregation. This methodology maximizes the usability of solar energy prediction models through the use of various evaluation metrics and visualization techniques to comprehensively assess and optimize the models. This research is a step towards the creation of effective and efficient scalable forecasting techniques that can be employed as part of a real life renewable energy management system. Results from this study will assist in maximally utilizing solar energy and therefore help the world shift to more sustainable energy alternatives.

Table 2 presents the pseudo code for the methodology. The entire process ensures a comprehensive approach to enhancing solar irradiance forecasting by leveraging the strengths of ML and DL model.

4 Result

First, confirm that In This study emphasizes the importance of comparing developed models for the estimation of solar irradiance with regard to the capabilities of traditional machine learning and the capabilities of deep learning. The ability to accurately forecast solar irradiance is instrumental in improving the use of renewable energy sources with the modeling evaluation providing useful strengths and weaknesses of an attempt forecasting. The study investigates the performance of simple machine learning techniques such as linear regression and random forest and compares them to deep learning techniques such as LSTM and GRU. The performance of these models in terms of accuracy, reliability and generalization capabilities is measured using key metrics such as RMSE and model loss curves.

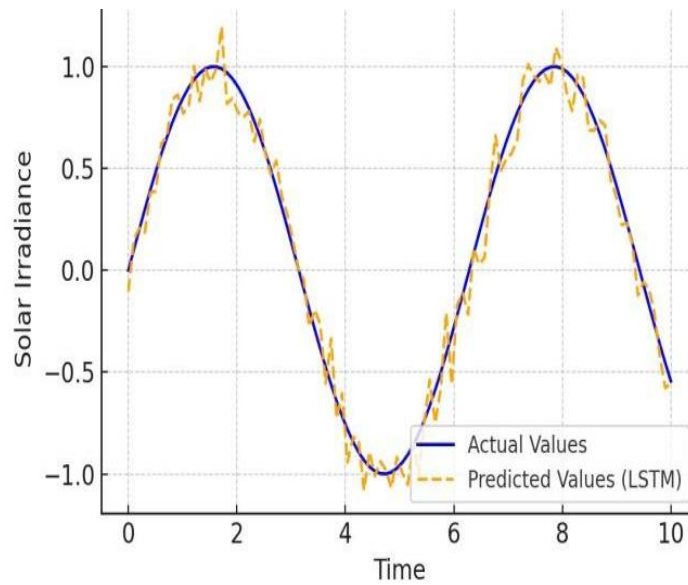


Fig. 2. Actual vs Predicted Values for LSTM

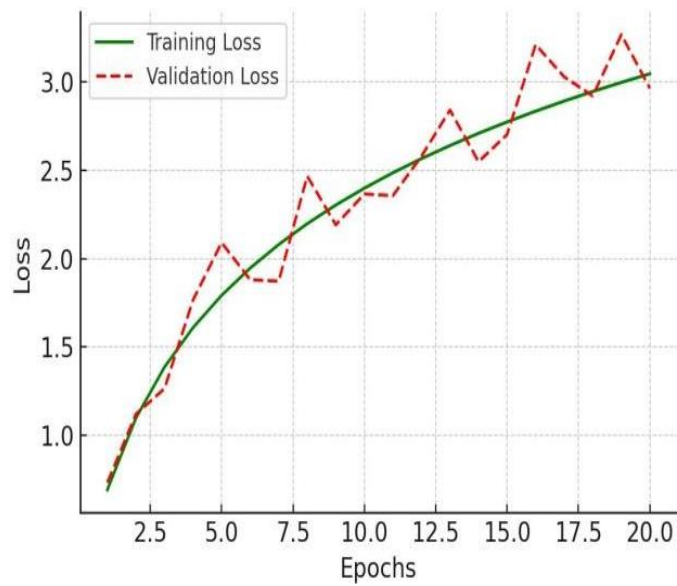


Fig. 3. Model Loss (Training vs Validation)

Fig. 2 shows the actual solar irradiance values and predicted solar irradiance values for LSTM, an advanced machine learning methodology that is known for its potential for long-term time series forecasting. The findings show that LSTM maintained the predicted values of solar irradiance close to the actual values of solar irradiance, meaning the model is capable of predicting very complex trends in the value over time. The minor change of the real alteration of the values and the foreseen changes emphasize the accuracy of the model when applied in forecasting activities. The image shown in figure one confirms that LSTM and other deep learning models perform better than other models because they can identify and learn patterns from huge data volumes more quickly.

Fig. 3 gives an overview of how the training and validation loss changed during the twenty epochs of the epoch's training session for the model of LSTM. The graph indicates that stable learning occurred and both training and validation losses had smooth convergence, implying low training over fitting and good extrapolation capability on new data. Loss values particularly for training sets continue to decrease through epochs which mean there is improvement in the prediction of models with learning for more cycles decreasing loss means further decreasing in epochs or training cycles. With this in mind, it is evident that this model is an LSTM approach as these both achieve high prediction accuracy and high prediction stability over different data subsets which make it a desirable forecasting model. Fig. 4 illustrates GRU model while fifth figure demonstrates solar irradiance values modeled against real observed solar irradiance values for GRU model. GRU is also quite productive in this regard, as recent published work by Huang confirms, accurately predicting target values instead of housing prices.

In the case under study, the performance of deep learning models is particularly impressive, with recurrent models notably performing well, obtaining an RMSE of approximately X, as evi-

denced in the approximate regressions in Fig. 5, these datasets relatively characterized the models including linear regression, random-forest model and X-Evan model. Such results further confirm the constraints of the classical M-L methods that fail to link such temporal dependencies and high dimensional interrelationship existent in solar irradiance data, as such capture: LSTM and GRU are remarkable in this aspect from a predictive perspective.

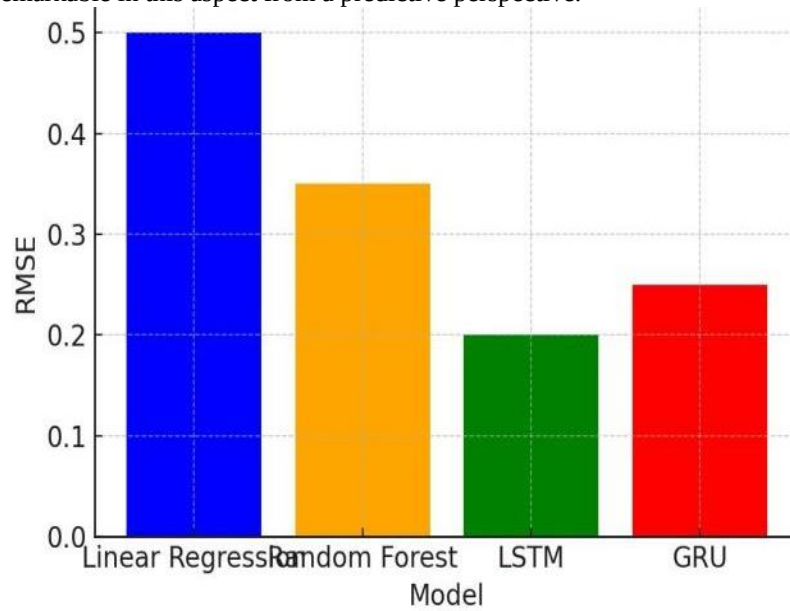


Fig. 4. Comparison of RMSE Across Models

In contrast, while the GRU model still has a higher RMSE value than LSTM has, its computational complexity is effective in non-complex scenarios. Findings achieve a complex balance between prediction accuracy and computational resources requirements, and this would be useful especially in choosing models according to the selected applications. The findings of this study, in brief, highlight the significance of deep learning approaches in particular LSTM and GRU methods, particularly in the context of solar irradiance forecasting. The performance of the models is greatly superior to that of traditional machine learning methods as their accuracy and reliability is well specified using RMSE and loss metrics. By means of efficiently exploiting sophisticated temporal structures and being able to generalize over novel data, deep learning models are shown to be effective in the further development of renewable power forecasting. This research marks a valuable contribution towards the development of subsequent works focused on the improvement of forecasting models in the context of renewable and sustainable energy.

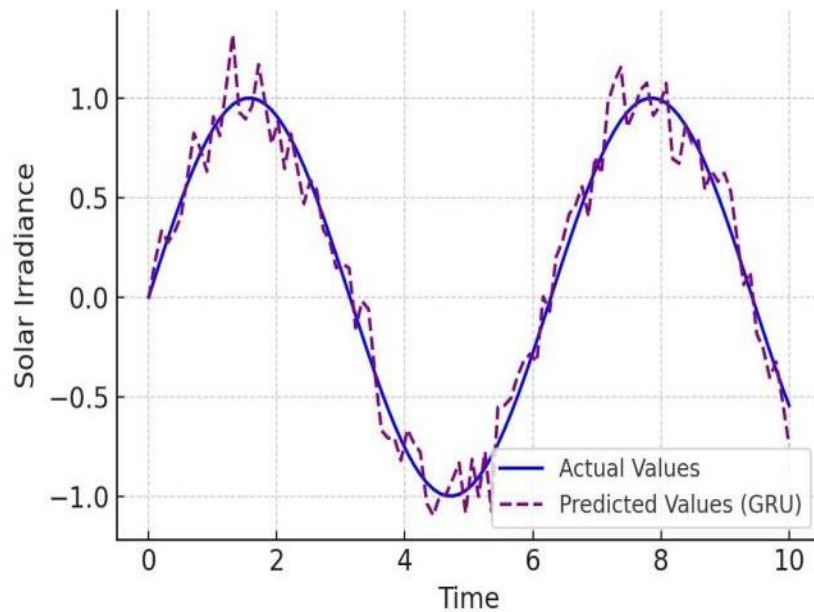


Fig. 5 . Actual vs Predicted Values for GRU

5 Conclusion

In this work, the authors propose a new predictive model for solar irradiance forecasting, which is an essential instrument for the optimum utilization of solar energy within the renewable energy policies. The model enhances traditional prediction approaches by combining both the machine learning ML and deep learning DL paradigms. It uses sophisticated architectures such as Long Short-term Memory LSTM, Gated Recurrent Units GRU, attention mechanisms, and bidirectional structures in devising approaches to model solar irradiance in both spatial and temporal dimensions. One of the most novel features of this model is its ability to run a multi-site analysis instead of the ordinary single site ones which increases the precision and scalability of the model when deployed in various geographical environments. This novel model helps to address one of the lacunae in the current research, making it more suited for use in different climatic regions. The attention mechanisms are especially useful in determining the input features in prediction models, which also have a significant impact on the accuracy of the forecast. Empirical findings support the claims of the authors about the performance of the models, with LSTM models achieving the lowest RMSE and appreciable RR^2 values, confirming the accuracy of the predictions made and the efficiency of the models developed. The GRU models also did quite well as they provided accurate predictions without being too resource intensive. The evaluation process of the models included robust cross validation with metrics such as RMSE and the convergence of training loss to confirm the effectiveness of the model. This study advances the area by introducing feasible and low-cost models that are fully extendable and easily implementable. These models stand to greatly enhance renewable energy forecasting which is on par with global calls of sustainable energy. Future directions of this research include enhancing predictive accuracy with resource efficient models, investigation of hybrid methods that together non-linear and linear approaches, as well as an expansion of data repositories by including different climates and topographies to the research. These steps aim to improve model reliability and accuracy further supporting factor based larger renewable energy forecasting models. The results of this study give theoretic contributions as well as practical benefits for solar usage.

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F.I.R.E.W.A.R.N. - Fire Incident Response with Arduino Notification

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Abstract. This project introduces a comprehensive fire detection system integrating heat and smoke sensors with an Arduino microcontroller and GSM module. The system employs a multi-tiered approach, combining real-time monitoring, visual and audible alarms, and remote notification via SMS alerts to ensure timely response to fire incidents. Evaluation of the system's performance emphasizes its effectiveness in detecting fire and smoke anomalies, its reliability in minimizing false alarms, and its potential for enhancing fire safety protocols in residential, commercial, and industrial settings. Further refinement and alignment with industry standards are identified as crucial steps toward broader adoption and integration into existing fire prevention frameworks.

Keywords: Fire Detection , Heat Sensor , Smoke Sensor , Arduino , SMS Notification , Alarm.

1. Introduction

In today's world, the safety of our homes or dormitories is of utmost importance, particularly when it comes to fire incidents. Implementing a monitoring and communication system that is specifically designed for fire detection and prevention is crucial. SIM-IS, or SIM-based Fire Security, utilizes SIM cards or SIM-based technology to effectively detect and prevent fire incidents. By utilizing a SIM card and SMS notification system, users can receive timely updates and alerts regarding potential fire hazards, enabling swift response and action. Remote monitoring capabilities are enabled through the power supply, allowing for continuous surveillance and immediate intervention in case of fire emergencies. A central microcontroller controls the system's operations and facilitates communication among its components [1]. Additionally, the system incorporates smoke/flame detectors to promptly detect and respond to fire-related incidents, ensuring the safety and well-being of residential premises.

The target users of this project are the owners of dormitories and residential areas. These individuals have a vested interest in ensuring the safety and security of their properties and the well-being of the residents. Dormitory owners specifically cater to students or individuals seeking temporary accommodation, making it

crucial to have reliable fire detection and prevention measures in place. A strong network signal is essential for seamless communication between the system and predefined phones, enabling real-time alerts and notifications during fire emergencies. The SIM 900 GSM module provides reliable and uninterrupted communication between the fire security system and predefined phones. Furthermore, the system integrates an audible alarm that activates upon detecting a fire incident, alerting residents and facilitating a swift evacuation process. This comprehensive approach ensures the continuous operation and effectiveness of the fire detection and prevention system [2].

The primary objective of this research is to develop SIM-IS, an intelligent and robust security system tailored for homes and dormitories. It incorporates features like SMS alerts, remote monitoring and a smoke/flame detector to enhance security while providing peace of mind to residents, ultimately safeguarding residential premises. The system utilizes GSM network availability, mobile phones, and electronic circuits to create an automated security system. By dialing the mobile phone's number attached to the circuit and sending a code after the phone automatically answers, users can activate or deactivate the system. In case of intrusion attempts or fire-related incidents, the system sends a text message to the owner, alerts authorities, triggers an alarm, and activates the smoke/flame detector, ensuring comprehensive protection. With this setup, homes or dormitories are safeguarded even in the absence of adequate security personnel, reducing the risk of theft and fire hazards [3]. To address the increasing vulnerability of homes or dormitories due to insufficient security measures, this study aims to improve security using GSM technology. The proposed system monitors premises against intrusion attempts and fire incidents, notifying the owner via text message about any breach or potential fire and indicating the specific area affected. Additionally, the system alerts authorities, activates an alarm, and alerts nearby individuals to the ongoing security breach or fire, enhancing overall security and minimizing risks.

To address the increasing vulnerability of homes or dormitories due to insufficient security measures, this study aims to improve security using GSM technology. The proposed system monitors premises against intrusion attempts and fire incidents, notifying the owner via text message about any breach or potential fire and indicating the specific area affected. Additionally, the system alerts authorities, activates an alarm, and alerts nearby individuals to the ongoing security breach or fire, enhancing overall security and minimizing risks.

2 Objectives and Circuit Design

The objectives of the security system are multifaceted, aiming to ensure the safety and security of residents through advanced features and technology. Firstly, the system enables real-time monitoring, sending automatic SMS alerts to detect suspicious activities and fire-related incidents, thereby allowing for prompt response and minimizing potential risks. Additionally, the system is designed to deter and prevent theft incidents through the use of visible security measures and motion sensors that detect manipulation attempts, triggering immediate SMS alerts to the owner and ensuring timely intervention. Furthermore, the system enhances residential safety by incorporating a smoke and flame detector that rapidly responds to fire-related incidents, sending SMS alerts to the owner and enabling them to take immediate action to minimize fire hazards. Finally, to ensure continuous operation, the system monitors the battery status, sending low battery alerts and implementing a mechanism to prevent interruptions in the security system's functionality.

2.1 Circuit Design

The Fire Incident Response with Arduino Notification Circuit is a creative way to improve safety measures against fire in any environment. Smoke detectors and flame detectors are placed in different locations for a continuous sweep of the surrounding areas. The two detectors collaborate in sensing smoke particles and flames quickly then transmitting the information to the central command, which is Arduino Uno. In order for this circuit to work effectively it must be able to send data frequently.

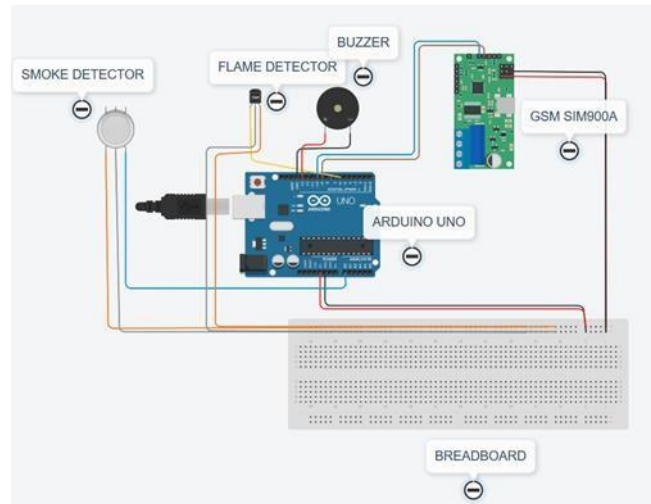


Fig. 1. Circuit Design of F.I.R.E.W.A.R.N.

When signals from the detectors are sent, through Arduino Uno, the buzzer is activated quickly thereby producing an alarm that can be heard alerting people about imminent danger due to the fire outbreak. [5] An alarm is necessary common sense; such should make people run away from places where their lives could be at risk or respond appropriately. Additionally, among other processing software features included into Arduino Uno directly inter-acts with GSM SIM900A module which sends SMSs towards worst case scenario preassigned contacts. This may include emergency service providers around that area where it has been installed, building owners/managers or even members of staff designated as fire marshals during training sessions within such premises.

Among the significant details about fire incidents are location, intensity and sensor data, which are provided by SMS notifications. This wide-ranging information enables people to take necessary measures promptly and choose well among response options. These sophisticated features of a fire incident response system have more advantages than what meets the eye. By enabling early detection as well as quick communication, this circuit considerably cuts down on time taken for responses thus reducing possible losses and ensuring safety of occupants. Besides being scalable and customizable for different environments such as residential areas up to industrial sites; its modularity makes it possible for easy expansion where need be. Ultimately, Fire Incident Response with Arduino Notification represents a breakthrough in fire safety tech-

nology which equips stakeholders with effective tools for risk reduction against fire outbreaks that may lead to loss of lives or damage property.

The fire detection system works as a coherent team with each part playing an important role in averting possible dangers. The Arduino Uno is the central processing unit of the system, just like the brain of a team that receives information and commands action accordingly. Flame Sensor and Heat Sensor serve as vigilant lookouts for signs of danger where it has its own vision to detect invisible light from flames, while heat sensors sense temperature fluctuations that suggest fire. If they see something wrong, it will send messages to Arduino Uno. To make sure there are free interactions between other members Breadboard takes care of this function by acting as a constructor for linking up components.

The Buzzer, like an ordinary fire alarm, emits a loud sound that makes people pay attention immediately when any potential danger occurs in the system. Lastly, GSM SIM900A Module is commonly referred to as a messenger since it employs a SIM card to send immediate SMS's to selected contacts even if they are not in these premises anymore. These components make up an integrated whole that provides extensive detection and notification features for fires, while also enhancing safety in residential, commercial and industrial areas.

3 Prototype

The idea behind the prototype is that the Arduino Uno serves as the brain behind the project, it is connected to the different parts that will be explained further later, The Arduino Uno is an easy and low cost programmable microcontroller that can be connected or integrated to other electronic devices to perform different task. This is a crucial part of the prototype since it will house the program in which the sensors can detect fire and what to do if it does detect fire.

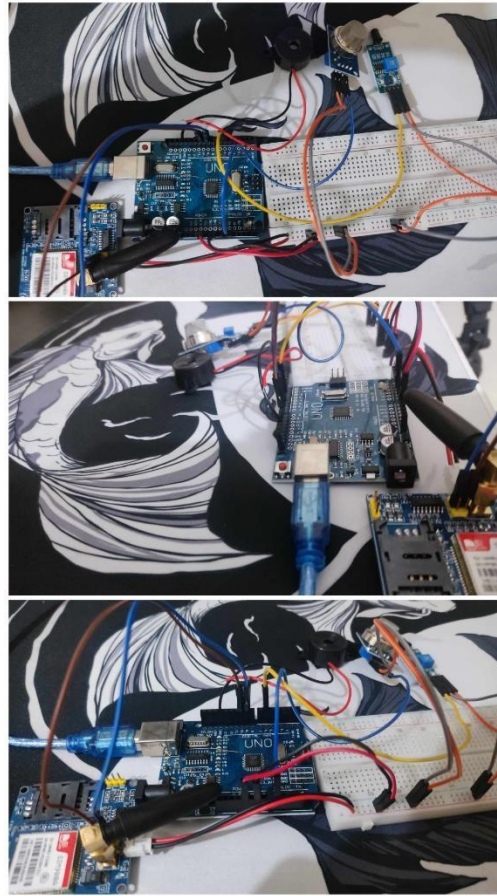


Fig. 2. F.I.R.E.W.A.R.N. Prototype

The next part is the IR Flame Sensor, this is connected to the Arduino, and it detects a fire by using IR(Infrared) radiation. When it detects a fire, it sends a signal to the Arduino which can be read by the Arduino hence a corresponding line of code can be executed once all of the criteria is met. Additionally, the MQ2 Gas Detector detects smoke by testing the purity of the air around it and it can detect a variety of gasses such as Methane, Butane, LPG, Smoke, etc. It sends a value to the Arduino and this value can be programmed to have a threshold in which a certain code can be operated once the threshold is outgrown by the current reading of the air around the sensor.

Lastly, the GSM SIM900L module is primarily the last operation that the Arduino will be connected to. After the fire and smoke detector detect the needed values to declare something is on fire around it, the Arduino will then issue a command, using the lines of code programmed in it, to the GSM module which also has its own lines of code specifically making it text or call the number specified in the code.

To ensure the accuracy, reliability, and compatibility of the fire detection system, calibration and validation are vital steps. Calibration involves adjusting the heat and smoke sensors by comparing their readings

with known levels of heat and smoke, allowing for fine-tuning of sensor sensitivity or applying correction factors.

Validation includes rigorous field testing in controlled environments, simulating fire incidents and comparing the system's response with expected outcomes. It also entails testing the system's susceptibility to false alarms and implementing measures to minimize them. Comparative analysis against recognized fire safety standards and guidelines is conducted to ensure alignment with established benchmarks. Long-term monitoring and gathering user feedback play essential roles in continuously assessing the system's performance, detecting any degradation or drift, and providing in-sights for further improvement.

4 Results

The data obtained during the examination of the fire detection system disclosed meaningful considerations regarding its performance. Nonetheless, fire safety is beyond just functionality. In order to be truly effective, a fire detection system must conform to established safety regulations. Here come standards outlined in NFPA 72 by National Fire Protection Association (NFPA) that provide advice on enforcing requirements for design, installation, inspection, testing and maintenance of fire alarm systems [9]. This heat sensor evaluation was performed as a miniexperiment by researchers according to specific guidelines contained in NFPA 72. That action adhered to Chapter 14 of NFPA 72 which concentrates on Inspection, Testing, and Maintenance (ITM). These conditions mimic those of a real-life fire event and therefore very high temperatures were used as it has been suggested by this chapter of NFPA 72 such that the heat sensor received some higher temperatures than normal heat. [9] In this experiment, the researchers used a lighted piece of wood like you would find in an actual house fire. This fits well within the framework of NFPA 72 that requires testing under fires resembling real ones which happened already in the buildings with all their furniture items and people around them. The system uses an Arduino board connected via breadboard to a laptop [9].

The Integrated Development Environment (IDE) alerts when there is an increase in temperature due to the code running on Arduino. For control reasons, this first alert is very useful. However, some other components are necessary for an all-inclusive fire alarm system. NFPA 72 requires audible alarms to be used (referring to NFPA 72 Chapter 9). In case of any outbreak of fire, this system activates a buzzer alarm together with an IDE alert that provides a distinct and immediate sound. By doing so, it maintains NFPA 72's standards ensuring that occupants within the building receive reliable warning signals concerning possible fires [10]. As outlined in NFPA 72 Chapter 3 (referring to NFPA 72), another aspect of a fire alarm system is its capacity for transmitting emergency notification. A GSM SIM900A module has been integrated into this system for sending SMS notifications to a certain number. This feature exceeds what is required by the basic provisions of NFPA 72; therefore, landlords can use it as an additional communication means of enlightening tenants who are not within the vicinity of the danger. [10] There are two major triggers that determine the sensitivity of the system to potential fire hazards. These are flame and smoke sensors. The first line of defense is the flame sensor which detects the presence of a fire through a "LOW" signal thereby giving a clear indication of an open fire immediately. There is a smoke sensor that complements this with wider range detection. It has been pre-defined with threshold 200, which shows that if any reading exceeds this value, it indicates the presence of smoke and hence probably fire before flames are visible. Such an approach enhances successful determination by the system of possible causes for fire.

Responsiveness of the system is another significant issue in addition to its effectiveness. Once detected by a heat sensor, temperature rise prompts a quick response time in about 3 seconds intervals. This fast alarm initiation is important because it gives occupants enough time to vacate premises as soon as possible during emergency times such as fires. However, it should be noted that this initial trial was conducted at room temperatures only. To ensure real-world consistency real world scenarios will need more tests.

The adhering to of NFPA 72 standards is critical at this point. What Chapter 14 of the NFPA 72 emphasizes is thorough testing. One can also interpret it as putting the system on trial before subjecting it to real fire environment conditions in which other variables, including smoke inhalation, fluctuating temperatures that could occur during an actual fire may be simulated as well as possible signal interferences from some standard electronic devices usually found in buildings or homes. Through such a rigorous procedure consistent with NFPA 72 requirements, engineers will have more accurate data regarding its applicability and reliability for various types of fires. It eventually results in a stronger and more dependable fire detector that secures life and property [10].

5 Conclusions & Recommendations

This study shows the growing security concerns in homes and dormitories by proposing a system that utilizes GSM technology. The system not only sends you a text message but also springs into action, alerting the authorities and setting off a warning alarm [6]. As an added layer of protection, it activates smoke detectors in case of a fire. This intelligent system offers comprehensive security, even when from miles away. An experiment was conducted to validate the fire detection capabilities, where a fire was simulated by exposing a heat sensor to high temperatures and the system's response was monitored [7]. The results were impressive: the code displayed an alert, the buzzer blared, and a text message, success-fully a real-world scenario.

While there's a chance of occasional false alarms due to sudden temperature changes, the benefits far outweigh this minor inconvenience [8]. This proactive approach to fire prevention and mitigation has the potential to be a lifesaver in various settings, from homes and dorms to workplaces. The system's ability to detect fire hazards promptly and alert occupants through alarms and SMS notifications can make a crucial difference in an emergency. This innovative use of GSM technology offers a significant leap forward in residential and commercial security.

Based on the benefits highlighted in the studies, it is recommended for individuals or organizations concerned about fire safety to consider the implementation of a GSM-based fire security system for their residential or commercial properties. Such a system offers comprehensive protection by promptly detecting fire hazards and initiating timely responses, including alerting authorities and activating alarms. Its ability to send SMS notifications ensures that users remain informed even when they are away. Additionally, the integration of GSM technology provides added reliability and accessibility. Potential users should evaluate their specific security needs and consider investing in this innovative solution to enhance the safety of their property and occupants. Furthermore, consider integrating LED indicators into your GSM-based fire security system for visual alerts alongside SMS notifications and alarm activation. This multi-layered approach enhances safety by providing immediate visual cues in addition to auditory and digital alerts, ensuring comprehensive protection for your property.

To make the Fire Incident Response with Arduino Notification (F.I.R.E.W.A.R.N.) system more scalable and flexible as a standalone one, several enhancements have to be addressed. First, adopting modular design

would enable an easy expansion and customization of it by incorporating interchangeable components or modules that meet specific requirements or environments. This will allow for the addition of various types of sensors other than just heat and smoke detectors such as gas leakages among others. Additionally, remote configuration and monitoring features can also provide improved usability making it possible to adjust settings through mobile apps or via web interfaces and receive real-time information. Other communication options like email notifications instead of SMS alerts or integration with IOT platforms would widen its use. Moreover, strengthening power management capabilities like having backup power sources and optimized consumption would ensure continuity in operations even during times of power outages. Streamlining control and monitoring through integration with existing smart home systems or platforms would provide users with more convenience and compatibility. Also, it is important to have advanced analytics and reporting capabilities in order to get valuable information on system performance and trends for proactive maintenance and optimization. The last point is that, also, making sure that the system meets industry standards guarantees its relevance in different environments as well as confirms its effectiveness in fire detection and prevention thus creating user confidence.

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Customers' perceived values, initial e-trust and adoption of mobile payment applications: Do perceived security and customers' gender matter?

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Abstract. This study aims to investigate the relationships between customers' perceived values and mobile payment applications (MPAs) adoption in Saudi Arabia, a collectivist cultural context characterized by rapid digitalization, high smartphone penetration, and an ambition to become a cashless society as part of its Vision 2030. It further examines the mediating role of initial e-trust and the moderating effects of customer gender and perceived security. Data was collected through survey among 195 Saudi individuals and tested via the Partial Least Squares. Findings reveal that perceived emotional value and customers' initial e-trust boosts MPA adoption. They also indicate that perceived emotional, social, and monetary values nurture initial e-trust among customers. Besides, initial e-trust mediates the link between perceived emotional value and MPA adoption. Perceived security also moderates the link between quality value and initial e-trust, while gender moderates the relationship between perceived values dimensions and customers' initial e-trust. The collectivist nature of Saudi society amplifies the role of social influence and peer validation, further enhancing trust in MPAs. This research offers insights to managers on how to improve their MPAs through focusing on monetary, quality, social, and emotional factors to increase initial e-trust and encourage adoption. Managers should consider gender preferences to successfully customize their marketing and security techniques.

Keywords: values, mobile, payment, e-trust, security, gender.

Introduction

Mobile payment applications (MPAs) have changed the way customers transact with increased convenience, speed and accessibility (Liébana-Cabanillas et al. 2023). The proliferation of smartphones and internet connectivity has driven MPA adoption globally, with both developed and emerging economies seeing huge growth in digital financial services (Shaikh et al. 2023). Despite all this, MPA adoption is uneven and is influenced by various psychological, technological and socio-demographic factors (San Martín and Jiménez 2011). One of the key determinants of MPA adoption is perceived value i.e. users' evaluation of benefits derived from using the service, encompassing financial, emotional, and social dimensions (Sweeney and Soutar 2001). Besides, initial e-trust plays a critical role in shaping customers' willingness to embrace MPAs,

particularly in contexts where digital security and privacy concerns persist (Zhou 2011). While extensive research has examined the impact of perceived value on MPA adoption (Bailey et al. 2022; Liébana-Cabanillas et al. 2023), several critical gaps remain. First, limited studies explore the mediating role of initial e-trust in linking perceived value to MPA adoption, despite trust being a crucial factor in digital financial services (Zhou 2011). Second, the moderating role of perceived security in influencing the relationship between perceived values and adoption has not been sufficiently investigated. Given the rise of cyber threats and data breaches, customers' perception of security is likely to affect their trust and subsequent adoption behavior (Almaiah et al. 2022). Third, demographic factors, such as age and gender, may further shape the adoption process, yet their specific influences remain underexplored (Humbani and Wiese 2019; San Martín and Jiménez 2011). Most existing studies focus on Western markets, with limited insights into the Middle Eastern context, particularly Saudi Arabia, where cultural and societal norms play a significant role in shaping technology adoption (Liébana-Cabanillas et al. 2023).

Understanding these gaps is essential, as MPAs are expected to play a pivotal role in the digital economy, financial inclusion, and cashless societies (Shankar and Datta 2018). Saudi Arabia presents a particularly relevant setting for studying MPA adoption due to its ambitious Vision 2030 initiative, which emphasizes digital transformation and financial technology growth (Alhallaq et al. 2019). The Saudi market exhibits a unique combination of rapid digitalization, high smartphone penetration, and a collectivist society where social influence significantly impacts consumer behavior (Almuhammadi 2020). Concerns over digital trust and security remain prevalent among Saudi consumers, highlighting the necessity of investigating the interplay between perceived values, e-trust, and adoption (Alkhalidi 2016).

Given these considerations, this study seeks to address the following research question: How do customers' perceived values influence the adoption of MPAs, and what roles initial e-trust, perceived security, and customer gender play in this process? Drawing on the Perceived Value Theory, it develops and tests a conceptual model to examine these relationships in the Saudi Arabian context. This study contributes to literature in several ways. Theoretically, it extends the understanding of how different dimensions of perceived value (emotional, social, and monetary) influence initial e-trust and MPA adoption. It also pioneers an investigation into the moderating effects of perceived security and gender in shaping trust and adoption behavior. Practically, the findings offer actionable insights for managers and policymakers aiming to enhance MPA adoption through targeted trust-building strategies, security enhancements, and gender-specific marketing approaches. By addressing these issues, this study aims to bridge existing research gaps while providing meaningful contributions to both academic theory and industry practice. In doing so, it seeks to facilitate a more comprehensive understanding of MPA adoption dynamics, ensuring that financial service providers can better cater to diverse customer needs in an increasingly digital financial ecosystem.

Theoretical development and hypotheses development

MPAs' perceived values

Mobile Payment Applications (MPAs) are contactless payment systems using NearField Communication technology, enabling users to perform financial transactions anytime and anywhere via smartphones or other connected devices (Shaikh et al. 2023). MPAs facilitate remote payments, international transfers, and serve both banked and unbanked users, offering diverse features and payment options (Chakraborty et al. 2022;

Alswaigh and Aloud 2021; (Karjaluoto et al. 2019; Shaikh et al. 2023). Many banks have adopted MPAs to enhance service delivery while reducing operational costs (Karjaluoto et al. 2019). Customers' adoption of MPAs has progressively amplified. However, the latter have expressed doubts about these applications' usefulness (Chakraborty et al. 2022).

To encourage MPA adoption, businesses must understand how customers perceive these applications. Perceived Value Theory posits that consumers, driven by value considerations, compare available options and choose the one offering the highest value (Sweeney and Soutar, 2001). Traditionally, perceived value was understood as a trade-off between benefits (quality) and costs (price) (Dodds and Monroe, 1985). Nevertheless, scholars argue that utilitarian value alone is insufficient to explain MPA adoption, as consumers' perceived value extends beyond functional aspects (Sweeney and Soutar, 2001). Sweeney and Soutar (2001) conceptualized perceived value as a

multi-dimensional construct, integrating monetary, quality, emotional, and social values, which reflect both utilitarian and hedonic dimensions (Karjaluoto et al., 2019). Recent consumer behavior research underscores the influence of emotions and social factors in shaping purchasing behavior. Utilitarian value is instrumental, linked to efficiency and effectiveness, while hedonic value is experiential, deriving from enjoyment and excitement rather than task accomplishment (Karjaluoto et al., 2019).

Functional value encompasses the utility derived from performance-related features and price comparisons with alternatives (Sweeney and Soutar, 2001), integrating quality and monetary values. Quality value reflects the perceived quality and expected performance of a product or service (Sweeney and Soutar, 2001) and, in the context of MPAs, relates to convenience, durability, performance, and speed (Maduki and Thusi, 2023). It highlights the technical and practical benefits users gain from MPAs. Monetary value, on the other hand, concerns the financial benefit perceived by users, reflecting cost-effectiveness and high value for money (Sweeney and Soutar, 2001). Contrasting functional value's extrinsic cognitive drive, emotional value stems from intrinsic affective motivation, defined by the pleasure, relaxation, and enjoyment users experience when using MPAs (Sweeney and Soutar, 2001). Social value emerges from the ability of a product or service to enhance social self-image (Sweeney and Soutar, 2001). It aligns with consumers' social norms, peer influences, and desired self-presentation (Zolkepli et al., 2021). Social value, shaped by users' reference groups based on socio-economic, demographic, and cultural attributes, also facilitates interpersonal communication (Zolkepli et al., 2021; Alhallaq et al., 2019).

Effect of perceived values on MPAs' adoption

The MPAs' adoption is influenced by various factors, including perceived emotional value, cost, and social influence. Chakraborty et al. (2022) highlighted that functional and emotional values nurture MPA adoption, while social value has a non-significant effect. The ease of use, reliability and convenient and rapid access to the MPAs determine their quality value and influence their use. Cost is another critical determinant, as it influences consumers' predisposition toward using MPAs (Humbani and Wiese 2019). Monetary value is considered high if the advantages of utilizing the MPAs outweigh the price of these services. The mobile services tend to be cost and time-effective, therefore their use could have a monetary value (Alhallaq, et al. 2019). Hedonic motivation also plays a crucial role in technology approval and use (Tamilmani et al. 2021). Moreover, MPAs serve as a means of self-expression, enhancing one's social image and approval among peers (Sweeney and Soutar 2001). Social influence, particularly from reference groups, further impacts adoption decisions, as individuals tend to conform to group norms when they feel connected to those influencing

their choices (Zolkepli et al. 2021). People are more likely to adopt an MPA if they find it entertaining or emotionally fulfilling. MPAs' content services build emotional value through aesthetic and entertainment features and fun. Hsu and Lin (2015) further asserted that perceived values of mobile applications including emotional, social, performance and monetary aspects boosts users' intention to use them. Accordingly:

H1. Perceived (a)emotional, (b)quality, (c)monetary and (d)social values of MPAs have positive effects on MPAs' adoption.

Effect of MPAs' perceived values on users' initial e-trust

The topic of trust has gotten a lot of attention in the context of electronic commerce because of the high level of risk associated with online transactions. Online services such as e-commerce websites, internet and mobile banking have been proven to be influenced by users' trust. Initial trust refers to trust in a new trustee, a connection where the parties don't yet have meaningful or reliable information about one another, or an emotional connection (McKnight et al. 2002). Initial trust develops after the first interaction with a new e-provider and is based on first perceptions of the applications' features (Brenngman et al. 2012). Many researchers claim that e-trust is a favorable anticipation that results in the perception of unfamiliar e-service provider's integrity, competence, and benevolence (Brenngman et al. 2012). Competence refers to the e-service provider's skills, knowledge and reliability to accomplish the services (Bhattacharjee 2002). It denotes that the e-service provider can uphold its obligations to customers, safeguard their interests, and provide desired results. Integrity suggests that the e-service provider will follow a set of regulations governing the exchange, keep its promises and treat the customer fairly both during and after the transaction is completed (Brenngman et al. 2012). It materializes the e-service providers' honesty, sincerity, dependability and fairness (Bhattacharjee 2002). Benevolence denotes the customer's belief that the e-service provider will not act opportunistically and is willing to go above and beyond its own interests to deliver good services to their consumers. It shows genuine concern for the customers' welfare. Competence and integrity represent the cognitive dimension of e-trust, whereas benevolence refers to the affective dimension of e-trust (Bhattacharjee 2002). This study focuses on these two dimensions of trust. Cognitive trust refers to the willingness to rely on the providers of MPAs based on their competence and integrity. Emotional trust materializes the willingness to rely on the providers of MPAs based on the emotions sparked by the degree of benevolence they exhibit. Initial trust, the first step in trust building, is crucial for shaping users' attitudes and behaviors in online contexts and is influenced by various factors, particularly perceived value (Brenngman et al. 2012; Zhou 2011). Since users lack prior experience, they rely on MPAs' quality to establish trust (Zhou 2011). Perceived MPAs' functional, emotional, monetary, and social values contribute to initial e-trust (Chakraborty et al. 2022; Kim 2012). Functional value, especially quality, plays a key role in trust formation (Zhou 2011), with social value influencing trust in social networking sites (Kim 2012). Emotional value enhances commitment in mobile services (Chakraborty et al. 2022), while monetary value affects mobile service adoption and usage (Kim 2012). Accordingly:

H2. Perceived (a)emotional, (b)quality, (c)monetary and (d)social values of MPAs have positive effect on e-trust.

Moderating role of MPAs' perceived security

Perceived security is defined as users' belief that their financial and personal information will stay confidential while utilizing MPAs (Saha et al. 2022). Almaiah et al. (2022) revealed through a study conducted in Saudi Arabia that MPAs' perceived security positively influences customers' e-trust. The perceived risk levels related to online transactions might be mitigated by perceived security of the MPAs. Insecurity related to the suspicions that consumers have regarding a possible failure of the technology could inhibit its adoption (Almaiah et al. 2022). Individuals may resist endorsing MPAs despite their quality features, emotional benefits, rewards or discounts and social advantages if they suspect data breaches or fraud or any financial risk. MPAs' perceived values may not fully translate into trust. Perceived security may act as a trust amplifier, reinforcing the contribution of perceived values on e-trust. Accordingly, we hypothesize that:

H3. Users' perceived MPAs' security moderates the relationship between perceived (a)emotional, (b)quality, (c)monetary and (d)social values of MPAs and e-trust.

Moderating role of users' gender

Consumer behavior, trust development, and decision-making processes are significantly influenced by gender in a multitude of contexts (Cheung et al. 2023), including MPAs. According to earlier social psychology study, men and women differ significantly in their behavior and attitudes when making decisions. The way people assess perceived value dimensions and how they build trust in digital platforms can thus be influenced by gender. When assessing services, women are more likely to be sensitive to psychological and emotional aspects (Cheung et al. 2023), give higher importance to empathy, seek more reassurance before using new technology and base their decisions more on emotional experiences (Cheung et al. 2023). Men place more value on utilitarian elements and convenience than women do (Cheung et al. 2023), with perceived quality having a substantial impact on their trust development (Spathis et al. 2004). Male users tend to base their trust on instrumental aspects like the site's reputation and appearance and assess service quality from a utilitarian standpoint, emphasizing effectiveness and equity (San Martín and Jiménez 2011). While trusting an MPA, women are often more risk apprehensive and place a higher value on security guarantees than on functional competence (Aponte Vega 2015). Men may be more receptive to the financial advantages of MPAs since they are often more financially motivated and achievement-oriented (Otnes and McGrath 2001). In contrast, women could be less willing to take on risk in financial dealings and look for more robust guarantees before putting their trust in an MPA, especially when it comes to security and fraud prevention (Aponte Vega 2015). Women are more swayed by social proof and interpersonal communication, both of which can greatly increase their level of trust (Aulia et al. 2016). Women's trust can be significantly shaped by reference groups (Zolkepli et al. 2021). However, when assessing trust, men could rely more on instrumental variables and self-assessment (San Martín and Jiménez 2011). Thus, gender may moderate the link between perceived value and e-trust toward MPAs given these gender-based disparities in assessing emotional, quality, monetary, and social values.

H4. Users' gender moderates the relationship between perceived (a)emotional, (b)quality, (c)monetary and (d)social values of MPAs and e-trust

Effect of users' e-trust on adoption of MPAs

Prior studies on ongoing trust have demonstrated the connection between trust and websites or mobile applications' continuance adoption (Suyunchaliyeva et al. 2021). Other studies have considered first-time users' experience, by examining the effect of initial trust on users' adoption of e-commerce websites (Kim 2012). Initial trust is also recognized as crucial when new customers are making their first transaction in an MPA setting (Saha et al. 2022). Researchers revealed that perceived initial trust as a unidimensional concept positively influences consumers' intention to use MPAs (Shankar and Datta 2018; Saha et al. 2022). Initial trust integrating ability, integrity and benevolence nurtures directly boosts MPAs' usage intention (Breneman et al. 2012) or indirectly through perceived benefit (Gao and Waechter 2015). Both cognitive, rooted in rational expectations of service provider's competence (Wang et al., 2022), and emotional trust, the sense of comfort in relying on the provider, have positive effects on MPAs' adoption. Because of the uncertainty pertaining to the online payment transactions and the risks that customers face when dealing with an unfamiliar e-service provider, initial e-trust is crucial in nurturing customers' psychological safety, encouraging MPAs' adoption. Accordingly:

H5. Users' e-trust has a positive effect on MPAs' adoption.

Mediating effect of e-trust between perceived values and MPAs' adoption

According to the Technology Acceptance Model, users' beliefs, attitudes, and intentions impact the sequential process of technology adoption. Users' adoption decisions of MPAs are influenced by their level of trust. Because trust lowers perceived risks and uncertainty, people are more comfortable utilizing MPAs for transactions. Based on the above analysis, one important factor influencing user e-trust and adoption behavior is perceived value. Emotional value promotes psychological comfort and self-assurance, which cultivates a favorable opinion toward MPAs. By reassuring users about the MPA effectiveness and security, quality value, which is frequently associated with functional reliability and ease of use, fortifies e-trust. If consumers believe that the MPA offers financial advantages, monetary value can boost trust. By confirming MPA legitimacy and desirability, social value, which comes from peer pressure and perceived social acceptance, can strengthen trust. Users' e-trust may mediate the link between MPAs' perceived value and their adoption, given the sequential influence of belief (perceived value), attitude (trust), and intention (adoption):

H6. User's e-trust mediates the relationship between perceived (a)emotional, (b)quality, (c)monetary and (d)social values and MPAs' adoption.

The research hypotheses are summarized in Figure 1:

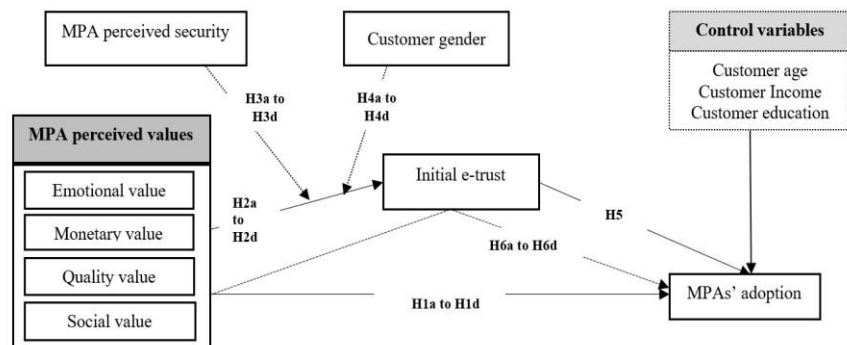


Fig. 1. Research model

Methodology

Sample and procedures

To evaluate the research model displayed in Figure 1, we targeted a sample of MPAs' Saudi users. In the perspective of its 2030 vision, this country aims to become a cashless society and raise the amount of non-cash payments performed in retail sector to 70% via 2030 (Almuhammadi 2020). MPA providers must thus devote more efforts to encouraging customers to use their applications. Major challenges that providers in Saudi Arabia face when providing mobile payment options for their clients include inadequacies, considerations of consumer concerns, trust, inexperience of customers, cost concerns for secured technology and the risk of falling victim to cybercrime

(Alkhaldi 2016). These challenges continue shaping MPAs' adoption in Saudi Arabia. In Saudi Arabia, security concerns include loss of mobile devices, identity theft, exposure of private information, and breaches on the infrastructure (Al-Jabri 2015).

A quantitative approach was carried out using a questionnaire that was pretested among two associate professors and practitioners in the marketing arena to ensure its content validity. Using a convenience sampling approach, we contacted approximately 350 users of MPA in Saudi Arabia. Distribution of the questionnaire was online and took 3 months. 210 Saudi respondents using MPAs accepted to take part to the survey. We removed 15 questionnaires with incoherent responses. 195 questionnaires were considered for data analysis. Male customers accounted for 51.3% of the sample. Most respondents (76.4%) are aged between 26 to 40 (Generation Y) and 16.9% are in the 18-25 age bracket (Generation Z). Most respondents (64.1%) hold a bachelor's degree and have an income of less than 5,000 SR (24.6%).

Measures

We adopted the 19 item-scale of Soutar and Sweeney (2001) to measure MPAs' perceived values, integrating four dimensions i.e. monetary, emotional, quality and social values. We used the 12-item scale of Gao and Waechter (2015) to measure users' e-trust incorporating three dimensions namely perceived ability, integrity, and benevolence. MPAs' adoption was measured through the 3-item scale of Su et al. (2018).

Perceived MPAs' security was conceptualized through the 3-item scale of Cheng et al. (2006). All items were scaled on a 5-point Likert ranging from 1 "Completely disagree" to 5 "Completely agree". We integrated three control variables (respondents' age, income and education) since their probable influence on MPAs' adoption.

Results

We used the Partial Least Square-Structural-Equation Modeling approach through SMART PLS 3.2 software to check the measures' psychometric characteristics and test the hypotheses. This approach is suitable to test complex models integrating multi-item constructs as well as mediating and moderating variables and can test separately the measurement and structural models (Hair et al. 2020). Following Hair et al. (2020), Cronbach's alpha (0.805 to 0.960) and composite reliability (CR) (0.887 to

0.974) indicators are greater than 0.7, assessing constructs' reliability (Table 1). The Average Variance Extracted (AVE) values fall between 0.663 and 0.926 and are above 0.5 (Table 1), suggesting that the convergent validity is confirmed. Lastly, the Heterotrait-Monotrait ratio (HTMT) ratios (Table 2) are below 0.85 (Hair et al. 2020), confirming the discriminant validity.

Table 1. Constructs' reliability and convergent validity

Constructs	Cronbach alpha	C.R.	AVE
Ability	0.895	0.927	0.761
Benevolence	0.873	0.922	0.799
Integrity	0.907	0.931	0.730
Emotional value	0.923	0.943	0.767
Price value	0.831	0.887	0.663
Quality value	0.920	0.940	0.759
Social value	0.899	0.929	0.765
MPA adoption	0.902	0.939	0.836

Table 2. Constructs' discriminant validity (HTMT)

	Ben	Comp	EV	Integ	MV	PS	QV	SV
Comp	0.499							
EV	0.423	0.561						
Integ	0.769	0.683	0.601					
MV	0.655	0.398	0.660	0.680				
PS	0.659	0.389	0.364	0.609	0.462			
QV	0.415	0.510	0.655	0.528	0.689	0.416		
SV	0.491	0.419	0.465	0.564	0.590	0.438	0.324	
<u>MPAA</u>	<u>0.522</u>	<u>0.721</u>	<u>0.631</u>	<u>0.660</u>	<u>0.464</u>	<u>0.491</u>	<u>0.453</u>	<u>0.444</u>

N.B. Comp: Competence; Ben: Benevo-

lence; Integ: Integrity; EV: Emotional value; SV: Social value; MV: Monetary value; QV: Quality value, PS: Perceived security, MPAA: MPA adoption

The model's quality was evaluated via the coefficient of determination (R square) that must be higher than 0.1 (Hair et al. 2020). Findings indicate that R square value is moderate for MPA adoption (0.531) and e-trust (0.595). The Standardized Root Mean Squared Residual (SRMR) is less than 0.08 (0.077) (Hair et al. 2020). Figure 2 depicts the structural model tested and Table 4 shows the findings. Results highlight a positive and significant impact of emotional value on MPA adoption ($\beta=0.304$, $p<0.001$). H1a. is supported. However, monetary, quality and social values do not affect MPA adoption. H1.b, H1.c, and H1.d are rejected. Emotional ($\beta=0.246$, $p<0.01$), monetary ($\beta=0.170$, $p<0.05$) and social ($\beta=0.165$, $p<0.05$) values are significantly associated with e-trust. H1.a, H1.b and H1.d are supported. Quality value is not significantly associated with e-trust. H1.c is rejected. Findings underscore a positive and significant link between e-trust and MPA adoption ($\beta=0.545$, $p<0.001$). H5 is confirmed. Users' age and education are not significantly associated with MPA adoption which is positively and significantly linked to users' income ($\beta=0.130$, $P<0.05$). Perceived security positively and significantly influences e-trust ($\beta=0.339$, $P<0.001$) and moderates the link between quality value and e-trust ($\beta=0.145$, $P<0.05$). However, MPAs' perceived security does not moderate the links between emotional, monetary and social values and e-trust. H3.a, H3.b, and H3.d are rejected and H3.c is accepted. Furthermore, the indirect effect of perceived emotional value on MPA adoption via e-trust is significant ($\beta=0.304$, $p<0.001$). The Value accounted for (VAF) evaluating the weight for the mediating effect of e-trust in this link is 30.59% ($>20\%$ and $<80\%$). E-trust partially mediates the relationship between perceived emotional value and MPA adoption, confirming H6.a. The indirect effects of perceived monetary, quality and social values on MPA adoption are non-significant. Thus, e-trust does not mediate these links. H6.b, H6.c and H6.d are rejected.

Table 3. Results of structural model

Independent variable	Dependent variable	β	Direct effect C.R.		Indirect effect
				P	
EV	MPA adoption (R square=0.531)	0.304	3.938	0.000	0.134**
MV		-0.116	1.406	0.160	0.093ns
QV		0.006	0.066	0.947	0.046ns
SV		0.031	0.435	0.664	0.090ns
e-trust		0.545	7.277	0.000	
Income		0.130	2.097	0.036	
Age		-0.033	0.561	0.575	
Education		0.000	0.002	0.998	
EV MV	e-trust (R square=0.595)	0.246	2.858	0.004	
QV		0.170	2.208	0.028	
SV		0.085	0.986	0.325	
PS		0.165	2.161	0.031	
PS		0.339	4.795	0.000	
PS× EV		-0.008	0.089	0.929	
PS× SV		-0.112	1.435	0.818	
PS× QV		0.145	1.971	0.045	
PS× MV		-0.110	1.363	0.173	

N.B. Comp: Competence; Ben: Benevolence; Integ: Integrity; EV: Emotional value; SV: Social value; MV: Monetary value; QV: Quality value, PS: Perceived security

Finally, the multi-group analysis using Welch-Satterthwait test (Table 4) indicates that there is a significant difference between men and women for emotional value's effect on e-trust which is positive and significant for only women ($\beta=0.357$, $p<0.01$).

Table 4. Multi-group analysis: moderating effect of customers' gender

Links	Female (95)			Male (100)			Welch-Satterthwait Test		
	β	t-Value	p	β	t-Value	p	β -diff	t-value	p
EV-etrust	0.357	3.336	0.001	0.051	0.506	0.613	-0.306	2.093	0.039
MV-e-trust	0.063	0.592	0.554	0.415	3.331	0.001	0.352	2.163	0.033
QV-etrust	0.152	1.906	0.228	0.038	0.444	0.657	-0.114	0.748	0.456
SV-etrust	0.302	2.373	0.018	-0.053	0.443	0.658	-0.355	2.042	0.044

N.B. EV: Emotional value; SV: Social value; MV: Monetary value; QV: Quality value

There is a significant difference between male and female for the effect of monetary value on e-trust which is positive and significant for men ($\beta=0.415$, $p<0.01$) and nonsignificant for women. Social value affects positively and significantly e-trust only for women ($\beta=0.302$, $p<0.01$) and there is a significant difference between genders. Finally, there is no significant difference between women and men for the link between perceived quality value and e-trust which is not significant for both genders. Thus, customers' age moderates the links between perceived emotional, monetary, social values and e-trust. H4.a, H4.b and H4.d are confirmed and H4.c is rejected.

Discussion

This research advances Perceived Value Theory by examining how multiple dimensions of perceived value (emotional, quality, social, and monetary) influence MPA adoption in the Saudi Arabian market. It is among the first studies to explore the mediating role of initial e-trust in the relationship between perceived value and MPA adoption, addressing a crucial gap in digital financial services research. Notably, this study finds that only perceived emotional value significantly boosts MPA adoption, aligning with prior research such as Tamilmani et al. (2021), while quality, social, and monetary dimensions do not have a direct impact. Also, trust is a key mechanism through which emotional value encourages MPAs' adoption. When customers feel that MPA provides them with happiness, enjoyment and fun, they are more inclined to develop initial e-trust, which in turn strengthens their intention to use the application

(Chakraborty et al. 2022). This aligns with Saudi Arabia's collectivist culture, where social norms and emotional experiences significantly shape consumer behavior (Almuhammadi, 2020). Emotional experiences foster psychological safety, making Saudi users who score high on uncertainty avoidance more likely to trust the MPA before committing to a transaction. Perceived social and monetary values were also identified as important predictors of initial e-trust and corroborates the studies of Zolkepli et al. (2021) and Chakraborty et al. (2022). Social value, in collectivist cultures such as Saudi Arabia, promotes community and peer approval, hence increasing trust in

MPAs. Given Saudi Arabia's high score in uncertainty avoidance, monetary value promotes dependability and equality while reducing perceptions of financial risk. In a highly digitalized market like Saudi Arabia, where consumers are accustomed to high-performance mobile apps, MPAs are expected to run efficiently as

a minimum requirement. Users may trust MPAs based on recommendations from friends, relatives, or influencers rather than relying solely on technical quality.

Unlike most previous studies, which consider only perceived security to be a direct predictor of users' e-trust (Almaiah et al. 2022), this study investigates its moderating role, providing more insight into how security concerns shape customers' trustbuilding and decision-making processes in digital financial transactions. Results align with those of Almaiah et al. (2022) who found that MPAs' perceived security positively influences customers' e-trust among Saudi users. Perceived e-security is particularly fundamental for risk-averse users, such as first-time users, who seek psychological reassurance before engaging in mobile financial transactions (Saha et al. 2022). It serves as another proof reinforcing trust and reducing the perceived risk, in addition to perceived quality that signals the provider's competence and commitment to satisfy customers' needs.

Compared to other studies, this research also includes age and gender as moderating variables, providing a more comprehensive view of how demographic differences influence the relationship between perceived value and e-trust. Results show that neither gender's e-trust is substantially impacted by perceived quality value, suggesting that providers should prioritize fraud protection and enhance security measures that are more important than quality for users. Besides, women's e-trust is impacted by emotional and social values, particularly in Saudi Arabia's collectivist culture. Women often rely on peer recommendations and emotional reassurance when adopting new financial technologies. Social value boosts trust through peer approval, while emotional value provides psychological comfort and pleasure. Men's e-trust is largely motivated by MPAs' monetary value. Men's inclination for cost-effectiveness and financial gains is shown in the strong impact that monetary value has on e-trust. Males are more likely to trust MPAs that provide observable financial benefits like discounts, cashback rewards, and lower transaction fees.

Conclusion

This study contributes to the digital marketing literature by emphasizing the effect of

MPAs' perceived values on MPAs' adoption and the mediating role of customers' e-trust in the Saudi Arabian context. It further pioneers the analysis of the moderating roles of security and gender between MPAs' perceived values and customers' e-trust.

In Saudi Arabia's rapidly digitalizing market, where high smartphone penetration and Vision 2030's push for a cashless society drive technological adoption, understanding the interplay between social value, peer influence, social values, e-trust and decision to adopt MPAs is crucial. This study offers insights to managers about the importance of creating high-quality MPAs with reliable, attractive and socially friendly features to raise their adoption rates. The collectivist orientation of Saudi society emphasizes the importance of community-driven marketing strategies. Companies should engage in trust-building projects, partnering with reputable companies, banks, and influencers, and promoting social marketing to enhance interpersonal relationships and facilitate transactions within communities. They should prioritize trust-building through security improvements. Strong fraud prevention measures, advanced encryption technologies, safe authentication procedures, and transparent data protection guidelines should be prioritized. Educational initiatives should be implemented to raise understanding of security measures, as first-time users are often risk-averse. Marketers should also create customized tactics based on gender-specific trust drivers to increase MPA adoption to be in line with the demands and preferences of male and female consumers. As emotional and social values

significantly influence women's e-trust, so marketers should focus on creating user-friendly experiences through visually appealing interfaces, gamification, and smooth customer service as well on leveraging referral schemes, influencer partnerships and community-driven involvement. To increase men e-trust who are more utilitarian in their decision-making, marketers can focus on providing financial incentives such as discounts and loyalty rewards.

This research has some limitations that could be addressed in other studies. First, the small sample size and convenience sampling method may affect the generalizability of the findings. Respondents were mostly young, well-educated individuals, who tend to be more innovative and quicker to adopt new technologies. Older and less educated users may perceive greater difficulty and risks in using mobile applications. Additionally, the study was conducted in Riyadh, Saudi Arabia, limiting its applicability to other regions or populations. Cultural factors in Riyadh may differ from those in rural areas or other countries. Future studies should expand the sample to include old and less-educated individuals and diverse regions for broader applicability. Future studies can examine the continuous use of MPAs and the moderating role of customer's age in the link between users perceived values and the dimensions of initial etrust. They may investigate other aspects related to MPAs' like convenience and innovativeness or e-service providers' reputation that may influence initial e-trust and the intention to adopt MPAs. A longitudinal study can be conducted to investigate trust's dynamic process before and after using MPAs.

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Heartbeat Sensor Circuit Using Photodiode with Piezoelectric Buzzer

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Abstract. This study suggests an innovative approach to improve conventional cardiac sensor circuits by combining auditory and visual feedback systems. The focus of this research is Heart-Trackr, an innovative heart rate monitoring device designed to improve inclusivity in heart rate monitoring across a range of populations. HeartTrackr utilizes advanced technologies such as photodiodes, piezoelectric buzzer, bright lights, and the Arduino Uno R3 microcontroller to minimize signal noise and maximize signal clarity. This user-friendly prototype pre-sents a novel approach to heart rate monitoring, allowing for more inclusive use of such devices.

Keywords: Heart Rate Monitoring · Pulse Monitor · Microcontroller · Integrated Circuits.

1. Introduction

Engineers through modern advancements in engineering and technology have greatly improved our way of life, making it much more comfortable. Incorporating engineering and technological knowledge into medical science has significantly eased the tasks of medical professionals across various fields. Among the abundance of medical data accessible, heart rate and body temperature are commonly utilized. These vital signs play a crucial role in diagnosing cardiovascular ailments, and without the assistance of such technology, doctors and healthcare providers would find it challenging to identify heart-related issues in the human body.

Heart rate or pulse is one of the most significant vital signs in medical practice. It is referred to as the number of times a human's heart beats per minute and it must be measured in beats/minute (bpm). In general, adults have a resting pulse rate that ranges between 60-100 bpm which indicates how frequent heart muscles contract. The frequency can vary if an individual is physically active, either going up or coming down. It should be emphasized though that a heart rate over 100 bpm may be dangerous especially when

accompanied by symptoms such as dyspnea or chest pain which necessitate immediate medical attention [1]. Therefore, any changes in a patient's heartbeat need to be handled immediately for purposes of averting future complications.

Various tools, apparatus, processes and approaches are used in the modern field of biomedical engineering to identify heart diseases. Such things as echocardiograms by ultrasonography, electrocardiograms (ECG), cardiac MRI or CT scans, angiograms, PET scan and many others have become commonly used in diagnosing cardiovascular disorders. One of the most popular diagnostic techniques is Heart Rate Monitoring with wide ranging applications. This technology enables cardiologists, clinicians to promptly assess issues with the heart or its functionality thereby stressing the need for right diagnosis when it comes to identification and treatment of different heart problems among patients. The integration of engineering and technology into medical science, exemplified by innovations like HeartTrackr, presents a promising avenue for cost-effective healthcare solutions. By leveraging advancements in circuit design and sensor technology, HeartTrackr offers a streamlined approach to monitoring vital signs, potentially reducing the need for expensive diagnostic procedures. This system's ability to provide real-time heart rate monitoring, coupled with its adaptability for visually impaired users, underscores its accessibility and potential cost savings in healthcare delivery. Furthermore, by focusing on optimizing output stage modifications, HeartTrackr aims to enhance signal quality while minimizing costs associated with hardware modifications. Ultimately, the implementation of HeartTrackr could lead to more efficient and costeffective management of cardiovascular health, benefiting both patients and healthcare providers.

2 Conceptual Framework

The conceptual framework acts as a foundational roadmap, offering a comprehensive perspective on the development of the concept paper. In this investigation, the Input-Process-Output (IPO) approach was adopted for the conceptual framework. This approach was chosen for its ability to effectively demonstrate the intricate relationship between the ideas and their relevance to HeartTrackr: A Heartbeat Sensor Circuit Using Photodiodes with a Piezoelectric Buzzer.

The three separate sections that make up this framework represent the paper's easy flow. First, the narrative input is presented in the first section. This includes the following important aspects: first, the creation of a new circuit design that is specifically designed to monitor the heartbeats of users who require heart condition monitoring; second, investigating the possibility of incorporating piezoelectric buzzers and small speakers into current heartbeat sensor circuits; third, the optimization of the output stage modification design to guarantee compatibility with different heartbeat sensor circuits; fourth, conducting simulations to evaluate signal quality and noise levels introduced by the output stage modification; and fifth, making sure that heart rate monitoring is inclusive by accommodating users who are visually impaired or who are in circumstances where visual cues might not be readily visible. Procedural steps, including data gathering, integration, and design and concept development, are covered in the second section. The third and last section represents the final result, which is a heartbeat sensor circuit with piezoelectric buzzers.

The following flowchart provides a visual depiction of the research flow to aid in comprehension.

Input	Process	Output
• The development of an innovative circuit design tailored specifically to monitor the heartbeats of users requiring heart condition monitoring. • The investigation of integrating piezoelectric buzzers and small speakers into existing heartbeat sensor circuits. • The optimization of the output stage modification to ensure compatibility with various heartbeat sensor circuits. • The conducting of simulations to evaluate the signal quality and noise levels introduced by the output stage modification. • The catering to those with visual impairment or those in situations where visual cues may not be easily observable heart rate monitor to user with • The enabling of the innovative device to make unique sounds when detecting irregular heart rates to alert users.	• Data Gathering • Integration • Design and Concept Development	• Heartbeat sensor circuit with piezoelectric buzzers

Figure 2. A project paradigm on HeartTrackr

2.1 Scope, Limitation, and Delimitation of the Study

The study aims to create a heart monitoring device using Arduino platform design that will help people with heart disease keep record of their pulse rate. The device will have a menu that will allow users to choose between options such as, check heart rate, view heart rate log, check pulse rate while at rest, and check pulse rate during an exercise. This project was limited by time constraints and the availability of materials to be used. The study is aimed to help provide a cheaper and user-friendly heart monitoring device. The target users for this study are the visually impaired and deaf, as it incorporates some features that are specially designed with them in mind.

3 Methodology

A static-group comparison quantitative research method was used for the study. Through this method, the accuracy of the HeartTrackr was tested in comparison to an actual heart rate monitoring device. The inclusion of a second comparison group in this design represents a minor improvement, but the pretesting is still

absent. Furthermore, neither group's members were chosen at random; as a result, the term "static group" refers to these groups as if they were already established and complete. In this design, the comparison group is not exposed to any treatment or condition, but the experimental group is. The comparison group's main goal is to essentially show how the experimental group members would have performed had they not received the treatment; however, this is only possible to the extent that the design guarantees that the comparison group is comparable to the experimental group [2].

3.1 Materials

The proponents utilize active devices that have both analog and digital components with their functions in the circuit. The components used are the following:

Arduino Uno R3. The Arduino UNO R3 is a microcontroller board. It allows microcontroller tinkering through its reset button, power jack, ICSP header, USB port, 16 MHz ceramic resonator, and 14 digital and 6 analog inputs and the Arduino IDE where users can program the microcontroller board. [3]

Piezoelectric buzzer. A piezo buzzer is an electrical gadget that emits sound [4]. It is used to mimic the rate in which the heart beats audibly to allow blind users to easily know and understand the speed of their heartbeat.

Photodiode. A silicon photodiode is a "PN" solid-state device that generates an electric signal when an incoming photon from a scintillation crystal causes an avalanche of electrons to accelerate the photoelectron [5]. The photodiode is used as the sensor to detect the heartbeat of the user.

Light Emitting Diode. Detects the moisture level in the environment. Typically utilizes probes or sensors to measure conductivity or capacitance changes in the soil or air, indicating moisture levels. [6]

Buttons. A button controls the electrical circuit through an internal switching mechanism that is activated by the user manually pressing the button. [7] It allows the user to choose what function will be activated through the programmed code in the Arduino UNO R3 microcontroller.

Liquid Crystal Display (LCD). Electronic displays known as liquid crystal displays (LCDs) are frequently seen in flat-panel televisions, and other devices. [8] It is used to show information to be easily seen and understood by users.

Breadboard. The Breadboard is used to connect the components of the circuit inside the container. It allows for quick and easy removal and replacement of components used in the project. It is a plastic block with a grid of electrical sockets where the components and connecting wires are attached. [9]

3.2 Electrical Design

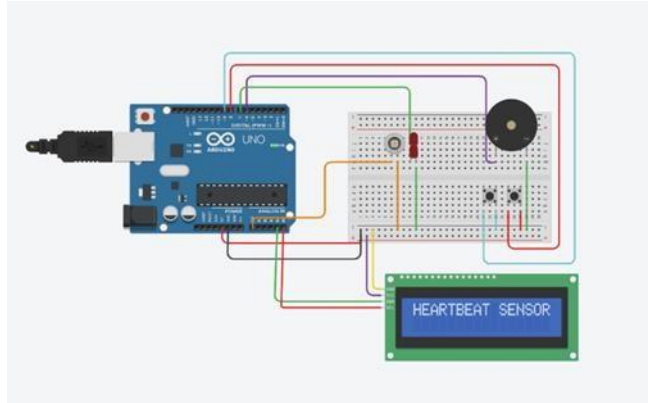


Figure 3.1 Circuit simulation in TinkerCAD

TinkerCAD, a program for simulating building and testing electronic circuits, was used to mimic the suggested circuit. The circuit performed as intended in the simulation, as such, this design was used for the prototype.

3.3 Programming Stage

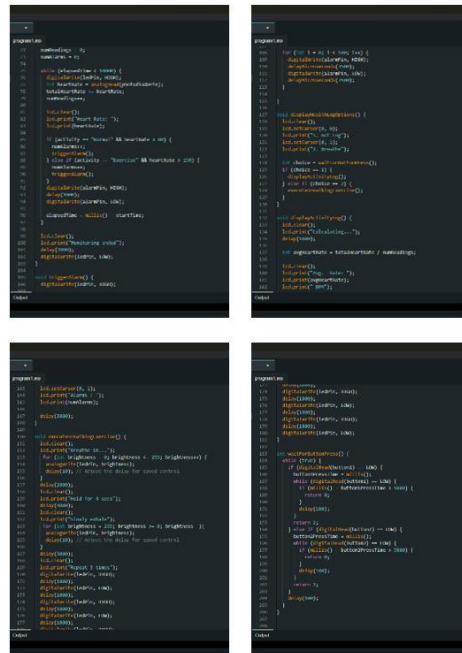


Figure 3.2 The Arduino IDE was utilized to program the Arduino Uno R3, as simulated in TinkerCAD. This is the code used in programming the Arduino Uno R3.

The provided code implements a health monitoring system utilizing an Arduino Uno R3 board and an LCD display. First, it begins by including the necessary library for interfacing with the LiquidCrystal display via I2C. Global variables are declared to store pin assignments for various components like LEDs, buttons, and a photodiode sensor, which are necessary for implementing different tasks in a breadboard circuit. Moreover, such a setup function initializes the LCD display and sets pin modes, and then prints an initialization message on the display.

The main loop continuously calls the `displayHomePage` function, which presents users with two options to (1) check their heartbeat or (2) access health logs. These options are displayed on the LCD, and the system waits for user input. Depending on the user's choice, different functions are called. For instance, if the user selects heartbeat monitoring, the system prompts them to choose between normal or exercise monitoring modes.

Heart rate monitoring is managed by the `detectHeartbeat` function, which continuously reads data from a photodiode sensor, calculates the heart rate, and displays it on the LCD. If the heart rate exceeds predefined thresholds based on the activity type (normal or exercise), an alarm is triggered. The `triggerAlarm` function handles the alarm mechanism, flashing an LED and emitting a sound.

Additionally, the system provides functionality for users to log their health data. The `displayActivityLog` function calculates and displays the average heart rate and the number of alarms triggered during the

monitoring period. The `executeBreathingExercise` function guides users through a breathing exercise using the LED to indicate inhaling and exhaling phases.

The code essentially sets up an interface on an LCD display for users to interact with. This health monitoring setup with Arduino is truly like having a helpful buddy to keep an eye on your well-being. It uses buttons and an LCD screen to make it easy for you to check your heart rate, get alerts if something seems off, and even guide you through calming breathing exercises.

4 Results and Discussion

The system's accuracy was tested by measuring the prototype's measured pulse rate and the pulse rate of a commercial heart rate monitor.



Figure 4.1 Prototype of HeartTrackr: Heartbeat Sensor Circuit Using Photodiode with Piezoelectric Buzzer



Figure 4.2 Prototype of HeartTrackr: Heartbeat Sensor Circuit Using Photodiode with Piezoelectric Buzzer – Main Menu



Figure 4.3 Prototype of HeartTrackr: Heartbeat Sensor Circuit Using Photodiode with Piezoelectric Buzzer – Menu 1



Figure 4.4 Prototype of HeartTrackr: Heartbeat Sensor Circuit Using Photodiode with Piezoelectric Buzzer – Pulse Monitoring



Figure 4.5 Prototype of HeartTrackr: Heartbeat Sensor Circuit Using Photodiode with Piezoelectric Buzzer – Health Log

This health monitoring program, designed for an Arduino system, is straightforward to use and provides users with essential tools for keeping track of their well-being. Upon powering up the system, users are greeted with a menu displayed on the LCD screen, presenting options to check their heartbeat or access health logs. By pressing corresponding buttons, users can navigate through the menu to select their desired function. If they choose heartbeat monitoring, they're prompted to select between normal or exercise modes. The system then begins monitoring their heart rate using a photodiode sensor, displaying real-time readings on the LCD screen. Should the heart rate exceed predefined thresholds for normal or exercise activities, an alarm is triggered, alerting the user to take action. Additionally, users can log their health data, with the system providing average heart rate and alarm counts. For those seeking relaxation, guided breathing exercises are available, accompanied by LED indicators to assist with timing.

4.1 Comparison of Data

This was done to check the accuracy of the data collected by the prototype. To test the accuracy, the data collected from the prototype is compared to the data collected from a commercial pulse monitor. This test was done in three parts: At rest (before exercise), During exercise, and at rest (after exercise). The test was repeated twice per part for more accurate data.

<i>Condition</i>	<i>Prototype measured bpm</i>	<i>Pulse Monitor measured bpm</i>	<i>Attempt Number</i>	<i>Percent Difference</i>
At rest (before exercise)	72	75	1	4.08163%
At rest (before exercise)	80	86	2	7.22892%
During exercise	128	129	1	0.77821%
During exercise	120	125	2	4.08163%
At rest (after exercise)	83	88	1	5.84795%
At rest (after exercise)	79	80	2	1.25786%

Table 1. The Comparison of the Data collected from the prototype and commercial pulse rate monitor.

5 Conclusions & Recommendations

One of the most important bodily measurements is the heartbeat rate, which can be used to identify heart disease and stop more catastrophic issues. This study described a heartbeat rate measurement device based on infrared light that may be used whenever necessary.

Despite the simulated circuit and the prototype working as intended, the proposed prototype presents inaccurate data. This may be caused by faulty components, circuit design, or program code. In theory, an active device like the Arduino Uno R3 microcontroller facilitates efficient data processing and decision-making. The LEDs will light up at the same time, the photodiode detects reflective light from the body and this signal is sent to the microcontroller to detect heartbeat. The piezoelectric buzzer will sound to mimic the user's heart beating. The buttons and LCD are utilized for user interaction of the project, the LCD acts as the monitor and the buttons to select from the programmed menu.

To increase heartbeat signal detection and measurement accuracy, researchers should explore different experiments with various component values and configurations to fine-tune the circuit's properties.

Explore the implementation of better circuit components, thereby improving the reliability of the heartbeat sensor circuit in real-world environments.

To improve the sensor circuit design, add new features, and meet the needs and demands of users, foster cooperation with academic institutions, research groups, and electronics enthusiasts.

Text-to-speech Integration. Adopt a user-centric design method, involving diverse disability populations to understand their need and preferences in heart rate monitoring.

Wireless Connectivity. Examine the incorporation of cutting-edge wireless technologies like ANT+ or Bluetooth Low Energy (BLE) to facilitate smooth data synchronization with wearables, smartphones, fitness applications, and other devices that are compatible.

Water Resistance. Explore methods to enhance water resistance in heart rate monitors for reliable operation during swimming and water sports, focusing on innovative materials and sealing techniques.

Memory Storage. Explore adding more memory storage to heart rate monitors for storing data and user preferences over longer periods.

Accuracy Improvements. Investigate improving heart rate accuracy with advanced techniques and studies assessing performance in different conditions.

Design Comfortability. Enhance heart rate monitoring devices through customer-focused design learning, refining form, materials, strap, and interface based on user input for improved comfort and aesthetics.

Assure adherence to pertinent safety regulations and regulatory standards that control the creation and use of medical devices and electronic sensors for healthcare applications.

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IoTA (IoT in Agriculture): RF Transmitter Integration on Sensor Networks for Enhanced Agriculture Monitoring

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Abstract. Advancements in technology, particularly wireless sensor networks (WSN), have revolutionized agriculture by simplifying complex tasks. WSNs, a subset of the Internet of Things (IoT), enable real-time monitoring of environmental parameters critical to farming. In response to resource depletion and rising food demand, a scalable system using 433 MHz RF modules connects multiple substations to a central station, allowing for the monitoring of expansive agricultural lands. Using NodeMCU, ATmega328p, sensors, and software tools, data on air humidity, temperature, soil moisture, and more can be processed. Firebase Realtime Database and Google Colab enable remote monitoring and analysis, empowering farmers with valuable insights. Future improvements focus on optimizing power consumption, extending network coverage, and enhancing component durability for sustainable agriculture.

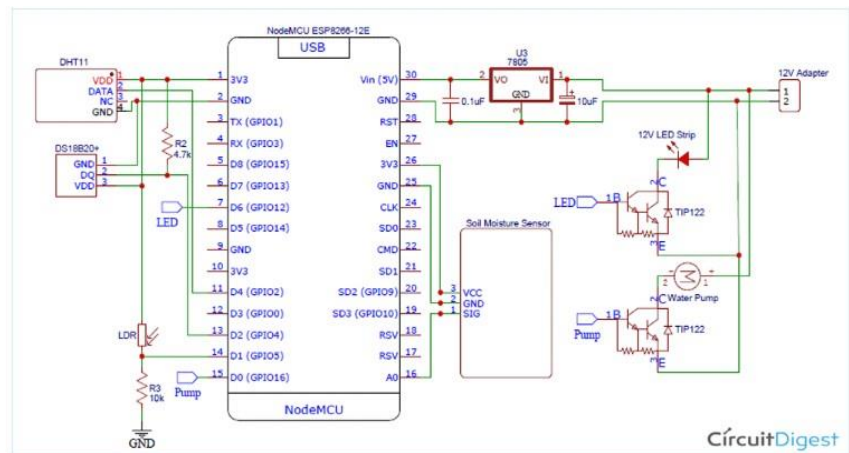
Keywords: Wireless Sensor Networks, Real-time systems, Databases, Monitoring, IoT, Agriculture

1. Introduction

As time progresses, technologies evolve, making it possible to do complex tasks with ease. One of these technologies is the Internet of Things (IoT), which is a system of interconnected devices that can be programmed to perform specific tasks and is connected and can be controlled through the internet with the help of cloud computing [1]. A subset of IoT, the wireless sensor network (WSN) is a network of spatially and strategically distributed sensors that collect real-time data from its surroundings, including physical and environmental conditions, which are then transmitted to the receiving station that processes the information and provides a certain response that was initially programmed [2].

The UN Food and Agriculture Organization estimates that due to the world's population expansion, which is exponential, 70% more food will need to be produced globally by 2050, as well as the reduction of arable

land and the depletion of limited natural resources, it is imperative to increase farm productivity. The problem has been made worse by the scarcity of natural resources, such as arable land and freshwater, and by the slowing trends in the yields of several staple crops. The changing makeup of the agricultural workforce is another issue that poses a barrier to the farming sector. Moreover, most countries have seen a decrease in agricultural labor. The necessity for less physical labor in farming has led to the adoption of internet connectivity solutions due to the shrinking agrarian workforce [3].



The proposed system is inspired by an “IoT based Smart Agriculture Monitoring System” project, which consists of only one station with NodeMCU ESP8266, sensors, and a water pump [4]. The system collects and processes data from sensors connected through electrical wires and uploads it to the internet. Monitoring was done with the aid of Adafruit IO, which serves as a bridge between connected devices and the cloud [5]. However, the reference system covered only a small area of farmland. With these, the researchers decided to integrate 433 MHz RF modules into the reference system to improve scalability for potential wide-scale farming applications. These modules consist of a transmitter and receiver that transmit and receive 433 MHz signals, respectively, enabling a wider area that the system can cover [6, 7]. Specifically, the proposed system consists of a main/central station and substations. The central station mainly consists of NodeMCU V3 ESP-12E and a 433 MHz RF receiver; meanwhile, the sub-station consists of an ATmega328p microcontroller chip, a 433 MHz RF transmitter, and sensors.

2 Objectives and Circuit Design

This project mainly aims to create a single main station and use substations of agricultural monitoring devices to create a network of sensor stations and be able to monitor more expansive areas. This means that only one NodeMCU for the main station will be utilized instead of independent stations that employ NodeMCU at each station, reducing power consumption, eliminating the need for additional modules, and enhancing the efficiency and range of monitoring. Furthermore, it also aims to assist farmers in monitoring certain conditions that affect the growth of crops by leveraging WSN based smart agriculture systems.

2.1 Main Station

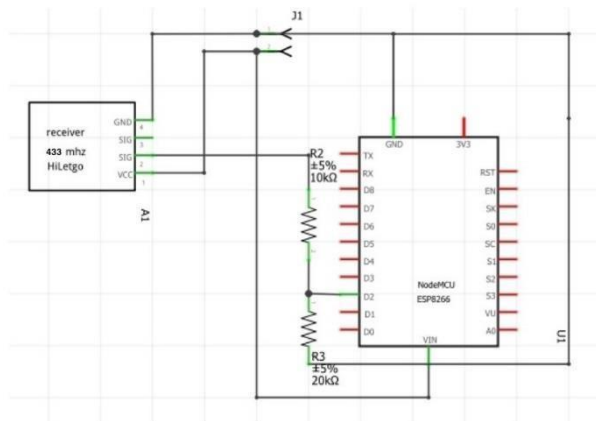


Fig. 2. Schemaric diagram of the proposed main station

The main station consists of a NodeMCU V3 ESP-12E connected to an 433 MHz RF receiver that receives data transmitted from substations. The voltage supply of both components are 5 volts. The Vin pin of the NodeMCU supports a supply voltage of 5 volts; however, its input/signal pins only support a maximum of 3.3 volts.

To reduce the input signal that it receives from the RF receiver's signal pin, resistors were connected in a voltage divider connection, establishing a ratio of 5:3.3 volts.

This station's primary function is to receive RF transmissions from the substations and transfer them to the Firebase Realtime database. It acts as the central hub for receiving data within the sensor network. It plays a crucial part in making sure that data is appropriately collected and sent to the Firebase Realtime database from the various substations. It serves as the gateway for real-time monitoring and managing critical environmental variables like temperature, humidity, and soil moisture.

Figure 3 displays the program running on the main station. The program starts by connecting to a WiFi network. Once connected, it tries to establish a connection with an NTP server to sync the time and then with

the Firebase servers. Identifiers such as the database URL and the project API key are used for this connection. After connecting to Firebase, the program performs authentication, which is required to be able to perform database operations.

The final step for the setup is to initialize the RF receiver. After the setup, a loop is initiated to continuously check for new messages received by the receiver. If a new message is detected, a process commences. The message is first split into separate values and then cast into their respective data types. Once successfully cast, a JSON object is created, which consists of the received data. Finally, this object is sent to the cloud database under a uniquely generated key. The loop continues running until the device is turned off, or if the connections with either the WiFi or Firebase are lost, in which case, the connections will be retried.

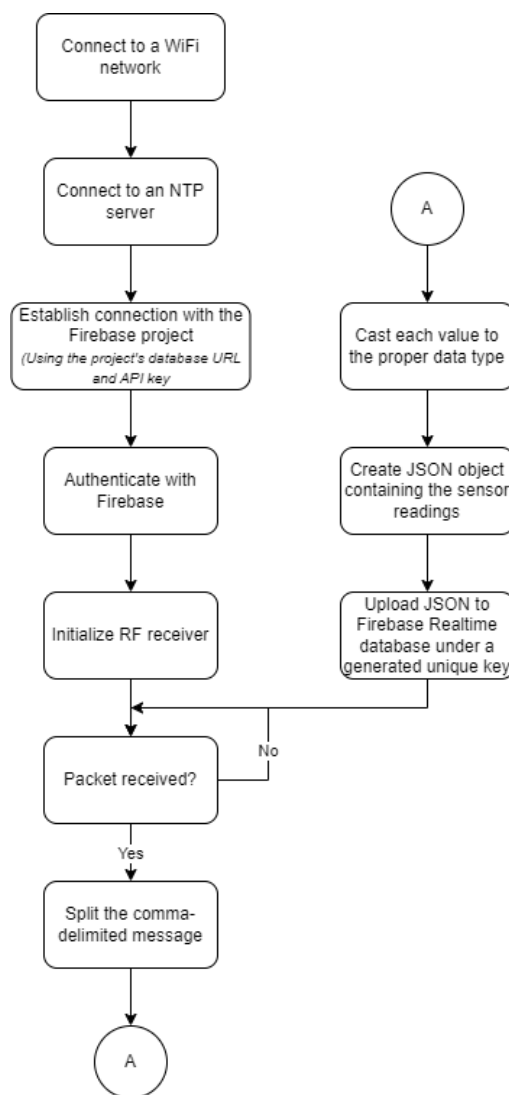


Fig. 3. Main Station Program Flowchart

2.2 Sub-Station

The substation consists of a standalone MCU connected to a 433 MHz RF transmitter and sensors for air temperature, air humidity, soil moisture, and soil temperature. The supply voltage of the aforementioned components is 5 volts. Resistors, capacitors, and an oscillator were utilized in order to stabilize the signal around the MCU.

The substation is responsible for communicating with the sensors and gathering data from them, which is then transmitted through the RF transmitter.

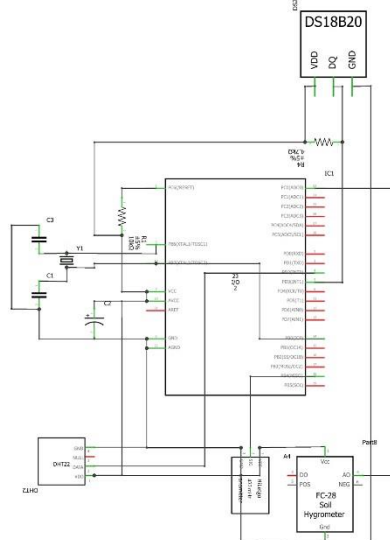


Fig. 4. Schematic diagram of the proposed Sub-stations

The program for the substation is illustrated in Figure 5. Upon power-up, the MCU initializes all sensors and the RF transmitter into their respective operation modes. Then, a loop is initiated, which begins with the obtaining of data from the sensors. The next step involves preparing the data by combining all the necessary values into a single string, separated by commas. This string is then transmitted to the main station via the transmitter. After transmission, the MCU waits for a predetermined time that can be adjusted to suit specific applications. The loop continues until the device is powered down.

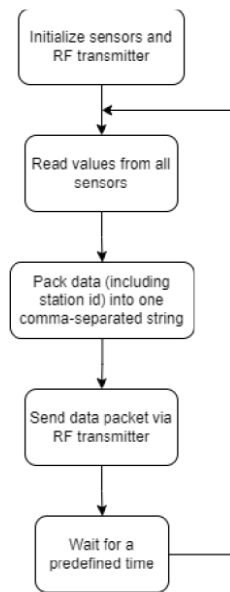


Fig. 5. Sub-station Program Flowchart

2.3 Materials

The materials required include a Node MCU V3 ESP-12E, ATmega328p, 433 MHz RF Transmitter and Receiver, Soil Moisture Sensor, DHT22 Sensor (temperature and humidity sensor), DS18B20 Sensor (digital temperature sensor), 16 MHz Crystal Oscillator, wires, breadboard, and 4.7k, 10k, and 20k resistors, along with 22 μ F capacitors.

3 SIMULATION, DATA AND RESULTS

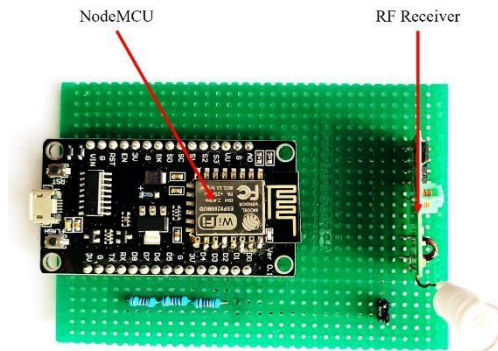


Fig. 6. Image of the Prototype for the Main Station

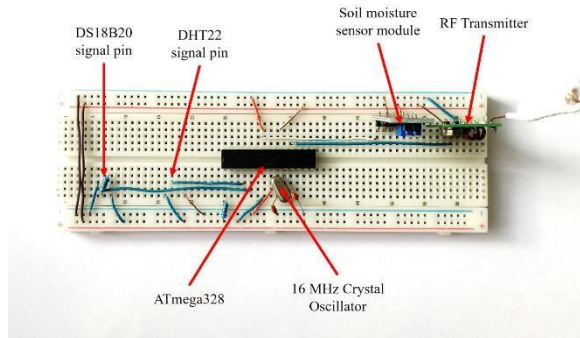


Fig. 7. Image of the Prototype for the Sub-station

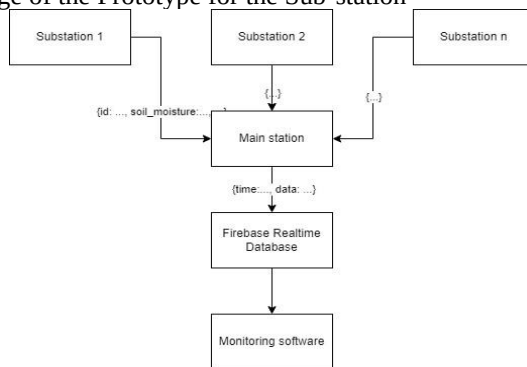


Fig. 8. Conceptual framework of IoTA

The RF receiver from the main station then receives the modulated signal and demodulates it so that the nodeMCU can process and upload the data to an online database (i.e., Firebase).

Three separate software projects were developed. One is for the main station, another for the substation, and the last is for the monitoring software. The developers utilized the languages C++ and Python for the said development. The Firebase Realtime Database was used in this project. The project utilizes several software libraries to interface with various components. The Radiohead library is used to communicate with RF modules, offering a full object-oriented library for transmitting and receiving packetized messages via standard data radios and other transports, making it compatible with a range of embedded microprocessors. The One-Wire library supports communication with the DS18B20 digital thermometer, which provides 9-bit to 12-bit Celsius temperature readings through a one-wire protocol that connects peripheral and controller devices. The DHT sensor library is required to obtain the appropriate readings from the DHT22 sensor, designed for inexpensive temperature and humidity sensing. The Firebase Arduino Client Library for ESP8266 and ESP32 enables compatibility with Firebase products such as the Realtime database, Firestore, Storage, Cloud Functions, and Messaging, while also supporting other Arduino devices with Client interfaces like WiFiClient, EthernetClient, and GSM Client. Lastly, the NTP Client library ensures accurate time synchronization by obtaining the most precise time and keeping it in sync with an NTP server, which is crucial for time-stamping the data acquired by the sensors.

Each substation is assigned a unique ID so the main station can determine who is sending the message. For transmitting the data, the substation microcontroller packages the message as a sequence of characters forming a string containing the station ID and sensor values, separated by a comma character. This is then unpacked by the main station for upload to the cloud database. For power consumption, it was considered that the substation would be deployed in places far from any power sources. For this reason, to improve the station's efficiency, the ATmega328 was used as a standalone chip instead of having it mounted on an Arduino. Upon testing, the substation got an average reading of ~13mA current consumption, making it possible to be battery-operated.

3.1 Data Structure

Firebase Realtime Database stores all data as JSON objects [8]. The toplevel structure of the data can be seen in Figure 9. In this system, the data follows the structure “stations” -> station_id -> randomly generated key.

Each station has its directory in which their data will be located. Each random key inside each station indicates individual updates from that station.

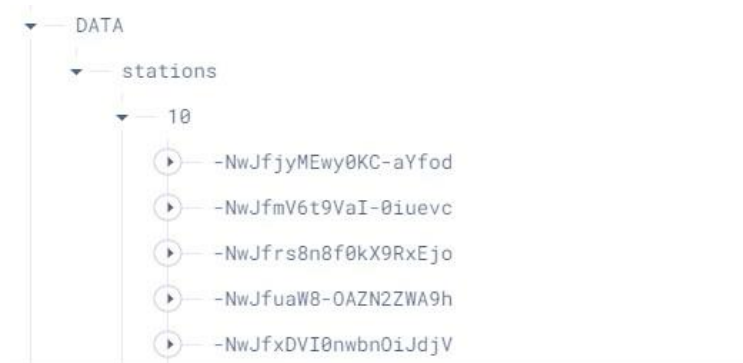


Fig. 9. JSON structure for storing the data

Firebase Realtime Database stores all data as JSON objects [8]. The toplevel structure of the data can be seen in Figure 9. In this system, the data follows the structure “stations” -> station_id -> randomly generated key. Each station has its directory in which their data will be located. Each random key inside each station indicates individual updates from that station.

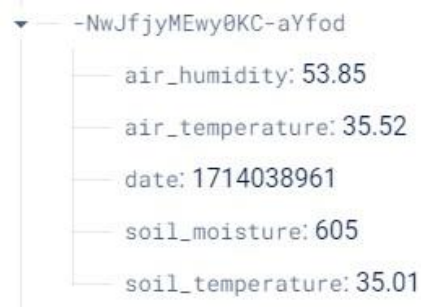


Fig. 10. JSON structure for the individual parameter updates

In Figure 10, an individual JSON update under a random key is shown.

The “air_humidity” field holds the percentage of the humidity reading. The “air_temperature” and “soil_temperature” fields have their respective values in degrees Celsius. The “soil_moisture” contains the raw analog value reading which ranges from 0-1023. And lastly, the “date” field is saved as a number referred to as Unix time. Unix time is a timestamp representation, which is commonly expressed as the number of seconds since January 1, 1970, at midnight (UTC), the start of the Unix epoch [9].

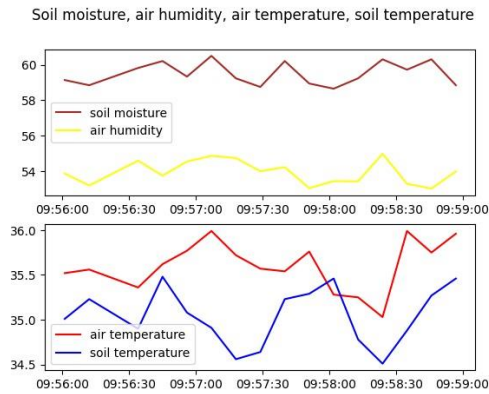


Fig. 11. Sample chart of sensor values over time. (From the Python Jupyter notebook for monitoring)

```
LATEST DATA: 2024-04-25 15:11:47
Soil moisture: 60.51%
Air humidity: 62.70%
Air temperature: 30.7°C
Soil temperature: 30.62°C
```

Fig. 12. Sample display of latest sensor values. (From the Python Jupyter notebook for monitoring)

Google Colab, connected to the database, was utilized for real-time data monitoring. Several functions are available, including monitoring the latest real-time values and plotting the data from the sensors using line graphs over a specified period. From figure 11, 2 line charts can be seen. The first plot plots the soil moisture and air humidity, while the second plot plots the soil air temperature and soil temperature. Every 10 minutes, the substation obtains readings from the sensors and sends them to the main station, then to the online database. From figure 12, the latest reading of air humidity, air temperature, soil moisture, and soil temperature with the time is shown.

4 CONCLUSION AND RECOMMENDATION

The development of an IoT-based smart agriculture monitoring system offers significant potential for enhancing food security and economic welfare in the agricultural sector, particularly amidst rising global food demand and the depletion of limited resources. The integration of 433 MHz RF modules and the implementation of a single main station and multiple substation networks into the system reduce power consumption and equipment costs, allowing the creation of scalable solutions as well as enhancing the overall effectiveness and range of monitoring capabilities of the system. By consolidating sensor data from multiple substations into a centralized station, farmers can access crucial information about environmental conditions, including

soil moisture and temperature, air humidity and temperature, and other relevant parameters, in real-time, enabling them to make informed decisions and optimize the utilization of resources.

Moreover, the utilization of Firebase Realtime Database and Google Colab, along with software libraries such as Firebase Arduino Client Library for data storage and visualization, provides users with intuitive interfaces for remote monitoring and analysis of sensor data, enabling data-driven crop management and yield optimization decisions.

Several key recommendations should be considered in order to enhance the system's performance and capability. Firstly, establishing a consistent power supply for each component is critical to sustaining stable data transmission. Opting for a PCB design can improve the device's physical dimensions and performance stability. The use of renewable energy sources, such as solar energy systems, provides a sustainable approach to powering the system, lowering dependency on traditional energy infrastructure. Exploring advanced power-saving techniques and energy-efficient components can further optimize power consumption, prolonging the operational lifespan of the system. Improving antenna design is crucial for increasing the range of RF transmitter and receiver connections, resulting in better network coverage and reliability. Enclosing the system's microcontroller in a weather-proof case is also recommended to protect the component from moisture, dust, extreme temperatures, physical harm, and other environmental factors. In addition, integrating pressure-based irrigation systems can enhance the functionality of systems in agricultural environments, enabling more efficient water management practices. By implementing these recommendations, the system can achieve higher performance, reliability, and sustainability.

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Assessing the Technological Readiness Level of Emerging Technologies for Sustainable Building Projects in Civil Engineering

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Abstract. The civil engineering sector is undergoing a technological transformation, with emerging innovations such as Structural Health Monitoring (SHM), Building Information Modeling (BIM), Artificial Intelligence (AI), the Internet of Things (IoT), and advanced materials showing great promise for improving efficiency, safety, and sustainability in infrastructure development. However, effective adoption of these technologies is contingent on a thorough knowledge of their maturity, as evaluated by Technological Readiness Levels (TRL), and their alignment with organizational and sustainability objectives. This study assesses the TRL of major technologies in sustainable building, noting important constraints such as technical immaturity, data management issues, high prices, talent gaps, and regulatory uncertainty. It also emphasizes enablers such as standardization, interoperability, and ethical issues. This study offers a complete framework for assessing technical readiness by combining quantitative approaches like NASA's TRL scale and Integration Readiness Levels (IRL) with qualitative assessments. The findings highlight the need for collaboration among policymakers, industry stakeholders, and researchers in addressing adoption issues and developing seamless integration solutions. This study provides actionable ideas for bridging the gap between innovation and practical implementation, resulting in a more resilient and sustainable built environment. To expedite the use of new technologies in civil engineering, future research should focus on advanced sensor technologies, data analytics, protocol standardization, and resolving ethical and environmental concerns. Addressing these gaps will allow the sector to fully realize the promise of these breakthroughs, resulting in global sustainable infrastructure development.

Keywords: Technological Readiness Level (TRL), Emerging Technologies, Civil Engineering, Assessment, Innovation.

5 Introduction

Civil engineering is amidst a disruptive, technology-driven revolution. These emerging technologies offer enormous potential for a paradigm shift in infrastructure development and management that is far more efficient, safe, and sustainable [1]. The realization of such potential requires a proper understanding of the maturity of emerging technologies, represented by their Technological Readiness Levels (TRL) [2]. The ever-increasing relevance of areas like SHM, treated within the work of [3], and the possibilities of AI in construction, researched by [4], render clarity on TRLs more urgent to enable informed decision-making and appropriate strategies. According to [5], such integration also requires an understanding of Integration Readiness Levels, hence adding another layer of complexity to the assessment. Finally, [6] demonstrated this with BIM, and [7] with their TOES framework, how a holistic approach considering organizational and sustainability factors becomes necessary for the successful adoption of technologies. Emerging technologies' quick growth has had a big influence on the construction sector, especially on civil engineering's creation of sustainable building projects [8]. Sustainability in construction has become essential as worldwide worries about re-

source depletion, climate change, and environmental damage have grown. The implementation of cutting-edge technology, including sophisticated construction materials, artificial intelligence (AI), the Internet of Things (IoT), and building information modeling (BIM), offers the potential to improve sustainability in building projects [9], [10]. However, the TRL which evaluates these technologies' maturity, viability, and scalability in practical applications, is what determines whether they are implemented successfully. To determine the factors that impact the adoption of developing technologies in the construction industry, this article will assess their TRL in sustainable building projects. A well-known methodology for assessing a technology's maturity from conception to full implementation is the TRL. The TRL framework was first created by NASA and has since been modified for use in a number of sectors, including civil engineering and construction. The framework has been used to assess the maturity of new technologies and to guide their development. It is a valuable tool for managing the risk associated with new technologies and ensuring that they are successfully transitioned from research to practice [11]. TRL is an essential tool for evaluating the viability and possible effects of developing technologies in the context of sustainable construction projects. Several new technologies have shown promise in encouraging environmentally friendly building practices. For example, BIM reduces material waste and energy consumption by facilitating effective design, planning, and resource management [12]. IoT-enabled smart sensors improve predictive maintenance and energy efficiency by enabling real-time building performance monitoring [13]. Furthermore, AI-powered algorithms improve risk management, cost prediction, and project scheduling, which results in better decision-making [14]. Additionally, using cutting-edge sustainable materials like carbon-negative cement and self-healing concrete helps to lessen the environmental impact of building projects [11]. Notwithstanding the possible advantages, there are a number of obstacles to the widespread use of these technologies. Widespread adoption is hampered by high implementation costs, a lack of technical know-how, and change aversion [15]. Furthermore, there are questions about compliance and integration with current building processes due to regulatory and standards concerns. Policymakers, business professionals, and researchers must work together to address these issues and develop frameworks that encourage the use of cutting-edge technology for sustainable building. In civil engineering, evaluating the technological readiness of new technologies is essential to figuring out their viability and influence on sustainable construction projects [16]. Although technologies like BIM, IoT, AI, and smart materials have a lot of potential to improve sustainability, their effective application hinges on removing adoption obstacles [17]. Construction stakeholders may make data-driven decisions and guarantee the successful integration of sustainable solutions into the sector by having a thorough understanding of the TRL of these technologies [18]. To promote a more robust and sustainable built environment, future research should concentrate on creating plans to close the gap between technical innovation and real-world implementation. The purpose of this study is to evaluate the TRL of cutting-edge technology in civil engineering projects including sustainable building. It specifically aims to pinpoint the main obstacles and facilitators affecting their adoption and offer advice and insights to industry participants on how to best integrate them for increased sustainability. This study advances knowledge of how new technologies may be successfully used in building projects to support sustainability by providing a thorough assessment of these innovations' technological preparedness. Additionally, this study highlights important aspects influencing technology adoption, which offers insightful information to researchers, industry experts, and policymakers. It finds implementation gaps and makes strategic suggestions to close them, guaranteeing that sustainable solutions are successfully integrated into building procedures. In the end, this assessment lays the groundwork for further studies that intend to hasten the adoption of cutting-edge technology, so promoting a more resilient and sustainable built environment.

6 Methodologies for Assessing Technological Readiness

There exist several methods for assessing the technological readiness of impending innovations. One of the most well-known among them is NASA's Technology Readiness Level (TRL) scale [19]. Its usefulness, however, may be difficult to apply, particularly in complicated systems [5]. Certain other approaches such as the Technology Project Readiness Level (TPRL) and Integration Readiness Levels (IRL) provide varied viewpoints [5]. A comparison of these and other key methodologies is presented in Table 1.

Table 3. Comparison of TRL Assessment Methodologies

Methodology	Description	Strengths	Limitations	Applicability to Civil Engineering
NASA TRL Scale	9-level scale from basic principles to operational system	Widely recognized, simple to understand	Can be subjective, doesn't capture all aspects of readiness	General, needs adaptation
TPRL	Focuses on commercialization readiness	Considers market factors	May not apply to all technologies	Limited
IRL	Emphasizes integration maturity	Useful for complex systems	Can be complex to implement	Highly relevant
Qualitative Assessments	Expert judgment, case studies, literature reviews	Provides in-depth insights	Can be subjective, requires expertise	Highly relevant

As table 1 illustrates, each method offers a different perspective for determining technological readiness. While the NASA TRL scale provides a general model, TPRL and IRL provide individual perspectives, with an emphasis on commercialization and integration, respectively. Qualitative assessments complement these quantitative models by providing insight into the particular circumstances of the technology and potential issues. Moreover, the TRL scale might not be able to address every dimension of readiness, such as organizational and external ones [7]. There are other approaches, like Technology Project Readiness Level (TPRL) [19] and Integration Readiness Levels (IRL) [5], which have different understandings of technology maturity. TPRL is concerned with the readiness of technology for commercialization, whereas IRL is concerned with how mature the integration of various technological components in a system is. The selection of the approach is based on the type of technology being assessed and the reason for the assessment. An extensive assessment can be a synthesis of various approaches for a more holistic picture of readiness [20]. As an example, the Waste Treatment and Immobilization Plant (WTIP) project utilized an External Flowsheet Review along with a Technology Readiness Assessment [20]. In addition to quantitative metrics, there is a need for qualitative evaluations. These entail expert judgment, case studies, and literature reviews to determine the performance, reliability, and usability of the technology for given applications. Quantitative TRL evaluation can supplement such qualitative analysis, resulting in a more penetrating and detailed technological readiness understanding [21]. For instance, in evaluating the readiness of BIM-based building permit procedures, Fuzzy-COPRAS, as a multi-criteria decision-making approach, combined with expert opinion was employed in computing weights for different criteria [21].

7 Emerging Technologies in Civil Engineering

Civil engineering is one of those fields that are continuously upgraded with time as new technologies crop up now and then. These can even change the way infrastructure is designed, built, and maintained. Some of the most promising emerging technologies in civil engineering include:

7.1 Structural Health Monitoring (SHM)

SHM involves applying sensors and data analysis to monitor the condition of civil infrastructure and detect likely damage [3], [22]. Some of the new technologies of SHM are fiber optic sensors [3], [22], lasers [22], [23], Micro Electro Mechanical Systems (MEMS) [3], [22], and piezoelectric transducers [24]. These sensors have the advantages of constant monitoring, increased accuracy, and improved safety over traditional inspection methods [23]. However, challenges are faced in data analysis, sensor fusion, and standardization of procedures to present SHM data [22]. Research is currently being conducted to develop data analysis methods, particularly through the utilization of deep learning methods [25], and to develop stronger and more affordable sensor systems [3]. The use of smart sensors [3] and UAVs [25], [26] in data gathering are notable developments too. TLS is also a promising candidate as a substitute for traditional inspection methods with advantages in safety, economy, and efficiency [23]. However, research gaps have been identified in developing model protocols for the introduction of FOS procedures [22] and quality issues to provide SHMs of good quality [22].

Case Study: The Tsing Ma Bridge of Hong Kong has a very extensive SHM system with sensors for measuring wind speed, temperature, and structural strain. Engineers have been able to identify and rectify structural problems before they could lead to failure using this system, making the bridge long-term sustainable. 115 temperature sensors were mounted on the Tsing Ma Bridge for temperature load monitoring. It has 6 ambient, 86-section, and 23 cable temperature sensors named P3, P1/P2/P4/P6, and TC, respectively [27].

7.2 Advanced Materials

Civil engineering is a rapidly changing profession because of the high performance and other important gains that are possible through new materials that exhibit dramatic advances in strength, durability, and sustainability. Such examples include smart materials, fibre-reinforced composites, and geopolymers. However, these materials are yet to be widely accepted due to several challenges that include a lack of standard guidelines and application codes, question marks on cost-effectiveness, and long-term performance. Nevertheless, high-performance composite applications keep increasing with the advancement in manufacturing technologies and their competitive advantage over conventional materials. Some of these materials, including steel and hemp, have reached a high level of technological readiness to the extent that their maturity for civil engineering projects is considered developed. New higher-performance materials are being designed to be employed in civil engineering [28]. They include smart materials [28], fibre-reinforced composites [28], polymer concrete produced by recycled plastics [28], and geopolymers [29]. Their use has the potential to offer durability, strength, and sustainability benefits [30]. Among the main challenges, however, is the lack of guidelines, codes, and specifications for their use [28]. In addition, the cost-effectiveness and long-term performance of some of these materials need further research [30]. According to [28], the use of high-performance composites is increasing. The authors note that composites are used in civil infrastructure because they offer a strong, durable, easy-to-install, and lightweight solution as an alternative to conventional construction strategies. The use of steel and hemp in construction reflects a high Technology Readiness Level (TRL) of nearly 7 [31]), reflecting its maturity to be used in civil engineering [31].

7.3 Digital Technologies

Digital technologies are transforming the design, construction and management processes in civil engineering and are focused on the following:

BIM: Digital technologies are transforming design, construction, and management procedures in civil engineering. Building Information Modeling (BIM) [6], [21] is among the forefront technologies facilitating collaboration, data management, and visualization throughout the project lifecycle [6]. The integration of BIM with other technologies such as digital twins [6], [32], the Internet of Things (IoT) [6], [33], and machine learning [6], [33] is opening up new smart infrastructure management possibilities ([6]. The integration of new technologies into the construction industry poses challenges such as data interoperability and standardization [21]. Research on the readiness for BIM-based building permit processes highlights the importance of addressing these challenges for successful technology adoption [21]. Blockchain technology is being explored to enhance transparency, security, and efficiency in construction projects [34]. The construction industry is undergoing transformations with technologies like BIM, UAVs, AR, and VR [30]. XR technologies, including VR, AR, and MR, are increasingly used for training, visualization, and condition assessment of civil infrastructures [35], [36]. Addressing barriers to women's participation in the construction industry is crucial, and training plays a vital role in facilitating the adoption of these technologies [30]. The effective implementation of XR technologies relies on human-computer interaction and the design of intuitive interfaces [19]. 3D printing [33], [37] is another emerging technology with significant potential to be implemented in construction and has the advantage of faster construction speed and minimal material wastage [37]. Yet, issues in the reliability and accuracy of drone-based inspections [38] and regulatory and safety concerns related to their deployment [26] continue to remain. More concerning, though, are the increasingly frequent applications of artificial intelligence (AI) and machine learning (ML) [39], [25], [4] to a range of civil engineering applications, including structural evaluation [39], damage detection [25], and risk mitigation [40]. Yet issues with data collection, model creation, and computational capacity need to be resolved [4]. Bridge engineers have been rapid in taking up the application of AI in bridge health monitoring (BHM) [35], for which there is high technological readiness [35].

BIM encompasses various dimensions, each contributing to sustainable construction practices:

- 3D Modeling:** The virtual building model enables visualization and analysis of the design alternatives, resulting in efficient designs with minimal material and energy waste. A major advantage is enhanced collaboration, as BIM provides a common digital platform for architects, engineers, contractors, and other stakeholders to work together, accelerating communication and reducing errors and disputes [41]. Improved visualization is also an advantage since BIM supports the development of comprehensive and interactive 3D models, which can aid stakeholders in visualizing and examining different design possibilities [42].
- 4D Scheduling:** Integration of BIM with project schedules facilitates appropriate scheduling and coordination of the construction process, reducing delays and optimizing the use of resources. These models can also be enhanced by linking them with schedules (4D) and costs (5D), which allows better planning at the design stage as well as better time and cost control, which is a must for any construction company [43].
- 5D Cost Estimation:** With the integration of BIM and cost data, accurate cost estimation and control, decision-making, and minimization of financial risk are possible. 5D (BIM) can facilitate operating facilities' life cycle cost management [44]. It is a common practice in the current day to utilize the

majority of 5D BIM tools to transfer quantities from 3D modeling and complete the estimation process via manual correlation of model elements with embedded cost databases [44].

Case Study: BIM-Driven Sustainability in New Zealand Construction: The New Zealand construction industry has witnessed a significant shift towards sustainability, driven largely by the Green Star rating system and the adoption of Building Information Modeling (BIM). Green Star rating use has generally governed BIM growth in transforming the construction industry towards attaining more ozone-friendly and profitable in New Zealand [45]. In addition to that, several past BIM-sustainability-focused studies were carried out focusing on the functioning of BIM for the improvement of existing building energy modelling (BEM) practice, optimization of building design energy consumption through the utilization of BIM and BIM sustainable metrics integrated into the preparation of construction cost estimates [46]; [47]; [48].

AI: Artificial intelligence is rapidly transforming the building industry, yielding various applications capable of making a building sustainable. AI algorithms can:

- Optimize Energy Consumption:** AI can audit building designs and operational information to quantify the potential for energy efficiency, producing a reduced carbon footprint and operating costs. Artificial intelligence software can enhance the integration of CDR technology with energy systems by analyzing data on energy demand, renewable energy output [49], and other variables to identify the most cost-effective and efficient means of reducing carbon emissions and maximizing overall system performance [50], [51].
- Minimize Waste Material:** AI can optimize material usage and minimize waste by analyzing construction plans and making precise forecasts of material needs. Waste material can be minimized with the adoption of a proper management system. Waste in construction is on the rise as there are inefficient waste management practices being followed in construction activities [52]. Key factors to be considered in minimizing waste are planning capability and behavior, quantity and specifications conformity, compatibility of the structural system, and effective and appropriate use [53].
- Improve Construction Processes:** AI can automate, analyze data for potential risks, and optimize construction schedules, leading to greater efficiency and reduced environmental impact. By automating repetitive processes, AI reduces human labor and increases overall project efficiency. Project timelines can be shortened, and task sequencing enhanced by construction teams [54].

Case Study: Amsterdam's Edge building features an AI-based building management system that optimizes energy usage according to occupancy levels and climatic conditions. The system has significantly reduced the building's carbon footprint and its overall sustainability performance. Amsterdam's Edge building is a case study of ideal AI use in optimizing energy utilization and reducing carbon emissions in business buildings [55]. The facility employs a futuristic system of IoT devices and sensors to collect live data on light, occupancy, and temperature [55]. That data is fed into an AI platform that changes heating, cooling, and light based on live occupancy and choice [55]. As a result, The Edge has been able to lower its energy usage by 70% than a typical office building, and this demonstrates how AI can assist in creating sustainable workplaces [55].

7.4 Sustainable Technologies

Sustainability is an increasing concern for civil engineering, and emerging technologies are arising to mitigate environmental effects and ensure resource efficiency. The utilization of recycled material [28], for instance, recycled plastics being utilized in polymer concrete, is a significant advancement toward sustainable construction [28]. Geopolymers present a substitute for conventional Portland cement, minimizing carbon

dioxide emissions [29]. Besides, new materials such as steel and hemp have been discovered to possess sustainability attributes [31]. Smart city infrastructure integration [31] also assists in contributing to sustainability through enhanced energy efficiency, traffic, and resource usage [31]. The application of new road materials [56] and scanning technologies [56] is improving the performance and lifespan of pavements [31], boosting the overall sustainability of transport infrastructures [56].

8 Challenges and Limitations

Despite the significant potential of emerging technologies, several challenges and limitations hinder their widespread adoption in civil engineering. These are summarized below:

8.1 Technological Maturity

Most emerging technologies are still in the development process, and their long-term performance and reliability should be further tested [37]. This is especially applicable to extremely complicated technologies or ones that consist of several integrated systems [5]. TRL Perspective: From the point of view of TRL, these technologies stand at a lower level, requiring considerable R&D to become robust enough for practical applications. Specific Civil Engineering Example: While new composite materials might show promising laboratory tests, their behavior over a longer period when applied to real bridges or buildings under varying environmental conditions, needs to be field-tested extensively. Potential Solutions: Ongoing studies, pilot programs, and establishing a standardized method of testing.

8.2 Data Management and Analysis

Successful implementation of most emerging technologies depends on having enormous amounts of good-quality data. Some of the challenges are data collection, storage, processing, and analysis [4]. Robust data management systems and sophisticated analytics methods need to be developed [25], [57]. TRL Perspective: Effective data management and analysis will result in a much higher TRL, as it works out the validation and refinement of technologies. Specific Civil Engineering Example: For instance, SHM systems generate massive datasets from sensor networks. Developing efficient methods to process and analyze this data to detect subtle structural changes is a significant challenge. Potential Solutions: Development of robust data management systems, application of AI/ML techniques for data analysis, and establishment of standardized data formats.

8.3 Standardization and Interoperability

Non-standardization and lack of interoperability among various technologies and systems may hamper their integration seamlessly [21]. Common standards and protocols need to be developed to promote the large-scale implementation of new technologies [21]. TRL Perspective: Indeed, integration readiness requires standardization and interoperability. Specific Civil Engineering Example: The non-existence of standard BIM object libraries for infrastructure components such as bridge elements and pipes contribute to the challenges of sharing and reusing BIM models among projects and software. Potential Solutions: Collaboration between industries for open standards, establishing common protocols for data exchange, and developing shared libraries of BIM.

8.4 Cost and Affordability

The comparatively high up-front cost of certain emerging technologies can deter adoption, especially by small firms or low-budget projects [58]. There is a need for research on low-cost solutions and business

models that facilitate technology adoption [59]. TRL Perspective: Cost-effectiveness is one contextual factor greatly driving real-world readiness. Specific Civil Engineering Example: For example, deploying advanced sensors for SHM, which are very expensive, has limited them to larger or more critical infrastructure. Potential Solutions: Research into affordable solutions, new business models, the creation of leasing and shared services, and government incentives for the adoption of technology.

The cost-effectiveness of adopting new technologies is an important factor that can make them adopted on a large scale. While some technologies are costly to invest in at the outset, they can be cost-effective in the long term and give a higher return on investment. For example, BIM can reduce waste of materials and errors during construction, which can save project expenses.

8.5 Skills Gap

Successful adoption of new technologies needs a talent pool possessing engineering along with technology skills [58]. The skill gaps need to be bridged with education and training programs [22]. The universities' assessment standards must also be aligned accordingly to the needs of the labor market [60]. TRL Perspective: The skill gap impairs integration readiness because it constrains the ability to use and interpret data effectively emanating from these emerging technologies. Specific Civil Engineering Example: For example, bridge engineers may be trained in data analytics and AI to make effective use of data obtained from the BHM systems. Potential Solutions: Focused education and training, the integration of emerging technologies into university studies, and on-the-job training with the involvement of industry.

8.6 Regulatory Frameworks

The absence of definite regulatory policies and guidelines governing the use of certain emerging technologies may create uncertainty and discourage their utilization [28]. There is a need for relevant standards and regulations to be formulated to facilitate the safe and appropriate utilization of such technologies [21]. TRL Perspective: Lack of proper regulations is an important contextual obstacle. Specific Civil Engineering Example: For example, ambiguous regulations associated with the use of drones for bridge inspections could retard their adoption even when the technology is mature. Potential Solutions: Elaboration of transparent but flexible rules and standards, involvement of regulatory authorities in the communicational process with industry participants, development of certification programs for novel technologies.

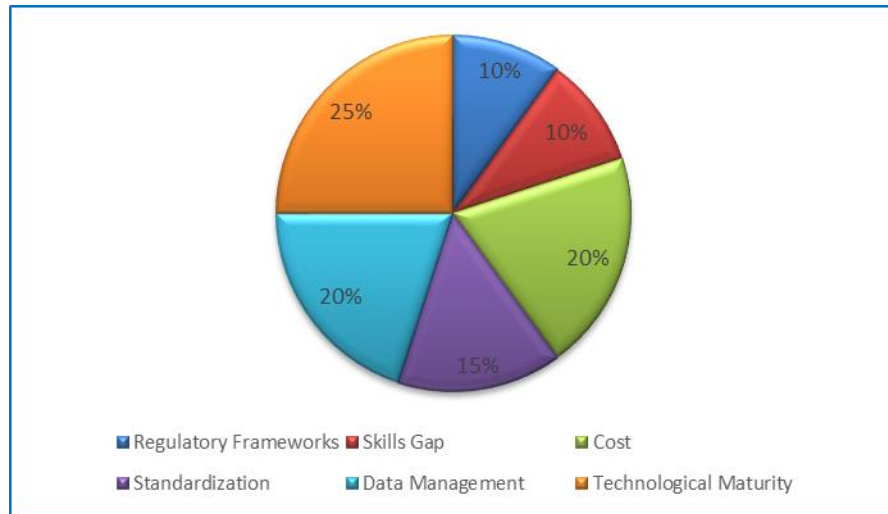


Fig. 3. Challenges of adopting emerging technologies in civil engineering.

9 Future Directions and Research Gaps

Future studies need to pay attention to the gaps and issues identified earlier. It is necessary to make sensor systems for SHM and other uses more reliable, cheaper, and longer lasting [3]. They also need to employ new technologies that will analyze existing data and its multiple layers. This means developing data fusion, anomaly detection, and predictive model algorithms [25]. Also, there should be some accepted guidelines for system integration and data interchange. This standardization will enhance the interoperability of various systems and technologies [21]. Also, easy-to-use interfaces and appropriately designed training courses need to be created so that future technologies can be effectively incorporated and productively used by engineers and other concerned people [61]. Careful consideration of the environmental impacts and sustainability of these technologies during their entire life cycle, including energy consumption, materials used, and waste generated, must be addressed [29].

10 Conclusion

Technology readiness levels assessment is vital to successfully integrate new technologies into civil engineering. A variety of TRL assessment methods exist, yet a holistic approach involving quantitative and qualitative metrics is mooted. Emerging technologies like SHM systems, new materials, digital twins, and artificial intelligence have tremendous potential to enhance the efficiency, safety, and sustainability of civil engineering works. However, there are difficulties in technological maturity, data management, standardization, cost, skills, regulation, and ethics. Future research must overcome these difficulties and develop strategies for the effective and responsible use of these technologies. These technologies will require integration by coordination between researchers, engineers, policymakers, and other stakeholders to achieve the maximum potential of these innovations and reduce potential risks. The historical development of civil engineering materials [62] puts into perspective the continued innovation and the necessity for cautious assessment of emerging materials and technologies [62]. In addition, the technological readiness level evaluation needs to account for overall organizational and external considerations, in addition to sustainability dimensions [7], for an

integrated holistic perspective. The combination of blockchain and BIM technologies demonstrates the promise of such hybrid approaches but simultaneously renders apparent managerial feasibility and obstacles to the deployment of these emerging technologies. The integration of blockchain and BIM ensures change tracking and data ownership [58]. The development of frameworks such as the TOES framework [7] can aid in this more holistic evaluation, rather than a purely technology-focused perspective of readiness [7].

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The Impact of Organizational Agility on Crisis Management in the Health Sector: A Case Study of the Ministry of Health in Bahrain

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Abstract This research explores the influence of organizational agility, including sensing agility, decision-making agility, and execution agility, on effective crisis management in the Ministry of Health in Bahrain. Employing a descriptive-analytical method, the data were gathered via a questionnaire used on a random sample of 133 officials in the Ministry's General Health Administration. The results demonstrate a statistically significant positive relationship between the concept of organizational agility and effective crisis management. Each agility dimension also showed a positive relation with the outcomes of crisis management. The study recommends that the Ministry of Health take strategic action in the enhancement of resource management through improved forecasting of human, financial, and material needs over the short and long term, updating the management information system to monitor the availability of resources, and utilizing them at the right time to enable effective decision-making and resource shortfall solutions.

Keywords Organizational Agility, Crisis Management, Sensing Agility, Decision-Making Agility, Execution Agility.

Introduction

The present global environment is replete with crises that disrupt economies, societies, and health sectors worldwide. The health sector faces numerous challenges that are unequalled by others, such as the COVID-19 pandemic, highlighting the need for speed and agility. Organizational Agility has come to the fore as the ultimate enabler to help healthcare organizations traverse such crises efficiently. This study addresses the organization's agility in terms of crisis management and focuses on the Ministry of Health in Bahrain. In light of this, this study will be able to provide recommendations for improving preparedness and response strategies by the Ministry based on how sensing, decision-making, and execution influence crisis management. This is as suggested by Pearson & Mitroff, 1993.

Literature Review

Organizational Agility

Organizational agility refers to the ability of the organization to monitor its environment for changes and to decide on and implement strategies quickly. Agility becomes even more critical in turbulent environments, where the response capability is usually decisive for whether an organization outperforms crises.

- Sensing Agility: The ability to promptly detect and interpret changes in the internal and external environment is relevant for acting early against any perceived change (Weick, 1995).
- Decision-Making Agility: The time required to make quick but well-informed decisions during a crisis calls for precious time (Joiner, 2019).
- Execution Agility: The ability to execute decisions quickly and effectively implies that an organization can implement changes with minimal disruption of its operational rhythm (Eric, 2021).

Crisis Management in Healthcare

Therefore, healthcare crisis management involves preparation, response, and recovery built around emergent health related contingencies. Therefore, the bottom line of effective crisis management in healthcare is the degree to which an organization can retain agility, particularly within its decisionmaking and execution processes. This has been confirmed in previous research, where an organization with greater agility could handle a crisis because such organizations could easily modify their strategies and operations. In this line, organizational agility is necessary to be by the most current crisis management frameworks, which will create a complementary effect in increasing resilience in the health sector.

The Role of Organizational Agility in Fostering Innovation

Organizational agility absent crisis management and creates an environment that enables innovation. Organizations can innovate more successfully if they can quickly adapt to new information or trends in dynamically changing environments (Martin, 2000). Such capability within the health sector is crucial because it offers innovative solutions to improve patient outcomes and streamline operations (Nejatian & Zarei, 2013).

Challenges to the Application of Organizational Agility in the Public Sector

Specific challenges have arisen in implementing organizational agility, especially in health organizations in the public sector. This pertains to challenges such as bureaucratic inertia, resistance to change, and how to manage the complexity of large-scale operations (Mintzberg, 1979). Addressing these challenges is imperative to improve crisis management and ensure public health organizations can respond effectively to various emergencies. (Pavelkova, 2020).

Organizational Agility Case Studies on Crisis Management

Plenty of case studies have demonstrated organizational Agility, particularly in crisis situations. For instance, the COVID-19 pandemic saw health organizations alter their operations and decision-making processes without many problems and managed the situation even better (Faramina et al., 2020). These case studies will no doubt go a long way in creating better organizational Agility for the Ministry of Health in Bahrain.

Research Hypotheses and Methodology

Hypotheses

H1: Organizational agility enables crisis management effectiveness in the Ministry of Health, Bahrain.

H1.1: Sensing Agility influences Crisis management in the Ministry of Health.

H1.2: Decision-making agility influences Crisis management in the Ministry of Health.

H1.3: Execution agility influences Crisis management in the Ministry of Health.

Sample

The sample for this study comprises employees from the Ministry of Health in Bahrain. This was a simple random sampling in which each employee had an equal opportunity to be selected for the research study. The sample size was determined using Krejcie and Morgan's 1970 formula for determining sample size from a given population. One hundred fifty employees were surveyed, and data collected from these surveys was used to analyze the data to test the research hypotheses.

Data Analysis and Results

Hypothesis Testing

The data analysis tests the relationship of organizational Agility-sensing and decision-making agility with crisis management effectiveness.

H1.1: In simple linear regression, it could be seen that the result of sensing agility significantly affects crisis management at the Ministry of Health. The outcome showed a positive correlation with the R^2 value of 0.624, indicating that sensing agility accounts for a 62.4% variation in the effectiveness of crisis management.

Table 1 Simple Linear Regression Results for H1.1 (Sensing Agility)

Independent Variable	β	R^2	F	Sig.
Sensing Agility	0.716	0.624	14.760	0.001

According to the results in Table 1, there is an important relationship between the independent variable "Sensing Agility" and the dependent variable under scrutiny.

With a β of 0.716, every increase of one unit of sensing agility will lead to an associated increase of 0.716 units of the dependent variable. This is a positive relationship; in other words, improvement in the level of sensing agility leads to a positive impact on.

The value of R^2 would be approximately 0.624, indicating that about 62.4% of the variance in the dependent variable is explained by sensing agility. This reflects the model's reasonably strong explanatory power. An F-value of 14.760 shows that the model is significant statistically. This would, hence, mean that the observed relation is very unlikely to be accidental.

The statistical significance is further supported by the p-value of 0.001, which gives enough evidence to reject the null hypothesis. This would imply that sensing agility significantly affects the dependent variable. So, Increasing the level of sensing agility can apparently improve the dependent variable.

H1.2: In this light, decision-making agility also influences crisis management, with R^2 being equal to 0.768, thus explaining 76.8% of the variance in effectiveness in crisis management, according to Simons, 2005.

Table 2 Simple Linear Regression Results for H1.2 (Decision-Making Agility)

Independent Variable	β	R^2	F	Sig.
Decision-Making Agility	0.808	0.768	20.803	0.001

Table 2 indicates a strong relationship between the dependent variable analyzed and the independent variable, "Decision-Making Agility."

From the coefficient of 0.808, moving one unit on decision-making agility increases the dependent variable by 0.808 units. This suggests a strong positive effect. R^2 - The R^2 value of 0.768 means that the decision-making agility explains about 76.8% of the variance of the dependent variable. This then means that the model is very strong in explanation. The F value of 20.803 implies that the model was statistically significant. This warns us that the relationship observed is not likely to be merely due to random chance. The p-value, 0.001 statistical significance, suggests the findings to be statistically significant; strong evidence exists for rejecting the null hypothesis. Hence, the outcome measured would mean an effective influence by the variable - decision-making agility.

H1.3: Execution agility influences Crisis management in the Ministry of Health. **Table 3**
Simple Linear Regression Results for H1.3 (Execution agility)

Independent Variable	β	R^2	F	Sig.
Execution agility	0.790	0.779	21.476	0.001

The results in Table 3 present the results of a simple linear regression analysis performed to test Hypothesis H1.3 concerning the effect of execution agility on a dependent variable.

These variables measure the agility in execution. The β value of 0.790 signifies a robust positive relationship between the execution agility and the dependent variable; this would mean that with each increase of one unit in execution agility, there should be an increase of 0.790 units by the dependent variable. R^2 of 0.779 would mean that about 77.9% of the variation in the dependent variable is explained by execution agility. The overall high R-value indicated a high model fit. The F-statistic here is 21.476, meaning the overall regression model is statistically significant. Sig. This is an essential result as represented by the p-value 0.001 below 0.05. This means that the effect of execution agility on the dependent variable is statistically significant. Therefore, there is a sound reason to accept the hypothesis that execution agility significantly impacts the dependent variable. From the information gathered, it seems that execution agility strongly and substantially affects the outcome under study positively. Hence, it is not something whose effect can be ignored in relevant studies.

Table 4 Descriptive Statistics for Organizational Agility and Crisis Management

Variable	Mean	Standard Deviation
Sensing Agility	4.21	0.58
Decision-Making Agility	4.35	0.62
Execution Agility	4.18	0.61
Crisis Management Effectiveness	4.30	0.60

The above table gives descriptive statistics on the variables measured on organizational agility and crisis management effectiveness dimensions through their mean and standard deviation. These represent the general view regarding the data's tendency to its center and the variability of the scores. Decision-making agility has the highest mean score of 4.35, indicating that it is seen as the most critical area. Execution Agility has the lowest mean score of 4.18. With that said, all variables demonstrate relatively proximate mean scores, showing that the agility means generally well in these areas.

Table 5 Correlation Matrix Between Organizational Agility Dimensions and Crisis Management

Variable	Sensing Agility	Decision-Making Agility	Execution Agility	Crisis Management Effectiveness
Sensing Agility	1.00	0.68	0.64	0.79
Decision-Making Agility	0.68	1.00	0.72	0.81
Execution Agility	0.64	0.72	1.00	0.77
Crisis Management Effectiveness	0.79	0.81	0.77	1.00

Above is the correlation matrix between organizational agility and crisis management effectiveness. Values reflect the strength and direction of relationships between variables. Interlinkages exist among the dimensions of sensing, decision-making, and execution, and together they affect crisis management effectiveness. Sensing Agility: It is strongly positively correlated with crisis management effectiveness at 0.79. This suggests that other things equal, the better the organization is at sensing changes in its environment, the better it is at managing crises. It also corresponds quite well with a decision-making agility of 0.68 and an execution agility of 0.64, which points out that an organization's ability to perceive and understand the context is close to its ability to decide and execute. For Decision-Making Agility, the correlation with the effectiveness of crisis management is significant at 0.81, which means that making swift and informed decisions highly enhances crisis management performance. Further, it reveals a very strong positive association with both sensing agility (.68) and execution agility (.72), indicating that good decisions are founded on good sensing and are important for execution. Execution Agility: This component reveals a positive association with crisis management effectiveness (.77). The associations with both sensing agility (.64) and decision agility (.72) further indicate the fact that good execution builds on sound sensing capabilities as well as on good and informed decisions. Crisis Management Effectiveness: This is the most dependent variable that shows to have the highest correlations with the two variables under discussion, decision-making agility at 0.81 and sensing

agility at 0.79. Therefore, it indicates that an organization should prioritize these dimensions to enhance its crisis management capability.

Overview of the Findings

These results affirm that sensing and decision-making agility significantly improve the Ministry's capacity for effective crisis management. The high R^2 values indicate that these dimensions of organizational Agility explain a considerable portion of the variation in crisis management success within the health sector. (Pearson & Mitroff, 1993).

Discussion

The results of this study establish the importance of organizational Agility in the spheres of sensing and decision-making as pertains to crisis management. Threat-sensing and rapid, informed decision-making would become critical factors in the Ministry of Health's capability to mitigate crises. This aspect of Agility in continuous training and development is also indicated in this study.

Conclusion and Recommendations

The study concludes that organizational agility can be considered a significant factor in effectively managing crises within the Ministry of Health in Bahrain. For enhancing crisis management capabilities, recommendations are to invest in the following areas:

- Training Programs: Ensuring improvement in Agility in decision-making and execution (Harroff et al., 2015).
- Technology Integration: Integrating advanced levels of information systems for agile responses to emerging (Martin, 2000).
- Continuous Monitoring: establishing a framework that constantly observes and enhances organizational Agility (Jomar et al., 2021).

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A New Model Proposal for Risk Analysis of Business Processes: ERP and BWM-Based Fuzzy Risk Evaluation Model

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Abstract. In companies, multiple processes are executed concurrently, and disruptions in one process may impact others. The sustainability of businesses depends on managing how these procedures are carried out. In order to show how well procedures work and pinpoint their shortcomings, this study suggests a novel method. This was accomplished by determining membership degrees and calculating risk magnitudes using a rule-based fuzzy logic method. Risks related to the process under investigation were thoroughly established in the study's initial phase. Then, it was determined that risk probability, risk detectability, and risk severity were the factors affecting risk analysis. Algorithmic algorithms were created to allow risk likelihood to be automatically calculated from ERP system reports. A checklist tailored to the ERP system's configuration was used to assess risk detectability. Business management qualitatively characterized risk severity by taking into account the possible negative consequences of risk realization on the procedure and the long-term viability of the organization. The Best Worst Method (BWM) was used to quantify the effect value of the severity parameter. The suggested model is a useful tool for decision-making processes and enables a more accurate evaluation of risk variables including uncertainty. ERP reports taken from a manufacturing company's operational data were used in a case study to illustrate the applicability of the created approach.

Keywords: ERP, Risk Analysis, Fuzzy (Ruled Based), BWM.

1 Introduction

Companies strive to improve their processes to gain a competitive advantage and enhance efficiency. In this context, Enterprise Resource Planning (ERP) has become a critical tool [3]. Through ERP systems, businesses aim to monitor and integrate their processes more effectively. However, for ERP systems to be utilized efficiently, risks within business processes must be accurately analyzed. Process improvement and risk-focused approaches help maximize the full potential of ERP systems, reducing costs and enhancing operational sustainability [3]. Despite the significant impact of ERP systems on process improvement, there is currently no widely adopted risk-based approach in practice. This study examines the benefits of ERP systems in enterprises, such as operational efficiency, cost management, and error reduction. However, it also identifies a gap in the literature regarding the insufficient analysis of operational, financial, and technical risks associated with these processes. As part of the literature review, the success factors and methodologies used in ERP-based process improvement projects were analyzed, and recommendations

were developed to enhance the effectiveness of these processes. This study specifically focuses on inefficiencies in the procurement process despite ERP implementation, analyzing risks related to supplier management, data accuracy, order errors, and delivery issues. A risk-based model was developed to provide improvement suggestions, aiming for more successful and sustainable ERP projects. The study's findings contribute to the development of new methods and strategies to enhance the role of ERP systems in process improvement.

The remainder of this paper is organized as follows: Section 2 presents the literature review, Section 3 outlines the fundamental steps of the proposed methodology, and Section 4 provides an example application. Finally, the study's findings are presented in Section 5.

2 Literature Review

A comprehensive literature review was conducted to highlight the role of ERP systems in process improvement efforts and the need for risk analysis-focused approaches. The literature review provides fundamental insights into the integrated working capacity of ERP systems, the operational efficiency advantages they offer to companies, and their potential risks. Additionally, it aims to identify gaps in existing literature from a risk analysis perspective. The review analyzed peer-reviewed academic publications spanning a 10-year period, with a total of 65 studies examined in detail. The impact of ERP systems and prominent methodologies was assessed through various case studies, surveys, and statistical methods.

2.1 The Role of ERP Systems in Process Improvement

ERP systems optimize information flow and enhance operational efficiency by integrating various functional units within a company. The literature review highlights the key contributions of ERP systems in the following areas:

1. **Productivity Improvement:** ERP systems enhance business efficiency through process reengineering and continuous improvement efforts [1]. It has been noted that post-ERP continuous improvement models lead to lasting advancements in business processes [2]. The integration of ERP in production processes has been found to increase efficiency [3], while ERP-CRM integration reduces defective production and saves time [4]. Similarly, ERP and MES integration has been shown to improve production flexibility and efficiency [5].
2. **Reduction of Error Rates:** ERP systems play a crucial role in minimizing errors through automation and traceability. Studies indicate that user-friendly interfaces and intelligent coding algorithms help reduce user errors [3]. Compared to manual data exchange, integrated ERP structures significantly decrease error rates [6]. In the healthcare sector, ERP-based process improvements ensure better traceability of information flow and prevent human errors [7].
3. **Interdepartmental Communication and Coordination:** One of the most significant contributions of ERP systems is the optimization of information flow between departments. For instance, ERP facilitates seamless data exchange between sales, marketing, and production departments, strengthening communication and collaboration [3]. Popular ERP solutions like SAP enhance interdepartmental data sharing [6]. Additionally, the integration of ERP with management control systems has been shown to improve organizational coordination [8]. Furthermore, ERP-MES integration enhances coordination between management and production levels, thereby increasing operational flexibility [5].

4. **Financial Advantages:** ERP systems provide cost savings and improve financial efficiency. The elimination of manual data exchange and reduced licensing costs contribute to financial benefits [6]. ERP systems enhance the accuracy of financial analysis, thereby improving business performance and competitiveness [8]. Additionally, ERP facilitates cost management and supports the financial sustainability of organizations [9]. Process improvement efforts linked to ERP implementations further contribute to cost reductions [10].

2.2 Methodologies Used in Literature

The literature review reveals that various methodologies have been employed in ERP and process improvement studies:

- **Case Studies:** Case studies are widely used to evaluate ERP project implementations. In particular, detailed case analyses have been conducted to understand the impact of an ERP project on specific businesses.
- **Surveys and Data Collection Tools:** User feedback has been utilized to assess the effectiveness of ERP systems and identify encountered challenges. Survey data have been analyzed to measure the impact of ERP on processes and develop recommendations.
- **Limited Statistical Analyses:** Statistical methods such as correlation analysis and regression analysis have been used to evaluate the performance and impact of ERP systems. These analyses help determine process improvement potential and highlight the effects of ERP functionality.

This study aims to contribute to the literature by prioritizing risk analysis-focused approaches in ERP-based process improvement projects. The findings from the literature review serve as a foundation for understanding the challenges faced in existing ERP projects and proposing solutions to increase their success rate. A critical evaluation of the literature will guide the development of new methods and strategies for future research in this field. Furthermore, the study suggests that a risk analysis-based approach is a critical component for ensuring the long-term success of ERP projects in businesses.

2.3 Comparison of ERP Systems in Risk Assessment

Different ERP systems exhibit various differences in risk assessment approaches [13]:

- **SAP:** Provides detailed data analysis with its modular structure; however, integration costs are high.
- **Oracle ERP:** Offers a database-focused management system, providing advantages in financial risk analysis.
- **Microsoft Dynamics:** Offers a flexible structure for SMEs but may present certain scalability challenges for large enterprises. Since the impact of ERP on risk analysis varies depending on system characteristics, business-specific analyses are required.

3 Proposed Method: ERP and BWM-Based Risk Assessment Model

ERP systems are fundamental software programs used by companies to integrate and coordinate information across all areas of a business [10]. A business process consists of a series of activities that take various inputs and produce outputs, such as reports or forecasts, that create value for customers. ERP software integrates tasks across different business functions, including sales, marketing, production, pro-

curement, logistics, accounting, and human resources, contributing to the efficient execution of business processes. To analyze the risks associated with business processes, this study proposes a new model. The steps of the proposed model are outlined below.

3.1 Selection of the Process to Be Analyzed

A company's functional activity areas consist of more specific tasks that enable the execution of various operations. Table 1 provides examples of business activity areas and their corresponding functional operations. These functional activity areas in businesses are generally categorized into four main functions: Marketing and Sales (M/S), Supply Chain Management (SCM), Accounting and Finance (A/F), and Human Resources (HR). Examples of the business functions within each area are illustrated in Figure 1.

Table 1. Examples of functional areas of operation and their business functions [10].

Functional area of operation	Marketing and Sales	Supply Chain Management	Accounting and Finance	Human Resources
	Marketing product	Purchasing goods and raw materials	Financial accounting of payments from customers and to suppliers	Recruiting and hiring
	Taking sales orders	Receiving goods and raw materials	Cost allocation and control	Training
	Customer support	Transportation and logistics	Planning and budgeting	Payroll
	Customer relationship management	Scheduling production runs	Cash-flow management	Benefits
	Sales forecasting	Manufacturing goods		Government compliance
Business functions	Advertising	Plant maintenance		

ERP processes are structured around these activity areas, consisting of main processes and their corresponding sub-processes. In ERP systems, these processes are generally classified as follows: Human Resource Management, Accounting and Finances, Sales Management, Customer Relationship Management (CRM), Procurement Management, Supplier Relationship Management (SRM), Production Management, Logistics and Shipment Management, Quality Management, Service and Maintenance Management, Project Management, Product Data Management (PDM), Document Management, Reporting. These classifications help structure ERP systems to efficiently manage and integrate business operations across various functional areas.

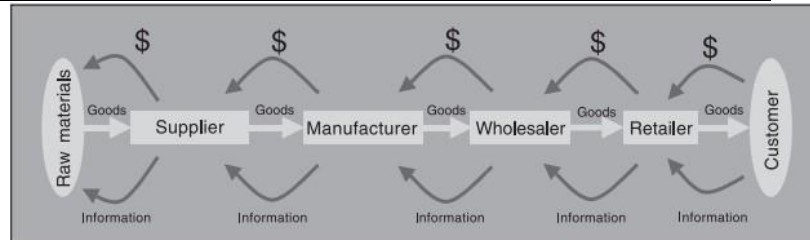


Fig. 1. Supply chain—from raw materials to customer [10].

3.2 Identification of Potential Risks in the Process

Each process is analyzed in detail to identify potential risks. During this step, analysis methods such as the fishbone diagram can be used to determine possible risks systematically. For example, in the procurement process, businesses may encounter the following key risks: order errors, insufficient approval processes, supplier-related risks, outdated information, and delivery errors. Businesses can develop strategies to mitigate potential disruptions and enhance process efficiency by identifying these risks.

Order Errors (R1): Entering incorrect products, prices, or delivery dates into the ERP system leads to the creation of incorrect orders and disruptions in the procurement process. As a result, significant cost increases and customer dissatisfaction can occur.

- **Incorrect Product (R11):** This occurs due to incomplete product information, carelessness, or outdated system data. It leads to poor inventory management, issues in supplier relationships, and financial losses.
- **Incorrect Price (R12):** Arises from outdated price information, incorrect quotations, or communication gaps. Incorrect pricing can lead to budget overruns, disputes with suppliers, and loss of profitability.
- **Incorrect Quantity (R13):** Results from incorrect data entry, lack of communication, or errors in needs analysis. It may cause inventory levels to either exceed or fall short. This can disrupt production processes, increase costs, and result in customer dissatisfaction.
- **Incorrect Delivery Date (R14):** Caused by planning errors or lack of communication. It disrupts the supply chain. Early deliveries increase inventory holding costs, while delays can lead to production halts and customer losses.

Insufficient Approval Process (R2): The lack of proper configuration in the approval mechanisms within the ERP system can lead to issues such as orders being placed without obtaining the necessary approvals. This can result in the procurement of incorrect or low-quality products.

- **Order Approval Omission (R21):** This occurs when orders are placed without obtaining the necessary approval during the order process.

- Order Change Approval Omission (R22): This happens when changes made to the existing processes are implemented without going through the designated approval mechanisms.

Supplier-Based Risks (R3): These refer to potential issues businesses may encounter in their relationships with suppliers.

- Integration Issues (R31): Arise when the ERP system is not compatible with the supplier's systems. This can lead to incorrect data sharing, misprocessed orders, or delays in operations.
- Supplier Dependency (R32): Over-reliance on a single supplier and the lack of alternative suppliers in the ERP system can result in increased costs and longer delivery times.
- Supply Chain Disruptions (R33): While ERP systems facilitate data sharing across the supply chain, unforeseen events (e.g., natural disasters, economic crises) can disrupt the supply chain. This requires rapid updates in the ERP system and the addition of alternative suppliers.

Outdated Information (R4): The lack of up-to-date stock or logistics data in the ERP system can lead to incorrect delivery planning and delays in order fulfillment.

- Outdated Stock Information (R41): This leads to incorrect material forecasting, unnecessary orders, or disruptions in production processes. This can result in increased holding costs due to excessive inventory or delays in customer orders due to material shortages.
- Outdated Price Information (R42): Negatively impacts cost and budgeting processes, leading to unnecessary cost increases or disruptions in supplier relationships.
- Outdated Supplier Information (R43): Causes orders to be sent to incorrect suppliers, delays, or procurement of low-quality products.

Delivery Errors (R5): Incorrect deliveries are a critical risk factor that can cause significant disruptions in supply chain management. Errors such as wrong products, defective products, incorrect quantities, and improper timing can disrupt production planning, leading to customer dissatisfaction and increased costs.

- Incorrect Product Delivery (R51): Delivering the wrong product instead of the one ordered disrupts production processes, causing time and cost losses.
- Defective Product Delivery (R52): Delivering products that do not meet quality standards leads to customer dissatisfaction and an increase in return processes.
- Failure to Deliver the Requested Quantity (R53): Delivering less or more than the required amount results in inventory management issues and operational disruptions.
- Failure to Deliver on Time (R54): Delays in deliveries cause supply chain disruptions or project delays.

3.3 Determining the Probability of Risks Occurring

The probability of each identified risk is determined using reports extracted from the ERP system. The formulas for calculating the probabilities of risks defined for the procurement process are presented in Table 2.

Table 2. Formulas Used for Risk Probability Calculation

Risk Name	Formula Used
Incorrect Product (R11)	(Number of canceled order lines + Number of returned order lines) / Total number of order lines
Incorrect Price (R12)	Number of order lines with changed prices / Total number of order lines
Incorrect Quantity (R13)	Number of order lines with changed quantities / Total number of order lines
Incorrect Delivery Date (R14)	Number of order lines with changed delivery dates / Total number of order lines
Order Approval Omission (R21)	(Total number of order lines – Number of approved order lines) / Total number of order lines
Order Change Approval Omission (R22)	(Total number of change order lines – Number of approved change order lines) / Total number of change order lines
Supplier Dependency (R32)	Number of products & services without supplier alternatives / Total number of products & services
Incorrect Product Delivery (R51)	Number of returned order lines due to "Incorrect Product" / Total number of order lines
Defective Product Delivery (R52)	Number of returned order lines due to "Defective Product" / Total number of order lines
Failure to Deliver Desired Quantity (R53)	Number of returned order lines due to "Incorrect Quantity" / Total number of order lines
Failure to Deliver on Time (R54)	Number of late delivered order lines / Total number of order lines

The probability values of the risks defined for outdated information could not be determined from the reports extracted from the ERP system. Therefore, the developed checklist is provided in Table 3.

Very High: VH; High: H; Medium: M; Low: L; Very Low: VL

Table 3. Checklist for Probability Calculation of Outdated Information Risks

Criteria	Criteria Fulfillment Status				
Do employees manually input stock records into the system for entry/exit?	✓				
Are some orders manually entered, and others scanned via barcode for entry/exit?	✓				
Is entry/exit done by scanning the barcode?	✓				
Is entry/exit done through RFID/RPA and barcode reading systems?				✓	
Is entry/exit information received via integrated systems like RFID or RPA at the gates?					✓
R41 Probability Result	VH	H	M	L	VL
Are price details manually entered into the system by employees?	✓	✓			
Is the update of price information monthly manually controlled?		✓			
Is price information automatically fetched by a system?			✓	✓	✓
Is price information automatically checked by the system monthly?				✓	
Is price information checked in real-time by the system?					✓
R42 Probability Result	VH	H	M	L	VL
Is supplier information entered manually?		✓			
Is supplier information entered both manually and through the supplier portal?			✓		
Is supplier information entered by the supplier on the supplier portal?				✓	
Is supplier information entered via integrated systems like RPA?					✓
R43 Probability Result	VH	H	M	L	VL

If a process has been designed to check the accuracy of supplier information, the probability level of R43 is increased by one level for each data point.

3.4 Determination of Risk Severity

The impact of each risk on business sustainability is defined using the Best Worst Method (BWM). The BWM steps are as follows [11]:

- Step 1: Identify a set of decision criteria. The criteria affecting the decision problem are defined as $c_1, c_2, \dots, c_n$.
- Step 2: Select the best (most important, most desired) and worst (least important, least desired) criteria among the identified criteria. At this stage, decision-makers determine the best and worst criteria without making any comparisons.
- Step 3: Compare the best criterion against all other criteria using a scale from 1 to 9.
- Step 4: Compare the worst criteria against all other criteria using a scale from 1 to 9.
- Step 5: Compute the optimal weights for each criterion.
- Step 6: Evaluate the consistency of the weights and their validity.

Although the BWM approach is employed in the current model, its benefits and drawbacks have been examined, and comparisons with the following alternative approaches have been made:

- AHP (Analytic Hierarchy Process): This multi-criteria decision-making (MCDM) technique is similar to BWM, except it necessitates that decision-makers compare each criterion pairwise. Although this procedure guarantees uniformity among decision-makers, it may make difficult issues more complicated [14].
- TOPSIS: Like BWM, it uses weights to analyze criteria, but it ranks alternatives according to how far apart they are from the best and worst options. Decision-makers may be able to make comparisons more easily as a result [14].
- Monte Carlo simulation is a superior method of modeling uncertainties than BWM since it evaluates risks using random scenarios and probability distributions. It does, however, require a lot of data and has significant computing expenses [15].
- Bayesian networks: These forecasting tools are used in dynamic risk analysis to represent probabilistic dependencies. In contrast to BWM's deterministic structure, Bayesian networks can handle ambiguous data [16].

For ERP risk analysis, each of these approaches has unique benefits; the best approach should be chosen in accordance with business requirements.

3.5 Determination of Risk Detectability

The detectability status of each potential risk within the process is determined. For this purpose, a control list is developed. The checklist for the risks identified in the procurement process is presented in Table 4.

Table 4. Checklist for Detectability Calculation

Criteria	Criteria Fulfillment Status				
Are requests opened through the system by the relevant unit?	✓	✓			
Are requests approved by the stakeholders?	✓	✓	✓		
Is the order checked and confirmed by the supplier?	✓		✓	✓	
R1 Detectability Result	VH	H	M	L	VL
Is the approval process automatically sent to the relevant person on time and complete, according to predefined templates and rules?	✓	✓			
Is the approval step approved only by the relevant person?	✓	✓	✓		
Is the approval process appropriately followed by all stakeholders?	✓		✓	✓	
R2 Detectability Result	VH	H	M	L	VL
Are there multiple suppliers for the service or product purchased in the ERP system?	✓	✓	✓	✓	
Does the system automatically suggest alternative suppliers?	✓	✓	✓		
Is the offer sent automatically to the supplier via the ERP system?	✓				
Is the supplier offer process monitored?		✓			
R32 Detectability Result	VH	H	M	L	VL
Is stock information checked at least every 6 months?	✓		✓		
Is stock information checked at least once a year?		✓		✓	
Is stock information automatically updated?	✓	✓			
Are the price details automatically updated with incoming offers?	✓				

R41 Detectability Result	VH	H	M	L	VL
Is price information checked monthly?		✓			
Is price information checked at least every 6 months?			✓		
Is price information checked at least once a year?				✓	
R42 Detectability Result	VH	H	M	L	VL
Is the supplier information automatically updated with incoming offers?	✓				
Is supplier information checked monthly?		✓			
Is supplier information checked at least every 6 months?			✓		
Is supplier information checked at least once a year?				✓	
R43 Detectability Result	VH	H	M	L	VL
Are there barcodes, QR codes, or other automatic recognition systems?	✓	✓			
Is there a control during product delivery?	✓		✓		
Is there control during production or shipping stages?		✓		✓	
R5 Detectability Result	VH	H	M	L	VL

3.6 Calculation of Risk Magnitude

In the step of calculating risk magnitude, a rule-based fuzzy logic approach has been used. The process steps are shown in Figure 2. The details are as follows [12]:

1. Fuzzification: This is the process of converting certain risk probability, severity, or detectability data into fuzzy sets. Inputs are transformed into fuzzy sets using membership functions, which express the degree of membership between 1 and 0.
2. Knowledge Base: IF-THEN rules are created using expert knowledge. Inputs are formed using logical operators such as "and" or "or."
3. Inference Engine: Using fuzzy logic, the fuzzified inputs are matched with the rules in the knowledge base, and fuzzy operations are applied to determine the output membership functions.
4. Defuzzification: This is the process of converting fuzzy outputs into a single crisp (exact) number.

The fuzzy set used for the fuzzification process of risk probability and risk severity, the first step of calculating the risk magnitude, is shown in Figure 2.

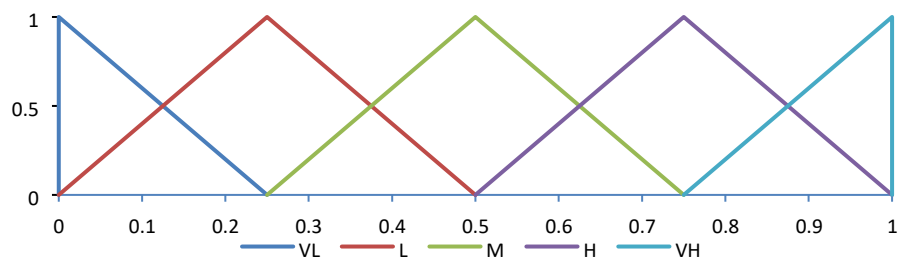


Fig. 2. Linguistic Variable for Likelihood and Severity

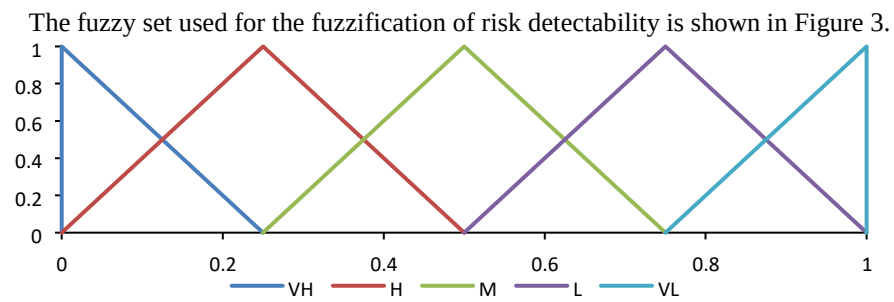


Fig. 3. Linguistic Variable for Detectability

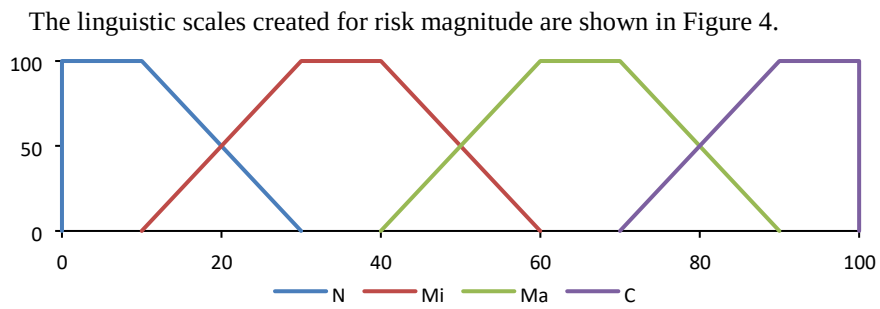


Fig. 4. Linguistic variable for risk magnitude

The rule base is provided in Table 5. Eq. 1 shows that the membership degree is determined by taking the maximum of the minimum values from the three fuzzy sets:

$$(\mu_A(LS_{ij}), \mu_B(SS_{ij}), \mu_D(DS_{ij}))$$

$$\mu_C(RM_{ij}) = \max (\min (\mu_A(LS_{ij}), \mu_B(SS_{ij}), \mu_D(DS_{ij}))) \quad (1)$$

where LS_{ij} , SS_{ij} , and DS_{ij} are probability, severity, and detectability scales determined for route i and decision criterion j , respectively. After the membership degrees and the rule base are determined, the risk magnitude for each risk factor is calculated using formula number 2 [12].

$$RM_{ij} = \frac{\sum_{C=VL}^{C=VH} \mu_C(RM_{ij}^*)(XC)}{\sum_{C=VL}^{C=VH} \mu_C(RM_{ij}^*)} \quad (2)$$

Table 5. Fuzzy IF-THEN rule

RL	S	D				
		VH	H	M	L	VL
VL	VL	N	N	N	N	Mi
	L	N	N	N	Mi	Mi
	M	N	N	Mi	Mi	Ma
	H	N	Mi	Mi	Mi	Ma
L	VH	N	Mi	Mi	Mi	Ma
		Mi	Mi	Mi	Ma	Ma
	VL	N	N	N	Mi	Mi
	L	N	N	Mi	Mi	Mi
M	M	N	N	Mi	Mi	Mi
	H	N	Mi	Mi	Mi	Ma
	VH	N	Mi	Mi	Mi	Ma
		Mi	Mi	Mi	Ma	Ma
	VL	N	N	Mi	Mi	Mi
	L	N	N	Mi	Mi	Ma
	M	Mi	Mi	Ma	Ma	Ma
	H	Mi	Mi	Ma	Ma	C
	VH	Mi	Mi	Ma	Ma	C
		Ma	Ma	Ma	C	C

H	VL	N	N	Mi	Mi	Mi
	L					
	M	N	Mi	Mi	Mi	Ma
	H					
	VH	Mi	Mi	Ma	Ma	C
		Mi	Ma	Ma	C	C
		Ma	Ma	C	C	C
VH	VL	N	Mi	Mi	Mi	Mi
	L					
	M	Mi	Ma	Ma	Ma	Ma
	H					
	VH	Ma	MA	Ma	C	C
		Ma	Ma	C	C	C
		Ma	C	C	C	C

4 Application

Since the purchasing process is of critical importance in terms of operational efficiency and cost management for businesses, this study analyzes the purchasing process of an SME operating in the industrial machinery manufacturing sector. In this study, the risk magnitude is calculated using the parameters of probability, detectability, and severity. Table 6 provides the risk probability obtained from the ERP system report and linguistic assessment for the risks encountered in the purchasing process.

Table 6. Risk Probability Results

Risk Name	Probability Result
Incorrect Product (R11)	0.0156
Incorrect Price (R12)	0.0265
Incorrect Quantity (R13)	0.0123
Incorrect Delivery Date (R14)	0.0174
Order Approval Omission (R21)	0.6968
Order Change Approval Omission (R22)	0.8214
Supplier Dependency (R32)	0.0833
Outdated Stock Information (R41)	High
Outdated Price Information (R42)	High
Outdated Supplier Information (R43)	Very High
Incorrect Product Delivery (R51)	0.0016
Defective Product Delivery (R52)	0.0004
Failure to Deliver Desired Quantity (R53)	0.0000
Failure to Deliver on Time (R54)	0.5538

The risk assessment related to the severity of risks arising from their occurrence has been evaluated by the company's senior executives, and the results obtained by applying the BWM method are shown in

Figure 5.

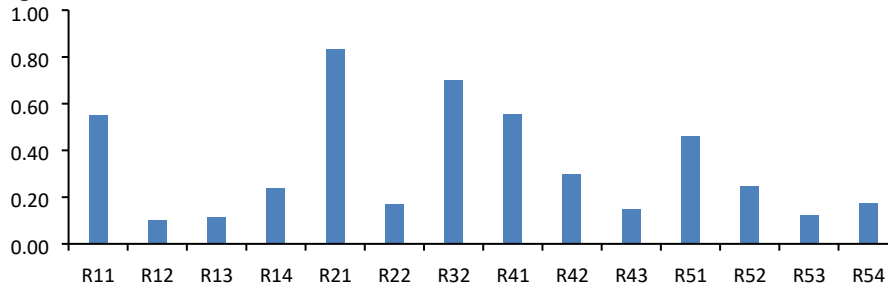


Fig. 5. Analysis Results Related to Risk Severity

Finally, the evaluation results regarding the detectability of the relevant risks are provided in Table 7.

Table 7. Risk Detectability Results

Risk Name	Detectability Result
Incorrect Product (R11)	High
Incorrect Price (R12)	High
Incorrect Quantity (R13)	High
Incorrect Delivery Date (R14)	High
Order Approval Omission (R21)	High
Order Change Approval Omission (R22)	High
Supplier Dependency (R32)	Low
Outdated Stock Information (R41)	Low
Outdated Price Information (R42)	Very Low
Outdated Supplier Information (R43)	Very Low
Incorrect Product Delivery (R51)	Low
Defective Product Delivery (R52)	Low
Failure to Deliver Desired Quantity (R53)	Low
Failure to Deliver on Time (R54)	Low

The final scores for the risk magnitudes related to the purchasing processes are obtained using Equation 2. The risk magnitudes are presented in Figure 6.

According to the results of the analysis, the main risks of the company are outdated stock information, missed order approvals, and outdated price information.

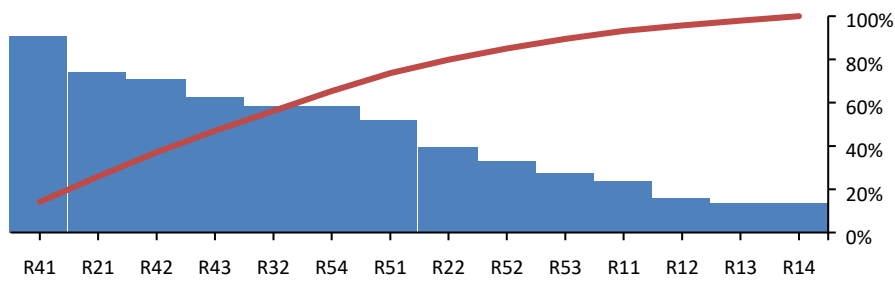


Fig. 6. Risk Magnitude Results

5 Conclusion

In this study, an ERP-based method has been developed for analyzing the risks in the processes carried out within the company. The rule-based fuzzy logic method was used for risk analysis in the developed method, and the values of the parameters such as probability, severity, and detectability, which are the parameters of the method, have been determined separately for each process carried out within the company. The risk probabilities are obtained from ERP reports extracted from the system, while the detectability of the relevant risk is identified through control lists that analyze the process steps of the evaluation. The impact of the risk occurrence on business sustainability is calculated using expert evaluations and the BWM method. The applicability of the proposed method was demonstrated by applying it to the purchasing process of a company operating in the manufacturing sector.

According to the results of the application, the main risk factors in the purchasing process of the examined company are Outdated stock information, Missed order approval, and Outdated price information, respectively.

Although subjective evaluations were used in the study, the limitation of the study arises from the fact that type-1 fuzzy numbers were used in all calculations. In future studies, using extensions of fuzzy sets would be useful for evaluating the flexibility in expert judgments and addressing the uncertainty in the probability parameters.

To lessen the BWM method's dependency on expert opinion, an AI-based prediction system is suggested: Machine Learning-Based Modeling: By learning from ERP data, it is able to evaluate risks dynamically. Real-Time Data Integration: Instant risk analysis can be carried out by obtaining real-time data from ERP reports. These methods offer scalability for big businesses and can be tailored to the dynamic structure of ERP systems.

ERP systems contain vital corporate data, hence cybersecurity risks are a major concern: Data Leaks: ERP systems are susceptible to hacks since they hold private financial and operational data. Risks of Unauthorized Access: User authorization procedures need to be reinforced. Data Encryption and Access Control: ERP solutions must incorporate data encryption and two-factor authentication. By strengthening ERP system security, these steps will increase firms' ability to effectively manage risk.

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Leveraging Data-Driven Supplier Segmentation for Improved Management in Digital Engineering Projects

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Abstract :

In the digital area, optimizing supplier management has become critical to maintaining a competitive edge, especially in engineering and digital projects. This paper tackles the problem of identifying homogeneous groups of suppliers to enhance supplier management by clustering algorithms. A data-driven approach with R statistical software was used to evaluate the performance of 22 suppliers regarding 10 key performance indicators (KPIs). Agglomerative hierarchical clustering is applied to group suppliers; the best number of clusters was shown by the inertia gain plot.

These results suggest a three-cluster solution revealing distinct profiles of suppliers according to their quality performance, product structural design support, and financial strength. A Chi-squared test carried out later on identified Ease of Communication, Quality Performance, and Level of Technology as having the strongest statistically significant relationships with supplier attributes. While the silhouette index indicated a weak to moderate cluster structure, the current research can be seen as laying a foundation for tailored supplier management strategies in enhancing supplier selection and ultimately, improving project outcomes and capacity for innovation in the digital area. K-means clustering was explored as an alternative, with the results suggesting it may not be as well-suited for this particular dataset.

Keywords : *Supplier Cluster ; Data-Driven Decision-Making ; Digital Transformation ; key performance indicators*

1. Introduction

In a period characterized by swift digital change and the growing importance of data-driven decision-making, firms looking to maintain a competitive edge now prioritize the optimization of supplier management [1].

Several factors are driving the growing significance of digital transformation and innovation in supplier management, including the demand for greater communication, enhanced supplier relationship management (SRM), higher efficiency, better data management, stronger risk management, and overall supply chain optimization. Effective supplier relationship management is becoming more widely acknowledged as a crucial factor in determining project success and overall organizational performance, especially in the context of complex technical and digital projects [2].

Choosing suppliers that can contribute to new solutions is crucial for long-term competitiveness since innovation is a major differentiator in today's changing business climate [3].

Additionally, it is essential to optimize decision-making procedures using data-driven methodologies [4]. Businesses can access large supplier datasets, efficiently monitor performance, improve compliance, reduce

expenses, and prevent fraud thanks to digitalization [5]. This research directly addresses the complex problem of finding uniform supplier clustering [6].

By combining key performance indicators (KPIs) that are rarely examined together, including product structural design support and financial strength, this research offers a novel viewpoint in contrast to conventional supplier segmentation techniques that mostly concentrate on cost and delivery time. Furthermore, a better comprehension of the underlying links between supplier features is provided by the combination of sophisticated statistical analysis, such as the Chi-squared test and silhouette index, with agglomerative hierarchical clustering. This method opens the door for a more strategic and efficient supplier management framework by enabling a more focused segmentation that is especially suited to digital engineering projects.

Addressing this gap the study uses clustering algorithms to classify suppliers according to these KPIs, which improves supplier selection and encourages creativity in engineering projects.

The central research question is: How can clustering algorithms be used to efficiently identify homogeneous supplier groups, and how can this segmentation enhance supplier management in engineering and digital projects? To illustrate the key themes and analytical focus of this study, a word cloud was generated (Fig. 1).



Fig. 1. Word Cloud of Key Concepts in Supplier Clustering Research
Source: Author's findings

The core methodological and outcome-oriented components of this study are often referred to as cluster analysis, Model, Algorithm, and Performance. The term cloud is a common expression.

The research will use clustering techniques to classify suppliers based on different factors and suggest personalized solutions for each participant, with a focus on innovation and digital transformation. This study is intended to close this gap. It aims to provide an information-driven approach that can improve the selection process and influence suppliers through multiple factors, including engineering-specific aspects such as technology capability or design guidance.

It aims to achieve these goals by providing information, as well as practical advice, on how the business should improve its supplier management practices in an increasingly digital world while also improving project delivery and increasing the potential for innovation.

2. Literature review

A key component of efficient supply chain management is supplier categorization, which helps businesses make better decisions and maximize resources. The process of evaluating suppliers was initially based on

conventional techniques, but it has since been transformed by the emergence of digital technology and data-driven methodologies. Basic clustering has given way to more sophisticated techniques that use in-depth data analysis for tactical benefit.

Early supplier categorization research concentrated on using clustering algorithms to divide suppliers into groups according to a small number of criteria. Hierarchical clustering is frequently used clustering techniques, as it has special advantages in distinguishing different supplier groups. A more sophisticated comprehension of supplier characteristics and its influence on supply chain effectiveness was made possible by this technique. However, the use of more advanced analytical approaches has become necessary due to the complexity of contemporary supply chains and the sheer amount of data accessible.

The yearly scientific production in supplier clustering research, 2000–2024, is shown in Fig. 2. According to the yearly scientific output, publications gradually climbed until 2018, after which they began to decline dramatically, with the most recent data point in 2024

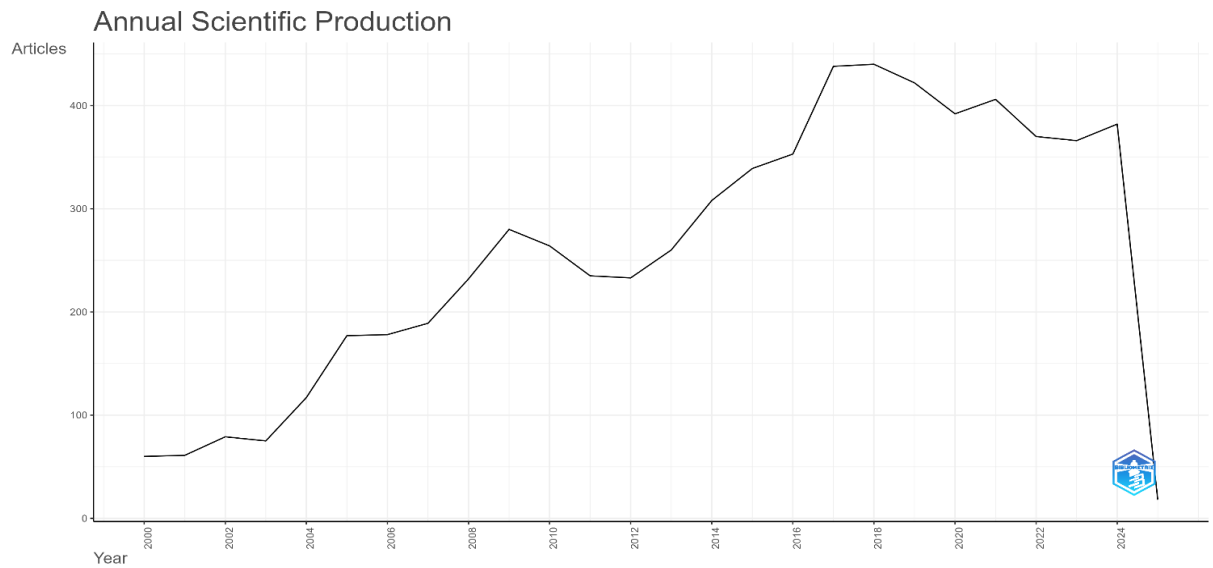


Fig.2. Production scientifique annuelle dans la recherche sur le regroupement de fournisseurs, 2000-2024.
Source: Author's findings

According to [7] this trend may indicate that managing suppliers that employ more intricate and data-intensive approaches calls for a better comprehension of big data analytics and machine learning techniques. The observed drop in publications may not be due to a decline in interest, but rather to a move toward more advanced, data-driven methods, especially the use of clustering algorithms for supplier segmentation [8]. This shift necessitates looking at new data sources and computational methods to increase the accuracy and efficacy of supplier clustering in the digital area. Further research is necessary to determine the precise causes of this publishing trend, including the potential impact of more modern techniques.

The criteria used to evaluate suppliers have broadened in the digital area to include more elements such as cost structures, quality standards, design skills, technical performance, and communication efficacy. For creative engineering projects, these requirements are becoming more and more important. The emphasis on Performance, Management, and Innovation may be illustrated using thematic mapping (Fig. 3).

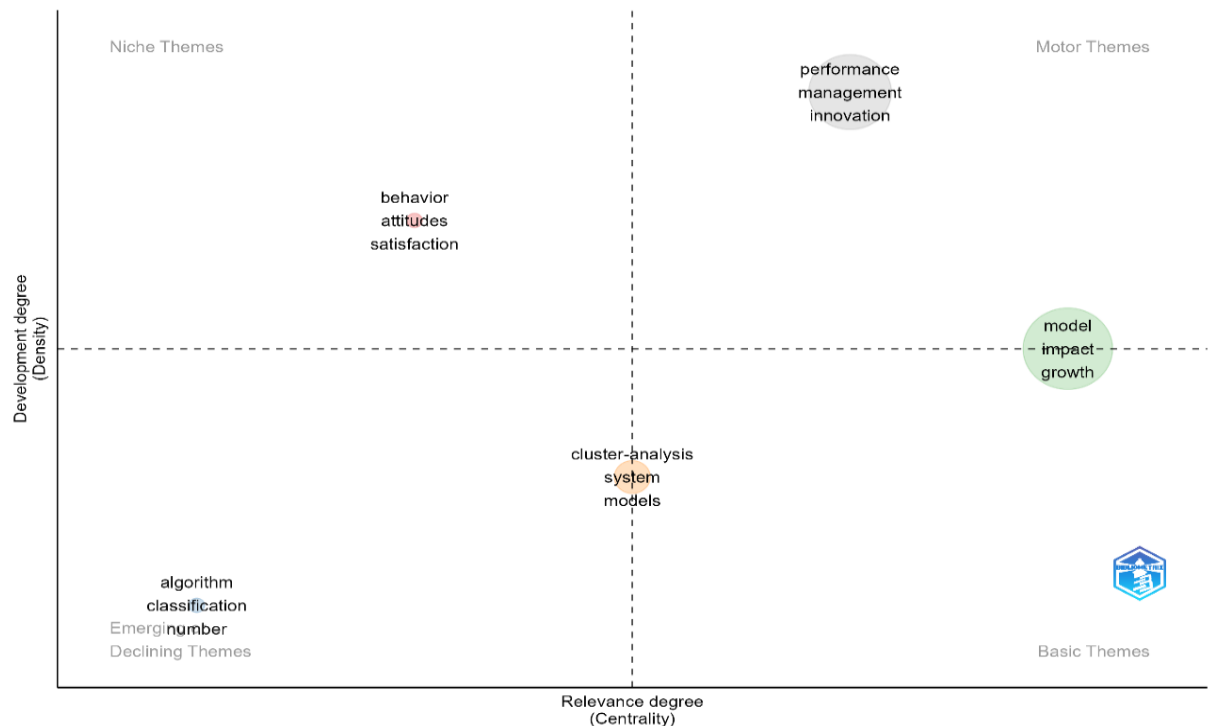


Fig. 3. Thematic Map of Supplier Attributes Based on Clustering Analysis
Source: Author's findings

Clustering Analysis-Based Thematic Map of Supplier Attributes The objective of innovation and enhanced performance via effective supply chains is reflected in the Motor Themes quadrant (Performance, Management, Innovation) of supplier categorization studies [9] Although they need further work, the Basic Themes (Model, Impact, Growth) are quite pertinent. Model, Impact, Growth (Basic Themes) is pertinent, but it needs more real-time data analysis in the digital era [10]. Terms such as Cluster-Analysis, System, Models are crucial. Algorithm, clustering, Emerging Number are less common (Declining Themes). The diagram serves as a foundation for supplier categorization research in the digital era.

By examining the co-occurrence of terms in the study literature, the shift in supplier assessment is further clarified. Fig. 4 illustrates the growing usage of clustering algorithms for strategy alignment and supplier performance.

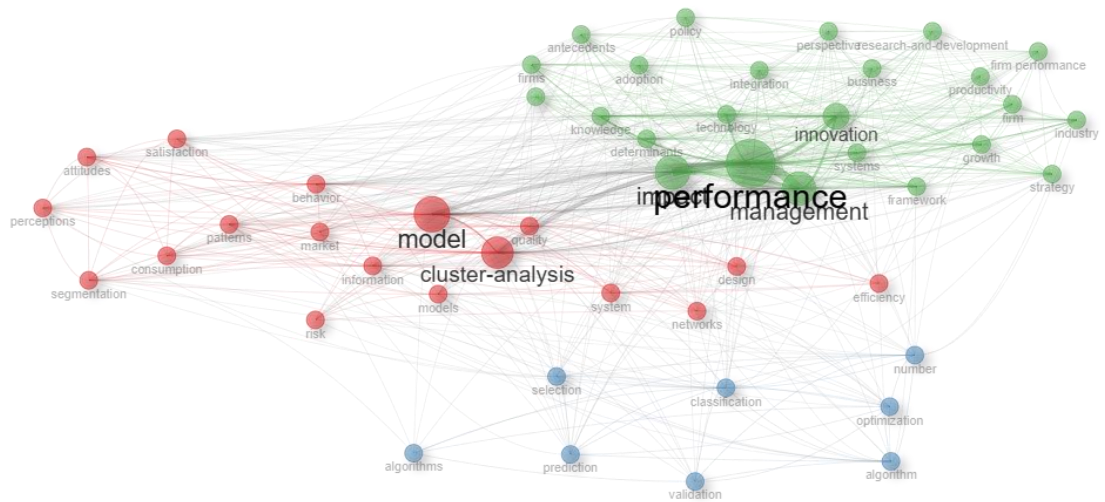


Fig. 4. Clustering-Based Supplier Clustering : A Keyword Co-occurrence Network

Source: Author's findings

A significant amount of research is probably concentrated on the connection between supplier clustering and

improved organizational results because of the strong correlation between performance management and innovation (green cluster) [11]. Data-driven decision-making tools are becoming increasingly important, as seen by the correlations between the red cluster cluster analysis and the blue cluster categorization [5]. On the other hand, the relative isolation of the algorithms cluster emphasizes how important it is to incorporate automated methods into clustering frameworks. An examination of the connections among these clusters might guide future research directions on applying clustering techniques to enhance supplier performance and strategy alignment in the digital era.

A change in priorities is revealed by examining the temporal dynamics of supplier assessment ideas from 2009 to 2022 (Table 1), as indicated by the frequency of different terms. At first, methods such as clustering and cluster analysis greatly facilitated supplier segmentation. Innovation and impact have increasingly acquired prominence, as seen by their growing references, although performance has continuously remained a highly valued trait. According to [12] current research on supplier innovation supports the idea that suppliers must provide strategic value in addition to operational efficiency. Furthermore, the prominence of innovation and impact reflects a move towards comprehensive and integrated supplier management approaches requiring a holistic assessment beyond traditional metrics. This evolution aligns with the need for suppliers to provide both strategic value and operational excellence in a rapidly changing business environment.

Table1. Temporal Dynamics of Supplier Evaluation Concepts (2009-2022)

Term	Frequency	Year(Q1)	Year(Median)	Year (Q 3)
cluster-analysis	296	2009	2015	2020
clustering	131	2010	2016	2021
performance	440	2013	2018	2021
innovation	198	2014	2019	2022
impact	304	2016	2020	2022

Source: Author's findings

In conclusion, the use of digital technology and data-driven approaches has significantly changed the supplier categorization landscape. Clustering techniques provide an effective way for businesses to divide up suppliers, maximize resources, and make well-informed decisions as they traverse the complexity of contemporary supply chains. Future studies should concentrate on using these methods to align strategy, improve supplier performance, and gain a long-term competitive edge in the digital era.

Building on these advancements, recent research has further expanded the scope of supplier categorization by integrating cutting-edge technologies.

Recent studies have explored the use of artificial intelligence (AI) and machine learning in addition to traditional clustering approaches to enhance supplier segmentation. Because AI can evaluate vast volumes of data and generate more dynamic and complete supplier profiles, improving decision-making. As a result, AI is becoming increasingly important in this context. To improve supplier management and project outcomes, for example, machine learning algorithms have been used to improve supplier performance [13]. This facilitates more targeted and efficient supplier management, encourages supply chain innovation, and reduces risk.

3. Research methodology

This section describes the data-driven strategy used to employ clustering algorithms to categorize suppliers. R, a popular statistical programming language, was used to do the analysis [14].

3.1. Data description

In this work, we examine a real-world case study that was conducted to assess the advanced model's effectiveness through testing. Data from an issue examined by [15] served as the basis for this application. A manufacturing business in the electronics sector wants to form strategic alliances with a group of creative suppliers.

The dataset includes performance data from 22 suppliers, assessed using 10 KPIs. We chose these KPIs, representing important facets of supplier performance, based on industry best practices and expert feedback. These are the variables:

- KPI 1 : Support in product structural design
- KPI 2 : Support in process design and engineering
- KPI 3 : Design revision time
- KPI 4 : Prototyping time
- KPI 5 : Technological level

- KPI 6 : Quality performance
- KPI 7 : Financial strength
- KPI 8 : Cost reduction performance
- KPI 9 : Delivery performance
- KPI 10 : Ease of communication

3.2. Data Heterogeneity and Box Plot Analysis

With a broad distribution over the 10 evaluation criteria, the box plot visualization reveals notable variation across the 22 vendors. The use of boxplots to evaluate supplier performance (Fig. 5) revealed significant differences across kPIs.

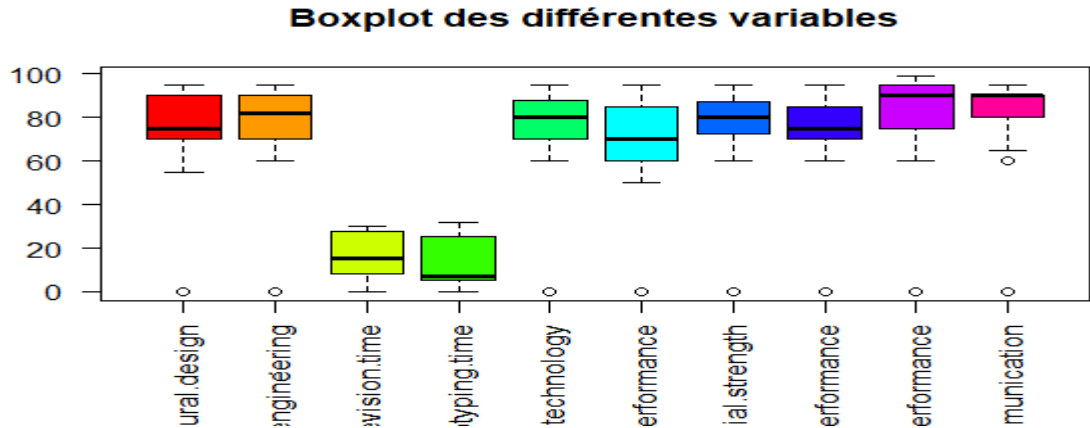


Fig. 5. Boxplot of Variable Distributions
Source: Author's findings

The boxplot highlights notable differences across several criteria and offers a thorough view of the distribution and variability of important supplier performance metrics. Significantly, factors including communication, engineering, and structural.design show minimal variability and high median values, indicating steady supplier performance in these areas. However, prototyping.time and design revision.time show many outliers and larger interquartile ranges, suggesting that suppliers' performance varies. The necessity of data-driven segmentation to find supplier clusters that align with project-specific criteria is highlighted by these disparities. The existence of outliers indicates that certain suppliers depart considerably from industry standards, which may provide risks or indicate areas for focused development initiatives. Utilizing sophisticated supplier analytics and clustering approaches improves supply chain resilience and operational efficiency, according to recent research [16].

Additionally, it has been demonstrated that using statistical techniques like silhouette analysis and hierarchical clustering enhances supplier selection by locating homogenous groups with comparable strengths and weaknesses. Strong data analysis methods must be used to improve decision-making and reduce risks in light of supplier management's growing reliance on digital transformation [17]. This work supports current attempts to optimize supplier management in engineering and digital projects by concentrating on multidimensional supplier clustering.

3.3. Chi-squared test

A Chi-squared test was used to determine the associations between supplier attributes and an categorical variable (Table2).

Table 2. Results of Chi-squared test

Feature	p-value	df
ease.of.communication	0.0007964786	6
quality.performance	0.0017046080	7
level.of.technology	0.0033642463	8
prototyping.time	0.0107465784	10
financial.strength	0.0107465784	10
delivery.performance	0.0107465784	10
support.in.product.structural.design	0.0176751302	11
support.in.process.design.and.engineering	0.0176751302	11
design.revision.time	0.0176751302	11
cost.reduction.performance	0.0176751302	11

Source: Author's findings

A greater link is shown by lower p-values in the chi-squared analysis, which shows the relative relevance of different factors influencing a categorical result. Communication ease ($p=0.000796$), quality performance ($p=0.001705$), and technology level ($p=0.003364$) are the most important factors, indicating that achieving success in these areas is very important for affecting the result. Delivery performance, financial strength, and prototyping time show modest correlations ($p=0.010747$), suggesting that they have a significant but smaller influence than the main factors. Last but not least, statistically significant but comparatively weaker relationships are shown by support for product structural design, support for process design and engineering, design revision time, and cost reduction performance ($p=0.017675$). Therefore, concentrating on communication, quality, and technology is likely to have the biggest impact, even though all qualities are tied to the outcome.

3.4. Clustering analysis

•Agglomerative algorithm

The agglomerative algorithm was used to identify distinct groups in supplier data based KPIs such as cost reduction, delivery performance, and support for product structural design [18]. This technique facilitates the analysis of different levels of cluster granularity and provides insights into hierarchical relationships within large datasets [19].

According to the literature, the agglomerative hierarchical clustering algorithm is one of the most popular clustering techniques in machine learning [20]. This data-driven approach gives a more nuanced understanding of supplier capabilities and aids in strategic decisions about supplier management and selection [21]. The dendrogram, which illustrates how suppliers clump together based on specific criteria, graphically depicts the hierarchical relationships between them [22]. The hierarchical clustering dendrogram (Fig. 6) displays three distinct supplier profiles.

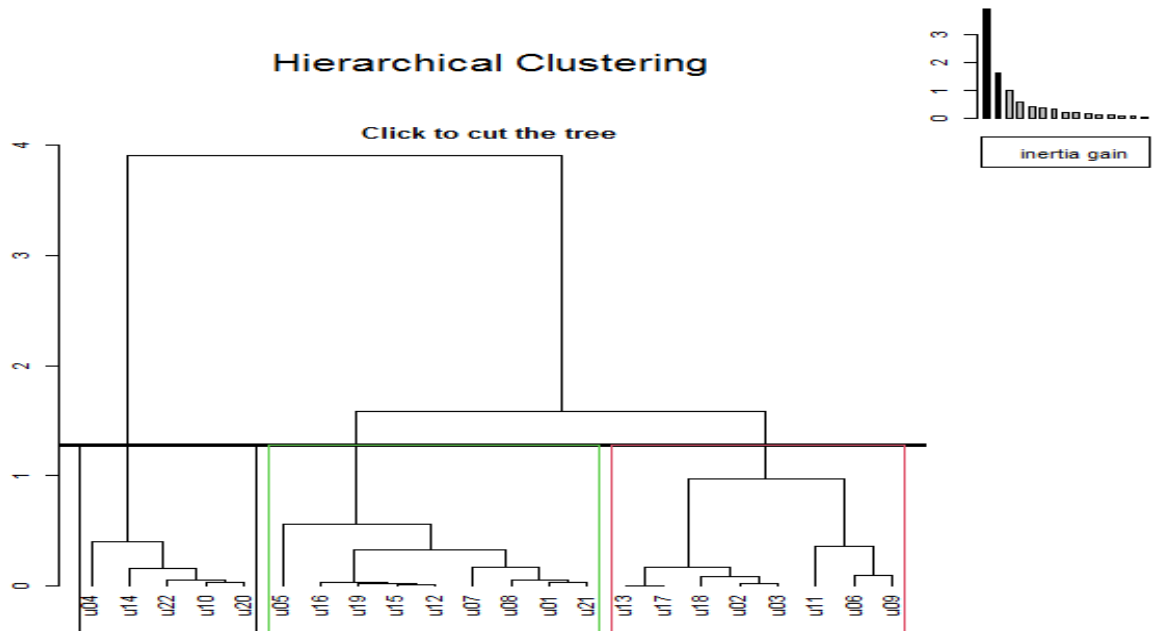


Fig.6. Hierarchical Clustering Dendrogram
Source: Author’s findings

The data has a three-group structure as revealed by the hierarchical clustering. The close internal cohesiveness of the first group points to a powerful underlying characteristic that all of its members share. The structure of the second group is a little looser, suggesting greater variability but a similar general character. The fact that the third group forms a unique and independent branch indicates that its traits differ from those of the other two groups. This segmentation is supported as significant and instructive by the significant decrease in within-cluster variation at the three-cluster level, as seen by the inertia gain plot.

We examined the inertia gain plot to identify the optimal number of clusters in order to reduce the amount of information lost while grouping providers [23]. The dendrogram and the inertia gain plot as seen in the dendrogram plot (Fig6) demonstrates that splitting suppliers into three clusters captures significantly more variation in the data than using only two.

More than the dendrogram we have the silhouette index which was used to evaluate how well the clustering findings worked [24]. The average silhouette index was 0.35, indicating a weak to moderate cluster structure, as seen in the silhouette plot (Fig7).

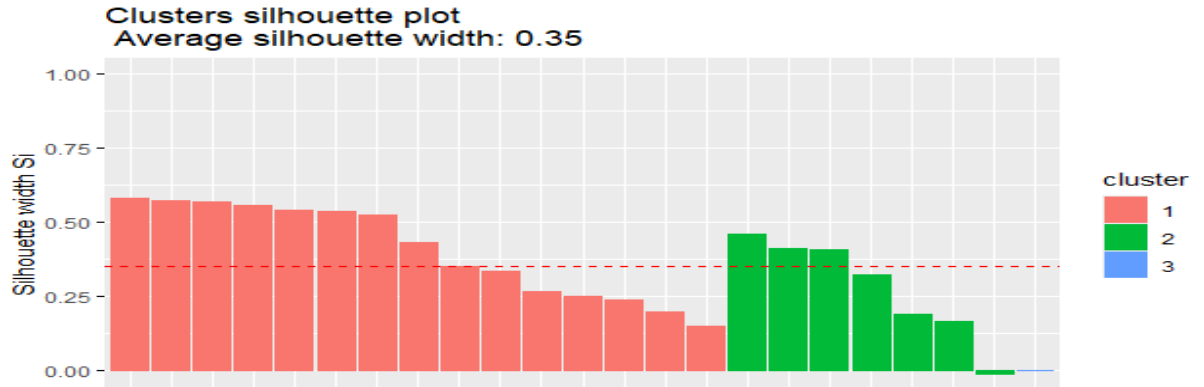


Fig7. Silhouette Plot of Clustered Data
Source: Author's findings

This implies that there is some overlap in the clusters that were created, even though the hierarchical agglomerative algorithm categorized providers based on their attributes (help with product design, delivery performance, etc.). Cluster 1, where most suppliers are located, has varying silhouette widths, indicating that certain providers do not fit within the cluster as well. Furthermore, Cluster 3 can be unique due to its narrow silhouette width and single provider. Despite Cluster 2's superior fit, the overall weak structure suggests that further refinement of the clustering approach is necessary to ensure a more dependable and actionable supplier segmentation for better supplier portfolio management and decision-making. This refinement could involve changing the number of clusters or looking into alternative algorithms.

In order to find discrete groupings in supplier data based on KPIs like cost reduction, delivery performance, and support for product structural design, the agglomerative hierarchical clustering technique was first used. This method makes it easier to examine various cluster granularities and offers valuable information on hierarchical relationships in big datasets. According to the literature study, one popular method for supplier segmentation is hierarchical clustering, which has the benefit of not requiring a set number of groups. When the ideal number of supplier categories based on the selected KPIs is unclear, this is very advantageous. Additionally, the computational benefits of hierarchical clustering are enhanced by the relatively modest dataset size of 22 providers.

However, a weak to moderate cluster structure was suggested by the comparatively low silhouette index of 0.35 obtained from the initial agglomerative hierarchical clustering study. This can be because of overlapping clusters, outlier sensitivity, or the limits of the silhouette index itself, which is based on the assumption that clusters are convex and well-separated. Though it suggests that the clusters might not be well-defined or distinct, a low silhouette index does not always mean that the clustering results are invalid. The 3-cluster solution was reasonable despite the low silhouette index, according to the inertia gain plots.

K-means clustering was used to overcome the constraints shown by the silhouette index and investigate alternate clustering options.

- K-means clustering

K-means is a partition-based clustering technique that seeks to separate the data into k distinct, with each data point belonging to the cluster with the closest mean (centroid). It is renowned for its scalability and efficiency, and its application serves as a benchmark for agglomerative hierarchical grouping.

In accordance with the three-cluster solution found by the agglomerative hierarchical clustering analysis, the number of clusters (k) in K-means was set to three in order to allow for a direct comparison. The silhouette plot for the K-means clustering is shown in Figure 6.

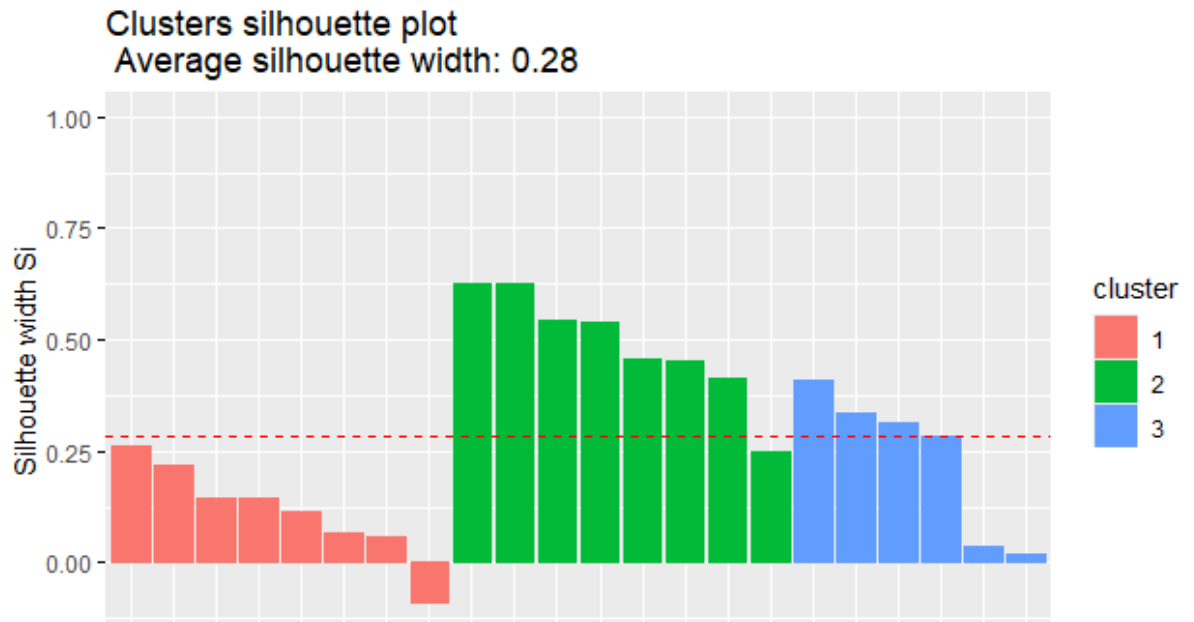


Fig.8. Silhouette Plot for K-means Clustering

Source: Author's findings

This silhouette plot suggests that the clusters created exhibit some degree of overlap, indicating potential limitations in the clustering approach. The average silhouette width of **0.28** suggests a weak overall structure, implying that the separation between clusters is not well-defined.

Several observations in Cluster 1 have low values, suggesting that some of the points in this cluster would not fit well and would be better categorized into another group. Cluster 1 also features a variety of silhouette widths. Because of its somewhat wider silhouettes, which indicate a better internal cohesiveness, Cluster 2 seems to be the most well-structured. The fact that Cluster 3 contains several observations with smaller silhouette widths suggests that it is not very distinct from the other clusters.

3.5. Comparison of Clustering Methods

Utilizing a bottom-up methodology, agglomerative hierarchical clustering identified three supplier groups according to KPIs such as cost reduction, delivery performance, and support for product structural design. Three clusters were supported by an inertia gain plot. However, a weak to moderate cluster structure was indicated by the silhouette index of 0.35. Although K-Means clustering was investigated as a substitute with $k=3$ for direct comparison, the abstract notes that the results indicated it might not be as appropriate for this

specific dataset. A lower silhouette index suggests a weaker cluster separation, despite the K-Means approach's computational efficiency. Agglomerative Hierarchical Clustering ultimately provided a more structured perspective and was more successful in this situation for supplier segmentation.

Even though neither approach produced flawless segmentation, agglomerative clustering opened the door for customized supplier management techniques by offering deeper insights into supplier relationships.

As a conclusion, the initial agglomerative hierarchical clustering shed light on possible supplier categories based on KPIs, despite a moderate silhouette score. Although K-means clustering was investigated as an alternative, the findings indicated that it might not be as suitable for this specific dataset. Due to the actionable insights and commercial applicability, the agglomerative hierarchical clustering provides more nuanced and interpretable findings, which are more valuable. Therefore, we recommend that for this specific project, suppliers be divided using agglomerative hierarchical clustering. In order to increase the robustness and interpretability of the results and modify the supplier segmentation method, more study is advised, including feature engineering and other distance measures.

4. Results and discussion

4.1. Presentation of clusters

The clustering technique effectively divided the 22 suppliers into discrete, uniform groups based on their performance across ten key performance indicators (KPIs), including critical aspects like product structure design support, technical proficiency, cost reduction, and ease of communication. Further analysis of these clusters reveals a strong link between supplier groupings and specific performance metrics (Table.3) notably, the level of technology employed, the support in process design and engineering, and delivery performance show the strongest association with cluster membership, indicating these were key differentiating factors utilized by the clustering algorithm.

Table 3. Link between the cluster variable and the quantitative variables

Variable	Eta2	P-value
level.of.technology	0.7568182	1.466714e-06
support.in.process.design.and.engineering	0.7051631	9.141697e-06
delivery.performance	0.6987396	1.121888e-05
prototyping.time	0.6274660	8.434822e-05
ease.of.communication	0.6180858	1.068255e-04

support.in.product.structural.design	0.5470371	5.402500e-04
design.revision.time	0.5280866	7.974290e-04
cost.reduction.performance	0.4305442	4.751935e-03
financial.strength	0.3745477	1.158364e-02
quality.performance	0.3114163	2.887944e-02

Variable	Cluster	v.test	Mean in category	Overall mean	sd in category	Overall sd	p.value
prototyping.time	1	3.358266	27.0000	14.27273	5.887841	10.635198	0.0007843319
design.revision.time	1	2.809749	27.16667	18.00000	3.670453	9.155227	0.0049580073
quality.performance	1	- 2.105498	62.5000	73.86364	12.162100	15.145643	0.0352479535
financial.strength	1	- 2.531140	70.83333	80.31818	11.696391	10.515730	0.0113692302
support.in.product.structural.design	1	- 2.928894	66.66667	78.77273	6.871843	11.599106	0.0034017071
support.in.process.design.and.engineering	1	- 3.120328	68.0000	79.81818	8.465617	10.628591	0.0018064970
ease.of.communication	1	- 3.499703	69.16667	83.40909	11.696391	11.420313	0.0004657769
delivery.performance	1	- 3.716034	69.83333	86.18182	9.668103	12.345910	0.0002023743
level.of.technology	1	-	65.0000	80.00000	5.773503	11.180340	0.0001665

		3.764970					690
cost.reduction.perfor mance	2	-2.13405	72.0000	78.18182	6.964194	10.03465	0.0328338 69
sup- port.in.process.design.an d.engineering	3	3.440709	90.375	79.81818	3.4977671	10.628591	0.0005801 916
cost.reduction.perfor mance	3	2.985856	86.750	78.18182	7.6933413	10.034651	0.0030978 674
level.of.technology	3	2.904738	89.375	80.00000	5.2663436	11.180340	0.0036756 121
sup- port.in.product.structur al.design	3	2.867742	88.375	78.77273	7.9839812	11.599106	0.0041941 189
delivery.performance	3	2.544414	95.250	86.18182	5.9739016	12.345910	0.0109461 322
ease.of.communicatio n	3	2.378368	91.250	83.40909	2.1650635	11.420313	0.0173894 684
quality.performance	3	2.261203	83.750	73.86364	13.1695672	15.145643	0.0237467 086
financial.strength	3	2.242308	87.125	80.31818	5.7323097	10.515730	0.0249414 470
prototyping.time	3	- 2.776027	5.750	14.27273	0.9682458	10.635198	0.0055027 697
design.revision.time	3	- 2.885103	10.375	18.00000	3.0388114	9.155227	0.0039128 537

Source: Author's findings

A clear hierarchy of importance is revealed by a detailed examination of the relationship between the cluster variable and the quantitative metrics listed. The most strongly correlated factor is Level of technology (Eta2 = 0.7568, p = 1.47e-06), suggesting that the clusters differ significantly in terms of technological sophistication. Delivery performance (Eta2 = 0.6987, p = 1.12e-05) and support in process design and engineering (Eta2 = 0.7052, p = 9.14e-06) come in close succession, indicating notable differences in the level of engineering support and the efficiency of delivery systems among the clusters. The exceptionally low p-values for these three variables provide compelling statistical evidence that these observed differences are not simply due to random chance. Therefore, in seeking to understand and characterize the distinctions between the clusters, a deep dive into these three core factors - the level of technology employed, the support available for

process design, and the effectiveness of delivery performance - is essential. These elements likely represent key drivers that define and differentiate the clusters under investigation.

Description of each cluster by quantitative variables :

The description of each cluster using quantitative variables is crucial for understanding the distinguishing characteristics within the dataset (See Table 4). By examining cluster metrics with variables we can successfully identify the elements that greatly distinguish these clusters. A more nuanced and practical understanding of the underlying structure of the data is made possible by this thorough analysis, which also facilitates focused interventions, well-informed decision-making, and the creation of successful strategies specific to each distinct group.

Table 4. Description of each cluster by quantitative variables

Source: Author's findings

Cluster1 : The main characteristics of this cluster include lengthy development cycles and low efficiency in a number of crucial areas. Companies who invest more time in design and prototyping but do not find a positive correlation with improved performance in other critical areas, particularly technology adoption, are represented by Cluster 1. This protracted development cycle could make it more difficult for them to innovate and compete successfully. Adopting innovative technology and optimizing company procedures can be their main priorities.

Cluster2 : One notable characteristic of this cluster seems to be a lack of emphasis on cost reduction. In terms of revenue, these companies are not doing well. To increase profits and bottom lines, they could need to concentrate on R&D and innovation or use cost-cutting measures.

Cluster3 : This cluster has a significant emphasis on efficiency as well as good operational skills. Companies in this cluster are notable for their investments in process engineering and design, which result in faster prototype times. This combination suggests a flexible and effective procedure for developing items, which will allow them to launch goods faster and maybe obtain a competitive edge. They put a lot of effort into streamlining company operations, which results in quicker product creation and more profits.

4.2. Managerial recommendations :

Enhancing Technological Assistance and Innovation :

Suppliers in Cluster 3 exhibit significant support in process design and engineering, as well as sophisticated technology skills. To capitalize on their advantages:

Promote strategic alliances with these suppliers to jointly create creative solutions suited to project specifications.

To encourage continuous improvement and incorporate innovative performance metrics into supplier contracts.

Encourage information sharing between these suppliers and those in other clusters by holding inter-company training sessions or collaborative programs.

Optimising costs and enhancing financial performance :

Cluster 2 suppliers show inefficiency in cost reduction . To improve their financial performance, they should:

Conduct routine audits to find any inefficiencies and areas for cost optimization.
To reduce operational costs, promote the use of digital technologies like process automation and artificial intelligence.

Create a system of price incentives by offering bonuses to suppliers who achieve cost reduction goals without compromising quality.

Enhancing Communication and Collaboration :

According to the study, one of the most important factors in supplier management is communication ease.

To improve this, use digital platforms for supplier management such as ERP and SRM to centralize interactions and guarantee greater transparency ; schedule frequent meetings and structured feedback sessions to help stakeholders align their strategic and operational goals ; and support intercultural communication and supplier relationship management training programs to reduce misunderstandings and increase the effectiveness of negotiations.

Strategies for Supplier Segmentation and Customized Management :

The findings of the study show that the profiles of each cluster are unique. A specific strategy for managing suppliers is required :

Contractual relationships should be modified according to supplier characteristics; innovators should have more flexible agreements, and underperforming suppliers should have tougher commitments.

Employing key performance indicators unique to each cluster, establish a continuous evaluation and monitoring methodology.

Reallocate resources in accordance with strategic priorities : extend investments to innovative, high-potential suppliers while reorganizing partnerships with suppliers that are facing difficulties.

5. Conclusion

In summary, this study effectively demonstrates how to categorize suppliers into homogeneous groups using clustering techniques, particularly the agglomerative hierarchical clustering algorithm. The research identified three distinct supplier profiles based on quality performance, product structure design support, and financial soundness. This analysis was conducted on 22 suppliers using 10 KPIs in a data-driven manner with R statistical software. Statistical analysis, including chi-square tests, revealed significant correlations between the identified supplier attributes and factors such as ease of communication, quality performance, and technical level. Although the silhouette index indicated a weak to moderate cluster structure, the findings provide a foundation for a more tailored approach to supplier management, ultimately enhancing project outcomes, supplier selection, and innovation capacity in the digital era. This study presents a systematic, data-driven method for supplier segmentation, contributing to advancements in supplier management within the context of digital transformation. Businesses can refine their supplier management strategies, streamline the selection process, improve project outcomes, and enhance overall innovation capacity by recognizing these homogeneous clusters.

It is important to acknowledge the limitations of this study, such as its dependence on the quality and availability of data and the need for validation across different industries and projects. The silhouette index also highlights opportunities to refine the clustering structure.

Future research should focus on leveraging cutting-edge technologies such as blockchain and artificial intelligence to enhance analysis and develop dynamic supplier management models that can adapt to rapidly changing environments. By further refining these strategies, businesses can optimize their supply chains and maintain a competitive edge in the digital era.

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Sustainability Challenges of Urban Air Mobility Facilities: A Semi-Desirable Perspective

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Abstract. In this paper, we explore semi-desirable facility location planning approaches to Urban Air Mobility (UAM) infrastructure, with a focus on sustainability. UAM, a component of Advanced Air Mobility (AAM), aims to integrate aerial transportation systems within urban environments using electric vertical takeoff and landing aircraft and vertiports. While UAM promises to alleviate urban congestion and enhance connectivity, its integration presents significant challenges in terms of sustainability and urban planning. Motivated by these challenges, we revisit the concept of semi-desirable facility location problems and discuss its applicability to UAM infrastructure planning. In particular, we discuss both the positive impacts — such as accessibility and efficiency — and the negative concerns, including noise, safety, risk, and environmental effects. Our main ambition is to provide decision-makers and planners with insights on incorporating environmental, social, and economic sustainability into UAM infrastructure planning to ensure long-term benefits for urban communities.

Keywords: Urban Air Mobility, Advanced Air Mobility, Semi-Desirable Facility, Sustainability, Location Optimization

Introduction

In recent years, Advanced Air Mobility (AAM) has attracted significant attention as a transformative concept in aviation. The main motivation of AAM applications is safe, sustainable, affordable, and accessible transportation for local and intraregional missions [1]. In this context, Urban Air Mobility (UAM) is an innovative air transport concept that is widely expected to be realized through the use of non-electric or electric vertical takeoff and landing (eVTOL) aircraft, operating from newly developed infrastructure commonly referred to as vertiports [2]. UAM can be defined as a component of the term AAM as it focuses on the integration of various aerial transportation systems within urban environments [3]. In other words, while UAM focuses specifically on urban environments, AAM encompasses a broader vision that extends beyond urban areas to include regional and rural connectivity. AAM integrates UAM as a key component but also addresses applications such as regional passenger transport, inter-city cargo logistics, and emergency services. UAM services primarily aim to reduce commuting times for long-distance trips in heavily congested urban areas [4].

The rapid development of UAM is transforming the landscape of urban transportation and logistics [5]. While it promises to alleviate urban congestion, reduce travel times, and enhance connectivity in cities, its

integration into urban environments presents significant challenges, particularly in terms of sustainability and urban planning.

Biehle [6] highlights the danger of social inequalities emerging from early UAM adoption in Europe, underlining the importance of integrating social sustainability indicators into planning frameworks. Moreover, Cohen et al. [7] provide a broad overview of UAM's development, ecosystem, and future market potential, emphasizing more general challenges such as safety, regulatory structures, public acceptance, and environmental impacts, and requesting further research on sustainability and social equity to enable successful UAM integration. The UAM infrastructure requires facilities such as air-taxi stations that can accommodate take-off, landing, refueling/recharging, and parking operations. In the literature, air taxi stations are typically classified as vertiports and vertistops [8]. A vertistop is used for customer pickup and dropoff only, whereas a vertiport serves additional functions, including battery charging, maintenance, docking, and repair, alongside facilitating passenger movement between locations [4, 9]. As another UAM term, a skyport often implies a more futuristic, multifunctional hub integrated into urban environments, supporting both air and ground transportation systems. Hasan [10] defines a skyport as an area or a facility that is designated for take-off and landing of aerial vehicles. Shin et al. [11] state that the configuration of these facilities determines the complexity of traffic flow management in the area.

An effective location plan for vertiports, skyports, drone hubs, and charging stations, plays a crucial role in the successful implementation of AAM and UAM systems. Such location plans involve strategic level decisions and therefore they must balance the competing objectives of accessibility, efficiency, and minimizing negative externalities [3].

There exist several studies which aim to determine the optimal locations for these facilities, considering objectives such as minimizing travel time, integrating with existing transportation networks, and maximizing accessibility and demand coverage. However, there is also a substantial body of literature that examines the adverse effects of these facilities, including noise pollution, safety concerns, and environmental disruption. For instance, location planning for vertiports is inherently complex due to the dual nature of these facilities. On one hand, they must be located close to high-demand areas to maximize accessibility and operational efficiency and to minimize travel distance from demand centers to facilities [12]. On the other hand, they must avoid sensitive locations, such as residential neighborhoods, schools, and hospitals, to minimize their negative impacts [13]. Therefore, we believe that the problem of locating UAM facilities should be evaluated within the framework of *semi-desirable* facility location planning. This modeling approach explicitly accounts for both pull effects (positive impacts, such as convenience and accessibility) and push effects (negative impacts, such as noise, safety, and environment).

In traditional facility location models, facilities are placed to either minimize total transportation costs (minisum) or reduce the distance from the facility to the furthest customer (minimax). Obnoxious or undesirable facility location models, on the other hand, typically involve maxisum and/or maximin models. However, many real-world location problems feature facilities with both desirable and undesirable attributes. For example, household garbage plants (facilities where garbage is collected, sorted, and used for heating) are desirable when located near residential areas, as this minimizes garbage collection and heat transmission costs. At the same time, these facilities are undesirable when located too close to residential zones due to environmental impacts such as air pollution, noise, and unpleasant odors. Similar considerations apply to facilities like chemical plants, nuclear power stations, airports, or vertiports. These types of location problems are named as semi-desirable facility location problems [14].

This paper explores potential applications of semi-desirable facility location planning approaches to the planning of UAM infrastructure, with a particular focus on sustainability. Semidesirable facility location problems, which have been studied extensively in other domains, provide a powerful framework for addressing the unique challenges of UAM. By explicitly modeling the push and pull effects of UAM facilities, these models enable decision-makers to balance competing objectives and make informed trade-offs.

The contributions of this paper are twofold. First, it provides a review of the literature on semi-desirable facility location models, with a particular focus on sustainability, and discusses the potential application of these approaches to UAM. Second, by incorporating sustainability considerations, it offers an overview of the negative impacts of UAM facilities, supporting our discussion that these facilities should be planned and evaluated as semi-desirable facilities.

The remainder of this paper is organized as follows. In Section 2 we provide a discussion on semi-desirable facility location problems and a brief literature review with a focus on sustainability. Section 3 discusses the social and environmental impacts of vertiport location problems. Section 4 presents a discussion of key findings and limitations. Finally, Section 5 concludes the paper.

Preliminaries and Related Work

Urban planning facility location models have been examined via several studies related to desirable and undesirable facilities. Brimberg and Juel [15], for instance, provided one of the earlier discussions regarding semi-desirable facility location problems with a primary focus on balancing accessibility and undesirability factors. Similarly, Krarup et al. [16] extended these models into discrete locations, and Church [17] integrated various facility location models encompassing social and environmental factors. In their analysis of infrastructural and regulatory concerns in sustainable UAM systems, Takacs and Haidegger [18] mention the most important areas in facility location and policy development as airspace management, safety, and environmental factors.

In contrast to existing reviews, in this paper, we primarily discuss semi-desirable facility location modeling approaches for UAM infrastructure planning with a focus on sustainability. Existing reviews have not comprehensively addressed the dual nature of UAM facilities, which must balance operational efficiency with urban sustainability. Our contribution addresses this gap by exploring how semi-desirable facility location models may be aligned with UAM's unique constraints. Additionally, we provide a systematic evaluation of the push and pull forces influencing UAM infrastructure, a topic that has not been a central focus in previous studies.

Semi-Desirable Location Problems

Facility location problems have long been studied in transportation planning, operations research, and urban planning. Traditional location models typically seek to minimize costs (e.g., operating costs, travel distance) or maximize service coverage, which tends to overlook the dual function of some facilities that create both positive and negative impacts. This imbalance comes into operation particularly in the UAM infrastructure environment, where the location of facilities must balance accessibility and operational efficiency with sustainability concerns such as noise pollution, environmental disruption, and public safety risks.

Since the issue of siting UAM facilities is intricate, it is necessary to revisit semi-desirable facility location problems in an effort to acknowledge existing methods considering both favourable (pull) and adverse (push)

effects. This study bridges the gaps in UAM planning for infrastructure by evaluating how semi-desirable facility location models strike a balance between social acceptability, sustainability, and efficiency of operation.

A facility is considered *semi-desirable* (sometimes referred as semi-obnoxious) if it has both positive and negative effects on the people living nearby. Location problems which consider semidesirable facilities aim to balance the desirable and undesirable impacts of a facility on demand nodes. Such problems are typically formulated as bi-objective problems, which inherently involve two conflicting objectives.

The semi-desirable facility location problem was initially introduced by Brimberg and Juel [14]. In their work, the authors proposed a bi-criteria model that aimed to balance two conflicting objectives: minimizing the distance to ensure cost-effective access to the facility's services while maximizing the distance to mitigate the negative impacts, such as pollution, associated with the facility. To address this, they adopted a minisum criterion for the first objective and minimized the weighted sum of Euclidean distances raised to a negative power for the second.

Their model was later extended to a discrete setting by Krarup, Pisinger, and Plastria [16]. Over the past two decades, although research on the semi-desirable facility location problem has been relatively limited, it has attracted attention from researchers. Various variants of the problem, formulated under different assumptions and using various distance metrics, have been explored. In addition, various exact and heuristic solution approaches have been proposed. For a comprehensive review of the semi-obnoxious and obnoxious facility location problem, interested readers are referred to [19] and [17], respectively.

For the problem of locating a single semi-desirable facility, let x_1 and x_2 represent the facility's coordinates, with the rectilinear distance metric defined as $d(x,y) = |x_1 - y_1| + |x_2 - y_2|$. [20] supports the use of rectilinear distance metrics, noting that adverse effects often travel along rectangular pathways, such as walls or corridors in factories, or within cities with block layouts. This makes the rectilinear metric a practical choice, especially in maximin objectives. Given N demand points with coordinates $b^i = (b_1^i, b_2^i)$ for $i = 1, \dots, N$, and S as the feasible region in continuous domain, and defined as a convex polygon in $\mathbb{R}^2$, the first *maximin* objective function models the undesirable effects by maximizing the distance between the facility and its nearest demand point:

$$\max_{(x_1, x_2) \in S} \left\{ \min_{i=1, \dots, N} (|x_1 - b_1^i| + |x_2 - b_2^i|) \right\} \quad (1)$$

The second *minsum* objective function models the desirable effects by minimizing the total distance between the facility and all demand points [21]:

$$\min_{(x_1, x_2) \in S} \left\{ \sum_{i=1}^N (|x_1 - b_1^i| + |x_2 - b_2^i|) \right\} \quad (2)$$

For brevity, we have presented the push-and-pull objectives in a single facility semi-desirable location model. In general, the primary goal in such problems is to balance the conflicting objectives of minimizing the facility's distance to demand points for accessibility, while simultaneously maximizing the distance to mitigate undesirable effects.

Related Work

In the urban planning setting, there is a rich body of literature on semi-desirable facility location problems. These problems aim at balancing positive and negative impacts of the facility. The positive "pull" effects

relate to factors such as accessibility and convenience, while the negative “push” effects stem from environmental or social disruptions. This duality makes semi-desirable facility location models particularly relevant for addressing UAM infrastructure planning problems. In this section, we review the literature on semi-desirable facility location models with a focus on urban planning and sustainability.

Considering the multi-objective nature of semi-desirable location models, several studies implemented bi-objective modelling approaches. Among these studies, Eiselt and Marianov [22] provided a bi-objective model integrating regulatory pollution constraints with cost minimization for siting landfills and transfer stations in solid waste management. Similarly, Coutinho-Rodrigues et al. [23] developed a bi-objective model that simultaneously minimizes investment costs and resident dissatisfaction for the urban waste container location problem. They also discussed the practical applications with an urban planning perspective. Gang et al. [24] considered another urban planning problem and proposed a multi-objective bi-level model for locating industrial and energy-related facilities. They investigated the trade-offs and conflicts in site selection between a stone industrial park and local governments and enterprises aiming to minimize pollution and costs. Eriskin and Karatas [25], on the other hand, tackled a location problem for fuel storage facilities and suggested a weighted goal programming method to model a bi-objective location problem. In their model, the authors incorporated a planning horizon that accounts for future energy demand.

In the context of emergency service facility planning, Teran-Somohano and Smith [26] presented a bi-objective evolutionary strategy for locating fire stations. In their model, the authors accounted for both social and non-social costs as well as service coverage. Plastria et al. [27] tackled a transportation infrastructure planning problem, and proposed a continuous location model for the design of transportation networks with repelling polygonal regions to maximize distance from sensitive areas.

There also exist several studies which investigated semi-desirable location problems from a methodological perspective. For instance, Brimberg and Juel [14, 15] proposed bicriteria and minisum models for maximizing accessibility and minimizing negative impacts. Juel and Brimberg [28] extended the problem structure to a network location optimization based on attraction and repulsion. Later, Heydari and Melachrinoudis [29] combined pollution dispersion in a bi-objective setting with a minisum network with elliptic maximin.

Various meta-heuristic and heuristic algorithms have been proposed for semi-desirable and semi-obnoxious facility location problems. For example, Golpayegani et al. [30] implemented a Particle Swarm Optimization (PSO) approach for solving semi-obnoxious line locations under rectilinear norms. Other studies that utilize a PSO algorithm include Qi [31] where the authors improved Pareto optimality and solution diversity. Similarly, Yapicioglu et al. [32] developed a bi-objective PSO that balances transportation costs and undesirable effects. As another bicriterion heuristic, Ortigosa et al. [33] included grid and random search algorithms. Skriver and Andersen [34] tackled the bi-criterion semi-obnoxious location problem and proposed an ϵ -approximation algorithm for computing Pareto-optimal solutions for planar as well as network location of facilities. Hui et al. [35] investigated the socio-economic implications of semi-obnoxious facilities in the context of urban renewal and identified housing affordability and environmental quality trade-offs.

Our literature review shows that the problem of locating semi-desirable and semi-obnoxious facilities is inherently multi-objective. Therefore, careful consideration must be given to balancing conflicting objectives, such as accessibility, cost efficiency, and environmental or social impact. Numerous optimization models have been proposed to provide effective solutions across various application domains. In practice, factors such as pollution control, zoning regulations, and socioeconomic conditions play a critical role in any real-world facility location strategy.

Table 1 provides a synthesis of previous studies on semi-desirable and semi-obnoxious location problems. It highlights the push and pull objectives used, the type of mathematical model, the solution approach implemented, and the general application domain. The table reveals that pull objectives primarily focus on mini-

mizing distance-related costs and improving accessibility, while push objectives aim to maximize distance to reduce social costs or minimize pollution, social impacts, and other undesirable effects.

The models used in these studies are predominantly Non-Linear Programming (NLP) or Mixed Integer Linear Programming (MILP), with a few exceptions using Linear Programming (LP) or other specialized models. Solution methods vary widely, ranging from exact methods to heuristic approaches like PSO and Evolutionary Strategies (ES). The application domains are mostly generic, with some specific applications in urban waste management, fire station location, and industrial park planning.

Table 1. Summary of Related Work

Paper Pull Objective		Push Objective	Model Solution Method Application Domain		
[14]	(min) transportation cost	(max) distance	NLP	TM [H]	Generic
[22]	(min) usual cost	(min) pollution	MILP	Exact	Urban waste management
[23]	(min) walking effort required by residents	(min) population dissatisfaction	MILP	Exact	Urban waste management
[36]	(min) transportation cost	(max) distance	MILP	Exact	Generic
[15]	(min) transportation cost	(max) distance	NLP	Exact	Generic
[30]	(min) distance	(max) distance	NLP	PSO [H]	Generic
[25]	(min) transportation cost	(max) distance	MILP	Exact	Locating fuel storage areas
[20]	(min) transportation cost	(max) distance	LP	Exact	Generic
[35]	(min) distance	(max) distance	SARAR	Exact	Generic
[31]	(min) transportation cost	(min) undesirable effects	NLP	iMOPSO [H]	Generic
[27]	(min) distance	(max) distance	NLP	MMA [H]	Designing transportation networks
[26]	(min) non-social cost	(min) social cost	NLP	ES [H]	Locating fire stations
[29]	(min) transportation cost	(max) distance	NLP	Exact	Generic
[28]	(min) transportation cost	(max) distance	NLP	Exact	Generic
[32]	(min) transportation cost	(max) distance	NLP	bi-PSO [H]	Generic
[34]	(min) transportation cost	(max) distance	NLP	BSSS & ED [H]	Generic
[24]	(min) production and transportation costs	(min) pollution and development costs	NLP	ACPSO [H]	Locating industrial parks
[33]	(min) transportation cost	(max) distance	NLP	bi-PSO [H]	Generic
Abbreviations:					
ACPSO: Adaptive Chaotic Particle Swarm Optimization			MILP: Mixed-Integer Linear Programming		
BSSS: Binary Social Spider Search			MMA: Margin Maximization Approach		
ED: Electromagnetic Dynamics			NLP: Non-Linear Programming		
ES: Evolution Strategies			PSO: Particle Swarm Optimization		
LP: Linear Programming			SARAR: Simultaneous Auto-Regressive and Auto-Regressive		
SDU: Subdivided Unit			TM: Trajectory Method		

Social and Environmental Impacts of UAM Infrastructure

The placement of facilities such as vertiports, drone hubs, and charging stations involves complex trade-offs between maximizing operational efficiency and minimizing negative externalities as depicted in Figure 1. These facilities, integral to UAM infrastructure, must be strategically located to ensure both accessibility and

sustainability. As UAM technologies evolve, so do the challenges associated with their integration into existing urban landscapes.

The impacts of vertiports on the surrounding social and environmental fabric are significant, extending beyond typical concerns of traditional infrastructure. As UAM vehicles such as eVTOL aircraft are expected to operate in close proximity to densely populated areas, several issues arise. These include noise pollution, safety risks, visual pollution, and privacy, among others. Given the novelty of UAM systems, the potential for unforeseen consequences is high, requiring advanced modeling techniques that can address uncertainty, multi-objective trade-offs, and longterm sustainability.

Below, we explore the social and environmental implications associated with the location of vertiports and similar UAM facilities. While the goal is to optimize operational efficiency, these externalities must be carefully managed to prevent adverse effects on public health, well-being, and urban quality of life.

Here we give an overview of the social and environmental impacts and consideration of UAM facilities.

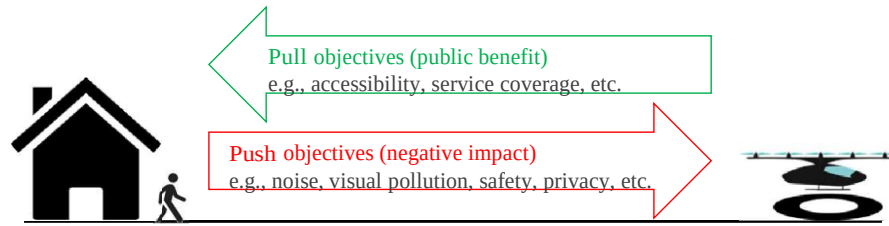


Fig.1. The pull and push objectives of UAM facilities.

Noise

Noise from airborne vehicles has been an important issue and source of annoyance while it impacts quality of life of people living in the vicinity of airports and heliports. A survey study conducted by Yedavalli and Mooberry [37] in Switzerland, Los Angeles, New Zealand, and Mexico City, for instance, has shown that a majority of the society is concerned about the type and volume of noise generated by the UAMs. In this regard, noise pollution is one of the most important factors that should be considered when making vertiport placement decisions. Even though the volume of the noise from an UAM is lower than that of a traditional helicopter, it is still a critical issue due to its frequency and tonal characteristics [38]. Hence, the public acceptance is highly influenced by how well UAM-generated noise blends with urban background noise. A recent study has shown that UAM vehicles generate about one-quarter of the noise of a four-seat helicopter, yet concerns persist about their impact on urban soundscapes [38]. Efforts to mitigate noise include optimizing flight paths, improving battery electrification technology, and designing quieter propulsion systems. With the development of new electrification technologies, urban background noise is expected to decrease, making the UAM-generated noise more detectable [38]. Therefore, the vertiport location problem will continue to take into account the noise pollution of UAMs in the future while necessitating innovative solutions for decreasing the noise of these vehicles.

Visual Pollution

Another major concern is the visual pollution generated by vertiports and frequent aerial movements of UAMs. Visual pollution can be defined as obstruction of scenic views and disruption of existing aesthetics that can cause anxiety, distraction and, reduced work efficiency. Being a subjective metric, visual pollution is hard to quantify and dependent of the observer [39]. In this regard, UAM networks can be perceived as intrusive by some individuals, while others may view them as symbols of technological progress. Addressing this issue, Thomas and Granberg [13] aimed at quantifying the factors that influence the perceived pollution caused by vertiports and UAMs movements.

Studies have highlighted that gradual deployment strategies could mitigate concerns about overwhelming the skyline with UAMs [37]. Moreover, integrating vertiports into existing infrastructure, such as rooftops of commercial buildings, may reduce their visual footprint while maintaining accessibility. To that end, a rigorous planning is required to ensure that vertiports blend seamlessly with urban landscapes while minimizing visual pollution.

Safety

A recent survey conducted by the European Union Aviation Safety Agency (EASA) has revealed that safety is one of the most important aspects for social acceptability of advanced air traffic services [38]. The casualties of the aircraft accidents are directly proportional to the population density in the vicinity of the crash site. Moreover, majority of the helicopter accidents occur during heliport landing and takeoff [40]. Therefore, vertiports are no exception to this fact. Since vertiports are more likely to be located closer to the community than heliports, the risks associated with their operation require more attention.

Concerns about the safety of vertiports range from operational risks, such as mid-air collisions, loss of power, and hazardous material spill, to infrastructure-related hazards, including sensor signal losses and adverse weather conditions [2]. Studies have revealed that people are particularly skeptical about the safety of rotary-wing aircraft, perceiving them as less reliable than fixed-wing alternatives [37]. To enhance safety, regulatory bodies emphasize adherence to stringent design standards, including the incorporation of emergency landing sites, fire suppression systems, and automated monitoring mechanisms [2]. Furthermore, vertiport placement should avoid high-density residential areas, obstacles such as skyscrapers, and regions prone to extreme weather conditions. Implementing a robust risk management system is crucial to ensuring public acceptability and operational reliability [2].

Privacy

To locate vertiports in proximity to residential areas raises significant privacy concerns. UAMs operating at low altitudes may inadvertently intrude upon private spaces, leading to anxiety of surveillance and loss of personal privacy [7]. Unlike conventional aircraft that operate at higher altitudes, UAM vehicles have the potential to introduce persistent privacy challenges due to their frequent takeoffs and landings. Surveys have revealed that concerns regarding privacy are often linked to the presence of onboard cameras and sensors that could be perceived as intrusive [41]. Regulatory measures, such as designating flight corridors that minimize overflight of residential zones, implementing privacy-preserving technologies, registering cameras, limiting type/positions of cameras, and enforcing strict data collection regulations, can help alleviate these concerns [7, 41]. Balancing technological advancements with ethical considerations is essential for increasing the public acceptance of UAM systems.

Discussion

The integration of UAM into urban environments presents a unique set of challenges and opportunities, particularly in the context of sustainable facility location planning. This paper has explored the application of semi-desirable facility location models to address these challenges, focusing on the balance between push effects (negative externalities) and pull effects (positive impacts) while incorporating sustainability considerations. In this section, we reflect on the key findings, discuss the implications of the proposed models and solution approaches, and highlight the limitations and potential directions for future research.

Our results imply that the implementation of facility location planning in the context of UAM suggests a multistakeholder decision-making approach. The implementations require coordination across policymakers, urban planners, transportation authorities, and local communities to optimally place facilities and maximize operational benefits while minimizing social and environmental disruption. Given the evolving demand for UAM, shifting regulatory landscapes, and ongoing technological advancements, additional research is essential to transform these models into real-time data-driven and adaptive optimization methods.

Facility location decisions are strategic and must be adaptable to accommodate potential future changes. This requires the use of flexible and resilient modeling techniques. Another important concern is data availability and reliability. Accurate and effective UAM infrastructure planning requires reliable data on demand distribution, environmental impact studies, noise pollution levels, and community preferences. However, considering that UAM is still in the development stage, comprehensive datasets are rarely available.

Such a limitation in data poses a challenge for decision-makers in developing evidence-based policies and strategies. Beyond this study's focus on balancing sustainability considerations through trade-offs between accessibility and the reduction of negative externalities, other key factors must also be considered. For an integrated approach which considers economic, technological, and legal/regulatory concerns, each of these issues should be considered within the context of cost-benefit analysis.

Considering the balance required in integrating UAM infrastructure into urban environments, strategic vertiport placement demands careful consideration of operational efficiency while minimizing negative externalities. Key concerns include noise pollution, where even quieter UAM vehicles can disrupt urban soundscapes due to unique sound characteristics, and visual pollution, which can be mitigated through gradual deployment and integration with existing infrastructure. Safety concerns require strict measures and risk management systems, while privacy concerns arise from low-altitude flights potentially intruding on private spaces, requiring regulatory oversight and privacy-preserving technologies. Ultimately, the successful implementation of UAM relies on structured planning, innovative solutions, and a commitment to balancing technological advancement with social acceptability.

Conclusion and Future Outlook

The rapid emergence of UAM has the potential to revolutionize urban transportation and logistics, offering solutions to mitigate traffic congestion, reduce travel times, and improve connectivity. However, the integration of UAM infrastructure into urban environments presents significant challenges, particularly in terms of sustainability and urban planning. This paper has addressed these challenges by exploring the application of semi-desirable facility location models, which provide a structured framework for balancing the push effects (negative externalities) and pull effects (positive impacts) of UAM facilities, such as vertiports and drone hubs.

In this paper we first provided a review of the literature on semi-desirable facility location models in urban planning, highlighting their relevance and adaptability to the unique requirements of UAM. Second, we investigated the objectives considered in locating UAM facilities such as minimizing environmental impacts, promoting equitable access, and integrating with existing urban infrastructure. We believe that these contributions aim to support decision-makers in planning UAM systems that align with the broader goals of sustainable urban development.

While the proposed approaches offer valuable insights, several challenges remain. The dynamic and uncertain nature of UAM systems, the data requirements for accurate modeling, and the need to account for economic, regulatory, and technological constraints highlight the complexity of this problem. Addressing these challenges will require continued research and collaboration across disciplines, including operations research, urban planning, and transportation engineering.

Building on the findings of this paper, several avenues for future research can be identified. For example, a future study can explore how UAM facility location planning can be integrated with smart city initiatives, such as IoT-enabled traffic management and renewable energy systems. Additionally, incorporating the perspectives of various stakeholders—including local communities, policymakers, and UAM operators—to ensure equitable and inclusive facility location decisions is a promising research direction.

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Urban Air Mobility: Key Innovations and Optimization Approaches

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Abstract. Urban Air Mobility (UAM) has the potential to transform urban transportation, but its success depends on overcoming challenges in product development and operations. In this paper, we present a brief review of existing literature to explore the role of innovative strategies and optimization methodologies in enhancing UAM performance. Our review includes innovation models, from technology-push to integrated approaches, and applications of fundamental optimization techniques to improve UAM operations. We also highlight key application areas and opportunities for improvement in UAM operations through innovative strategies and optimization techniques, addressing critical challenges and accelerating the development and deployment of UAM systems. This work provides insights for decision-makers and researchers seeking to advance the development and deployment of sustainable and efficient UAM systems.

Keywords: Urban Air Mobility, Advanced Air Mobility, Semi-Desirable Facility, Sustainability, Location Optimization

Introduction

Urban Air Mobility (UAM) is gaining attention as an innovative solution for urban transportation. The advances in the last decade in distributed electric propulsion, batteries, and autonomous driving, UAM services have facilitated UAM services [1]. However, challenges such as safety, regulations, infrastructure, and cost-effectiveness hinder rapid deployment. This paper explores the role of innovation and optimization in UAM operations planning and product design, providing a brief overview of the approaches used in the industry.

The key to maintaining a competitive position in the rapidly evolving field of Advanced Air Mobility (AAM) lies in the capability to develop and commercialize innovative products efficiently [2]. As urbanization, environmental concerns, and technological advancements reshape transportation, companies in the AAM sector are under increasing pressure to adopt innovative strategies and optimization techniques in their product development processes. The emergence of electric vertical takeoff and landing (eVTOL) aircraft, UAM systems, and autonomous flight technologies has created a new frontier in aviation, demanding faster, smarter, and more sustainable solutions.

In this context, the ability to innovate and optimize has become a critical driver of success. Companies must navigate challenges such as regulatory compliance, technological uncertainties, shorter product lifecycles, and changing customer expectations. The integration of innovative strategies and optimization methods

in New Product Development (NPD) processes is essential to address these challenges and seize opportunities in the AAM market. For instance, industries like automotive, electronics, and aerospace have demonstrated that a significant portion of their revenue comes from recently developed products, underscoring the importance of effective NPD strategies [3].

However, the high failure rates of NPD projects and the termination of many R&D initiatives before commercialization highlight the need for careful strategy selection and implementation. In the AAM sector, where the stakes are high due to safety, regulatory, and technological complexities, companies must adopt innovative NPD strategies and leverage optimization techniques to minimize risks and maximize returns. This study explores innovative strategies and optimization applications utilized in UAM. It provides a brief review of the literature and an analysis to serve as a resource for decision-makers, planners, and researchers working in the UAM sector.

The remainder of this paper is organized as follows. Section 2 discusses the concept of innovation and its relevance to UAM. Section 3 examines optimization techniques and their role in UAM. Finally, in Section 4 concludes with recommendations for future research.

Innovation Strategies in UAM

The concept of innovation was first introduced by the Austrian economist Joseph Schumpeter, who defined it as a critical driver of economic change [4]. According to Schumpeter, innovation is not limited to the development of new products, but also encompasses the introduction of new production methods, the creation of new markets, and the discovery of alternative sources of raw materials [5]. His perspective underscores the transformative nature of innovation, highlighting its role in disrupting traditional industries and shaping emerging technologies.

In the context of UAM, innovation plays a pivotal role in product development, commercialization, and large-scale adoption. UAM technologies, such as eVTOL aircraft, AI-driven autonomous flight systems, and smart urban infrastructure, exemplify how innovation reshapes transportation by offering sustainable and efficient mobility solutions. As the industry evolves, companies must integrate Schumpeter's principles of innovation with modern optimization strategies to overcome regulatory, economic, and technological barriers, ultimately driving the future of urban air travel.

First Generation Innovation Model: Technology push in the early development of UAM

The *Technology Push* model depicted in Figure 1, one of the first generation innovation models, is a linear innovation approach that emerged in the 1950s. This model primarily focuses on research and development (R&D) efforts, if technological advancements drive market needs rather than being shaped by them [6]. During this period, governments and companies emphasized increased investments in R&D to accelerate economic growth and technological leadership. It was believed that innovation could be more effective by introducing new products based on technological breakthroughs rather than responding to market-driven demands. This approach is especially relevant to early Vertical Take-Off and Landing (VTOL) aircraft research, where technological advancements were the main driver of development, rather than immediate commercial needs [7]. During the 1950s and 1960s, several experimental VTOL aircraft were developed under military and government-funded research programs, demonstrating the characteristics of the technology push model. Notable examples include:

- Short SC.1 (1957) – Developed as a British VTOL testbed featuring four lift jets and a propulsion jet, focusing purely on technical feasibility rather than commercial applications [8]
- Bell XV-3 (1955-1966) – An early tilt rotor aircraft designed to test the transition from vertical lift to forward flight, demonstrating the technology-first approach of this era [9]
- Hawker Siddeley P.1127 (1960s) – A key milestone in vectored-thrust propulsion, later influencing the Harrier Jump Jet and setting the stage for future UAM aircraft designs [10]

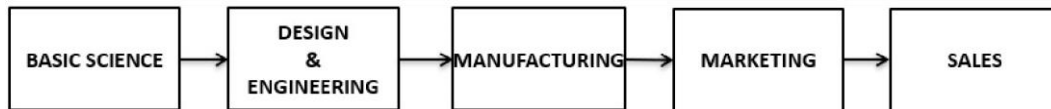


Fig.1. First Generation Innovation Model (Technology Push Model from [6])

The Technology Push model assumes that “Technology meets the needs of markets”, reinforcing the idea that new inventions naturally create demand rather than responding to it. This was especially true in the post-World War II era, where governments focused on expanding technological capabilities through heavy investments in aerospace and military research [6]. Until the late 1960s, this model was viewed as a discovery process, where information was transformed into new products by following a structured sequence of development stages.

Second Generation Innovation Model: Market Pull and Demand-Driven Advancements in UAM

The Second Generation Innovation Model given in Figure 2, known as the *Demand-Pull Model*, emerged in the late 1960s, shifting the focus of innovation from purely technology-driven advancements to market-driven development. Unlike the Technology Push model, where innovation was led by scientific discoveries and R&D, the Demand-Pull model emphasized consumer needs and market demands as the primary drivers of technological progress [11]. This shift resulted in industries increasingly aligning their R&D investments with real-world mobility challenges, ensuring that new products and services effectively met customer expectations and transportation needs.

In the context of UAM, this transition was evident in the rise of commercial helicopter operations and the early exploration of urban air transport services. Major cities, particularly New York and Los Angeles, experimented with scheduled helicopter flights, providing an early indication that aerial mobility solutions could help alleviate urban congestion and improve transport efficiency [12]. Services such as Los Angeles Airways (1947–1971), New York Airways (1953–1979), and Trump Air (1980-1990) were introduced to cater to commuters, business travelers, and airport transfers, demonstrating that market demand existed for faster, more convenient urban transport.

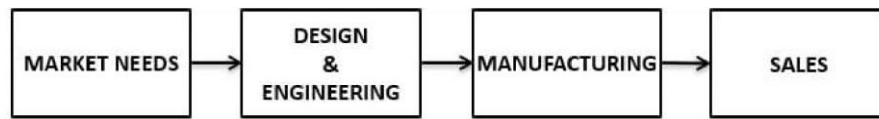


Fig.2. Second Generation Innovation Model (Demand Pull Model from [6])

Third Generation Innovation Model: The Coupling of Technology and Market Needs in UAM Evolution

The Third Generation Innovation Model given in Figure 3, also known as the *Coupling Model*, emerged in the late 1970s and early 1980s as an evolution of previous innovation frameworks, integrating both Technology Push and Demand-Pull approaches. Unlike earlier models that treated R&D and market needs separately, the Coupling Model fosters continuous interaction between technological advancements and consumer demands, ensuring that innovation aligns with practical applications [13].

This approach has been instrumental in the development of UAM, where the convergence of eVTOL technology, AI, and autonomous systems has been shaped by regulatory requirements, infrastructure development, and evolving passenger expectations [14]. The shift from early helicopter-based urban transport to fully electric eVTOL aircraft has been driven by both technological advancements in propulsion, aerodynamics, and AI-driven flight controls and the market's need for quieter, safer, and more cost-efficient aerial mobility solutions [12].

Companies such as Joby Aviation, Lilium, and Volocopter have embraced this model, working closely with the Federal Aviation Administration (FAA) of aviation regulators, EASA (European Union Aviation Safety), and city planners to establish realistic operational frameworks for urban air transportation [15]. Furthermore, public-private collaborations, such as NASA's UAM Grand Challenge, highlight how stakeholder feedback loops shape innovation, guiding UAM from research and prototyping to market readiness [16].

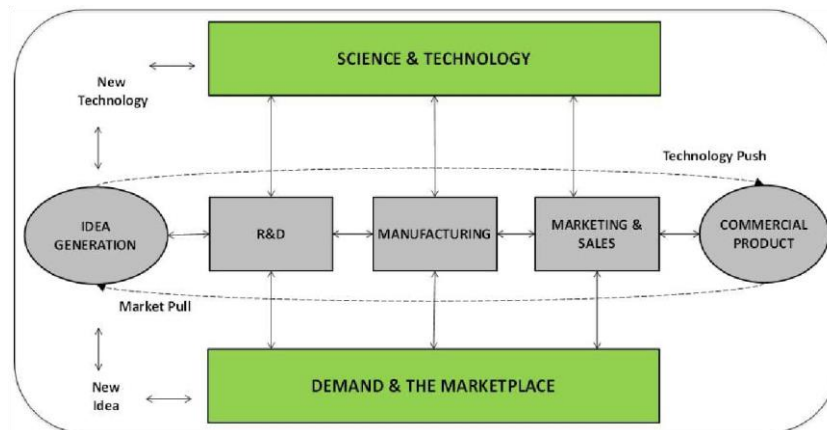


Fig.3. Third Generation Innovation Model (Coupled Model from [6])

Fourth Generation Innovation Model: Integrated Innovation Processes for UAM Commercialization

The Fourth Generation Innovation Model given in Figure 4, also known as the *Integrated Model*, emerged in the mid-1980s as a response to the limitations of sequential innovation processes, introducing parallel and cross-functional development to enhance speed, efficiency, and adaptability [17]. Unlike earlier models that followed a linear approach, the Integrated Model emphasizes collaborative innovation, where multiple stakeholders—including teams, market strategists, regulatory bodies, and infrastructure developers—work simultaneously to accelerate technological advancements and market adoption.

This model has been particularly relevant to the UAM sector, where aircraft development, regulatory frameworks, and urban infrastructure must evolve together to ensure seamless integration [18]. Studies highlight that research presented at the DICUAM (Delft International Conference on Urban Air Mobility) has contributed to discussions on synchronized system integration, where UAM vehicle development, airspace management, and city planning must progress concurrently to avoid bottlenecks and improve efficiency [19].

Additionally, the HorizonUAM project showcases how simultaneous advancements in battery degradation research, multimodal transport optimization, and operational modeling align with the principles of parallel innovation processes [18]. This model’s efficiency is also reflected in NASA’s UAM Grand Challenge, where industry leaders, government agencies, and technology firms collaborate in real-time data-sharing environments to refine regulations, airspace policies, and autonomous flight safety standards simultaneously [20].

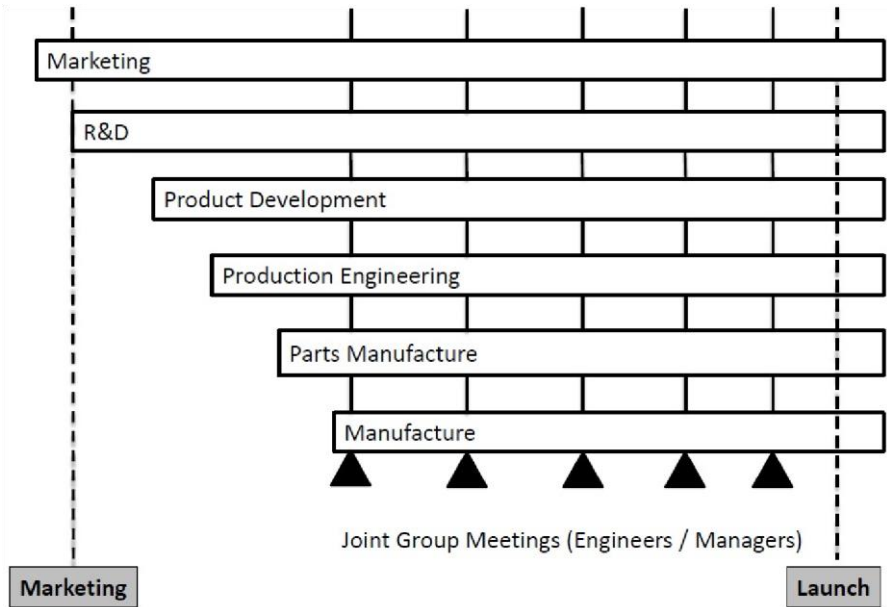


Fig.4. The Fourth Generation Innovation Model (Integrated Model from [6])

Fifth Generation Innovation Model: Networking and Collaborative Ecosystems in UAM Development

The Fifth Generation Innovation Model given in Figure 5, also known as the Networking Model, emerged in the 1990s as a response to the increasing complexity of technological innovation and globalization. Unlike earlier models that focused on internal R&D, this model emphasizes external collaboration, open innovation, and multi-stakeholder engagement, ensuring that technological advancements are co-developed through a network of companies, research institutions, and regulatory agencies [21]. The Networking Model integrates joint research initiatives, realtime data-sharing, and international strategic alliances, enhancing situational awareness, supply chain efficiency, and industry-wide cooperation [22]. It enables industries to accelerate innovation cycles by breaking the traditional boundaries of in-house R&D and fostering a connected ecosystem where knowledge flows freely between stakeholders.

In the context of UAM, the Networking Model is essential for integrating diverse technological, regulatory, and market-driven innovations. Given the complexity of UAM ecosystems, which require coordinated efforts among aircraft manufacturers, city planners, air traffic control authorities, energy providers, and digital infrastructure developers, the application of networkdriven innovation strategies has accelerated the development of sustainable UAM solutions [23]. Unlike traditional closed innovation systems, where knowledge creation and product development remain confined within a company, modern UAM initiatives leverage open innovation to collaborate on vehicle design, airspace management, and infrastructure planning simultaneously [16].

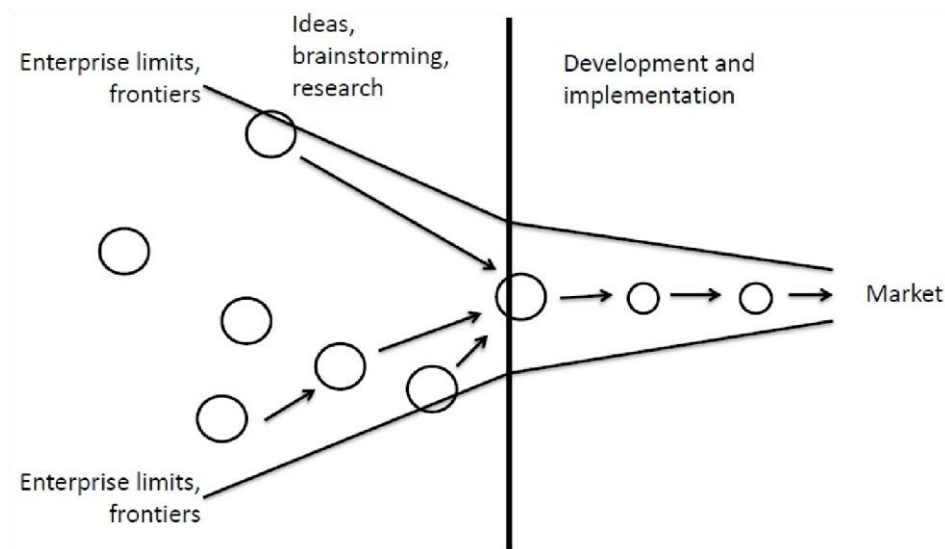


Fig.5. Closed Innovation Model (from [22])

The transition from traditional aviation to UAM requires next-generation digital networking, particularly in airspace management, AI-driven flight routing, and 5G-enabled communication systems. Studies emphasize the importance of integrating real-time data analytics, AI-based decision-making, and IoT-enabled moni-

toring systems to manage UAM operations efficiently [16]. The shift toward collaborative ecosystems is evident in projects such as NASA’s AAM Initiative, which brings together industry leaders, government agencies, and academic institutions to codevelop and test UAM technologies in a shared research environment [14].

Sixth Generation Innovation Model: AI-Driven Open Innovation and Autonomous UAM Systems

The Sixth Generation Innovation Model given in Figure 6, also known as *Open Innovation and AI-Driven Co-Creation*, represents the most advanced stage of innovation, characterized by realtime collaboration, AI-powered decision-making, and decentralized innovation ecosystems. Unlike earlier models, which relied on linear or networked interactions, this model embraces global connectivity, autonomous learning systems, and open-source data platforms to accelerate technological advancements [20]. Organizations no longer innovate in isolation but instead participate in vast knowledge-sharing ecosystems, leveraging AI, machine learning, digital twin simulations, and blockchain-driven transparency to ensure sustainable, efficient, and scalable technological progress.

In the UAM sector, this model is transforming how air transportation systems are developed, tested, and deployed. Traditional aircraft innovation relied on closed R&D environments, long regulatory cycles, and human-controlled operations, whereas modern UAM development integrates AI-driven route optimization, predictive maintenance, autonomous fleet management, and digital simulations into a fully connected ecosystem [12]. Autonomous air taxis and AI-driven air traffic control (ATC) systems are examples of how self-learning AI enhances operational efficiency, safety, and scalability [24].

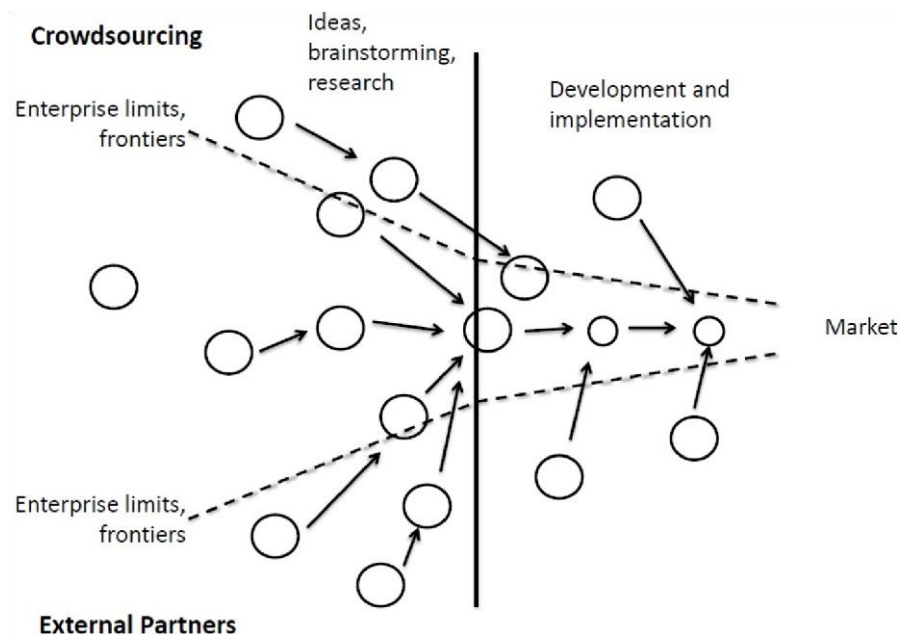


Fig.6. Open Innovation Model (from [22])

The transition to AI-powered co-creation models in UAM is evident in real-world projects, such as NASA's AAM initiative, which brings together manufacturers, urban planners, airspace regulators, and digital infrastructure developers to co-develop autonomous air transportation networks [15]. These collaborative efforts rely on shared simulation environments, AI-driven regulatory analysis, and decentralized fleet optimization, ensuring that technological and policy innovations evolve simultaneously. Additionally, real-time data integration from sensors, AI-based flight path adjustments, and decentralized traffic management systems are shaping the future of fully autonomous UAM [19].

One of the most critical advancements under the Sixth Generation Innovation Model is the use of digital twin simulations to enhance UAM deployment. Digital twins create virtual replicas of air taxis, vertiports, and air corridors, allowing real-time testing of operational scenarios, safety risks, and passenger demand patterns before real-world implementation [24]. These AI-powered simulations are essential for overcoming scalability and regulatory challenges, enabling data-driven policymaking and infrastructure planning [18].

The future of UAM under the Sixth Generation Innovation Model will be driven by selflearning AI, real-time policy evolution, and a fully interconnected digital infrastructure. As UAM ecosystems continue to evolve, AI will enable predictive fleet management, dynamic pricing models, and decentralized mobility-as-a-service (MaaS) platforms, ensuring that air taxis become an integral part of smart cities [19]. By embracing open innovation, real-time AI-based decisionmaking, and decentralized operational frameworks, the UAM industry is set to become the first large-scale transportation network to be managed by fully autonomous, AI-driven systems, marking a new era in aviation.

Use of Optimization in UAM

Optimization plays a crucial role in enhancing the efficiency, feasibility, and scalability of UAM systems. Given the complexities in vehicle design, infrastructure development, demand forecasting, fleet management, and air traffic control, optimization techniques serve as fundamental tools to improve performance while reducing costs and operational inefficiencies. This section explores how optimization is applied in key domains of UAM, analyzing existing literature and solution methods.

Air Vehicle Conceptual Design Optimization

A configuration of air vehicles for UAM, such as eVTOL aircraft, must reconcile aerodynamics, strength, energy efficiency, and noise reduction. Parameter selection such as battery weight, rotor configuration, and aerodynamics significantly influences overall performance. Optimization techniques play a crucial role in solving such issues by controlling compromises between energy consumption, noise production, and vehicle stability.

A number of studies used multi-objective optimization (MOO) approaches to improve the trade-offs in UAM vehicle design. For example, Pacini et al. [25] presented an MOO framework that optimizes rotor blade designs to reduce noise emissions while increasing aerodynamic efficiency. Similarly, Finger et al. [26] adopted an MOO approach to maximize battery weight and propulsion efficiency for increased flight range and sustainability. In another study, Afonso et al. [27] described how powertrain efficiency in an eVTOL aircraft can be improved with a Geometric Programming (GP) formulation. Hendricks et al. [28] developed a multidisciplinary optimization environment that tightly couples propulsion system design with aircraft trajectory optimization. Their approach integrates various subsystems, including propeller performance, electrical systems, and thermal management, allowing for a more comprehensive analysis of UAM concepts.

There are also studies which implement integrated approaches to tackle not only aerodynamic performance but also cost, structural performance, and mission constraints. For instance, Brown and Harris [29] developed a comprehensive design and optimization framework that considers lift-to-drag ratio trade-offs, disk loading trade-offs, and operating costs to allow for rapid evaluation of alternative designs for various mission profiles. In another study, Hendricks et al. [30] used a multidisciplinary optimization approach for designing turboelectric tiltwing configurations, touching on electrified propulsion, acoustics, and automation. Such integrated optimization frameworks enable designers to explore large, tightly coupled design spaces efficiently, leading to more optimized and innovative UAM vehicle configurations.

Optimization in Vertiport/Skyport Location Planning

One of the most challenging problems in planning UAM operations is deciding on the locations for vertiports and/or skyports. Locations that are planned ineffectively may lead to longer travel times, greater energy costs, and limited passenger access. Vertiport/skyport location problems are typically addressed through optimization techniques.

To tackle the UAM location problems, researchers mostly adopted network flow models to account for passenger demand distribution across urban areas. Studies also incorporated several realistic constraints such as regulatory zoning and noise pollution levels. As an example, Imanov [31] proposed a risk-based optimization method that includes safety factors in the vertiport location problem, analyzing potential collision risks and environmental impacts. Data-driven models are also implemented to account for population density, urban traffic flow, and multimodal connectivity.

Rendon et al. [32] used machine learning-based predictive models to optimize vertiport locations through the prediction of demand fluctuations over time. Additionally, Volakakis and Mahmassani [33] introduced an equitable access optimization model for well-balanced and inclusive vertiport placement. The model integrates socio-economic factors for ensuring maximum accessibility of UAM infrastructure in order to mitigate urban transport deserts. The framework targets encouraging equitable access to aerial mobility services while avoiding discontinuities in urban transport networks. Similarly, Chae et al. [34] considered a vertiport location problem for in a discrete space setting, and considered constraints such as infrastructure feasibility and urban mobility rules. Their study focuses on operational efficiency and accessibility balancing so that a sustainable vertiport network can be obtained. Studies such as [35, 36] pose the vertiport location problem as a hub location problem and propose mathematical models.

As another stream of research on vertiport optimization, Brulin and Olhofer [37] presented a bi-level network design methodology that applies activity-based transport simulations to distribute vertiports optimally according to dynamic demand and user mode choice. Their method enhances the quality of location planning by integrating user behavior and travel patterns into the optimization itself, so that vertiports better reflect real mobility needs. Macias et al. [38] introduced a vertiport location model that considers the constraints of vehicle ranges and urban mobility patterns. It combines facility location models with vehicle performance constraints to determine locations for vertiports that offer maximum coverage and accessibility while considering operational requirements of eVTOLs. These methods validate the requirement to blend social equity, sustainability, and dynamic urban development concerns with operational efficiency in vertiport planning.

Fleet Structure and Schedule Optimization

One common limitation of earlier UAM optimization studies is the oversimplification of the relationship between demand forecasting and fleet allocation. While demand forecasting is a predictive process, fleet optimization is a prescriptive process that must integrate real-time operational constraints. Recent studies implemented demand forecasting techniques for optimizing fleet structure and route scheduling for UAM networks.

As an example, Yang et al. [39] showed how deep learning models can leverage historical transportation data to predict changes in UAM travel demand. They used Long Short-Term Memory (LSTM) networks to capture temporal dependencies in demand patterns, resulting in more accurate forecasts compared to traditional time series methods.

Recent research has further expanded on the optimization techniques for UAM fleet management. Hohmann et al. [40] proposed a 3D air corridor network optimization problem which considers multiple stakeholders as well as societal interests. They aimed at generating the Pareto optimal solutions for a given set of logistic hub positions and paths connecting those hubs.

Integer programming and reinforcement learning models have been applied to UAM fleet management optimization for dynamic deployment of eVTOL vehicles on real-time demand.

Chauhan and Martins [41] investigated adaptive routing strategies to enhance fleet performance through optimized vehicle allocation, effectively matching supply to varying levels of demand. In another study, Paul and Chowdhury [42] proposed a graph-based reinforcement learning framework for UAM fleet scheduling. Their approach formulates the scheduling problem as a Markov Decision Process over a graph space, incorporating real-world constraints such as aircraft characteristics, passenger demand, and electricity pricing. This method demonstrates the potential for more efficient and adaptable scheduling in complex UAM networks.

Paul et al. [43] introduced a graph learning-based scheduling model that is capable of accommodating operational constraints, time-varying demand, and environmental uncertainty. Representing the UAM network as a dynamic graph, their model offered real-time decision aid in fleet deployment for various conditions, including weather disruption and changing passenger flows. Ko and Ahn [44], on the other hand, proposed a battery management, vertiport charging infrastructure, and fleet heterogeneity-based on-demand fleet scheduling system to enhance vehicle utilization and reduce operating downtime. This advanced approach indicates the growing interest in integrating operational realities from everyday life into UAM fleet optimization to ensure resilience and efficiency in highly dynamic city environments.

Optimization in Air Traffic Management

Since UAM systems are embedded in urban airspace, air traffic management (ATM) is an important task and challenge. Unlike conventional aviation, UAM vehicles move in congested, low-altitude routes where real-time optimization of trajectories is necessary to avoid congestion and enhance safety. Optimization methods in ATM mostly focus on airspace coordination, conflict detection, and traffic flow management.

In their study, Taye et al. [45] proposed an energy-aware strategic traffic management framework that addresses the dual challenge of safe traffic management and energy efficiency. Their approach utilizes a mixed-integer linear programming model to assign optimal ground delays and speed profiles to each aircraft, demonstrating potential enhancements in operational safety, time efficiency, and energy consumption balance.

Furthermore, holistic optimization approaches have also been used to improve overall ATM performance. For example, Karahasanovic et al. [46] developed an algorithm that considers all possible airplane trajectories simultaneously to determine globally optimal decisions for each aircraft at any given time. This method not only optimizes spatial movements but also incorporates temporal aspects, potentially revolutionizing decision-making processes in air traffic control. Additionally, Sridhar et al. [47] explored various modeling and optimization techniques in traffic flow management, highlighting the importance of collaborative decision-making processes and the integration of weather-related factors in ATM strategies.

Simulation-based and AI-driven optimization approaches have been commonly employed to model air traffic scenarios and predict congestion patterns. Rendón et al. [32] suggested an AI-driven system that adjusts flight routes dynamically to minimize airspace conflicts and optimize landing sequences. Furthermore, decentralized flight management systems use blockchain-based communication networks to allow UAM vehicles to share airspace information in real-time to reduce the risk of mid-air collisions.

In their study, KrishnaKumar et al. [48] proposed a graph reinforcement learning-based decision support system for air traffic control for vertiports. The model generates optimal policies that allow congestion-free flows and safe sequencing of arriving and departing aircraft, and which update real-time in response to changing operating conditions. Moreover, Khoshdel et al. [49] presented the SkyGrid framework, which uses ground traffic rhythmic control principles to air intersections. SkyGrid optimizes UAM vehicle flow in busy air paths via energy consumption optimization and delay minimization and guarantees safe aircraft separation. Recent research reflects the increasing adoption of new AI approaches and control methods to enable scalable and efficient UAM traffic management over dense urban airspace.

Discussion and Conclusion

Innovation and optimization based studies in UAM reveal a progressive shift from technology-driven approaches to AI-powered, open innovative ecosystems. Each innovation model has contributed uniquely to shaping the development, commercialization, and scalability of UAM technologies. In the early stages (First and Second Generation Innovation Models), technology-driven R&D efforts and market demand for faster urban transportation laid the foundation for aerial mobility. The Third and Fourth Generations introduced feedback loops, integrated processes, and real-time adaptation to regulatory and infrastructural needs, allowing eVTOL development to align with urban planning, air traffic control, and safety regulations.

The Fifth and Sixth Generations of Innovation Models have accelerated technological breakthroughs through collaborative ecosystems, AI-driven design optimization, and data-driven decisionmaking. Unlike previous models, which relied on linear or network-based innovations, the latest approaches embrace global connectivity, decentralized AI networks, and autonomous regulatory adaptation. Companies such as Joby Aviation, Lilium, and Volocopter, in collaboration with NASA, EASA, and the FAA, have demonstrated how network-driven innovation fosters faster and more scalable UAM solutions. AI-based simulations, digital twin modeling, and predictive analytics are now central to aircraft design, operational planning, and infrastructure development, ensuring that UAM solutions remain cost-effective, efficient, and adaptable to urban environments.

Our review revealed that optimization strategies are crucial for advancing UAM by improving vehicle performance, operational efficiency, and economic viability. These strategies significantly impact air vehicle design, optimizing energy use and battery size. They also focus on the strategic placement of vertiports and skyports to maximize coverage and reduce travel times. Furthermore, optimization improves fleet

management by planning efficient routes and schedules for UAM vehicles. Finally, it plays a crucial role in airspace management and autonomous flight operations, ensuring safe and efficient use of urban airspace through advanced trajectory management and AI-driven flight path optimization. These efforts collectively drive innovation in UAM, addressing key challenges related to safety, efficiency, and scalability.

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A Comprehensive Study on the Evaluation of Success Factors of Manufacturing Dimensions in Industry 4.0 Concept

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Abstract. The rapid advancement of digital transformation has significantly impacted industrial production, evolving from Industry 1.0 to Industry 4.0 and now transitioning into Industry 5.0. This study examines three key digital transformation solutions, referred to as Manufacturing Execution Systems (MES), Predictive Maintenance (PM), and Energy Management (EM). These solutions are key tools for real-time data analysis, process planning and cost optimization, enhancing efficiency and performance as they have a direct impact on strategic KPI's. Although these solutions have been widely implemented in various industries, there is a lack of comprehensive analysis which compares advantages of these solutions and provide a guidance to manufacturing facilities in their adoption. This study employs a multi-criteria-decision making based approach to create a strategic roadmap for manufacturing facilities in Türkiye undergoing Industry 4.0 transformation and offering insights into the transition towards Industry 5.0. by evaluating and ranking the critical benefits of these solutions. By bridging the gap between theoretical frameworks and practical implementations, the study contributes to the development of more informed and effective digital transformation strategies. To integrate opinions of experts from Türkiye's manufacturing industry regarding the evaluation of digital transformation solutions, fuzzy logic is utilized and Fuzzy SWARA method is applied. The findings reveal that efficiency is the most influential factor in digital transformation investments, followed by performance improvement, direct positive impact on company KPI's, real-time data analytics, cost reduction and process planning. Additionally, the study identifies key sub-criteria under each main category, providing a structured assessment of how these solutions impact industrial operations. **Keywords:** Digital transformation, industry 4.0, fuzzy logic, fuzzy SWARA.

Introduction

Digital transformation and digital revolutions are becoming increasingly significant. This process, which began with the Industrial Revolution, has progressed through Industry 1.0, Industry 2.0, Industry 3.0, and Industry 4.0. These revolutions are parallel to the advancement of technology. Industry 1.0 revolution started with the use of water and steam power in industrial production in England at the end of the 18th century [1]. The introduction of electricity to the manufacturing processes marked the beginning of Industry 2.0, while oil was introduced as an alternative

to coal in the same period. Industry 3.0 era was initiated by the adoption of programmable logic controllers (PLCs) and their integration into manufacturing processes. This period saw significant improvements in efficiency in autonomous production processes. However, with the rapid market changes and the rise of global supply chains has limited available technological advancements in Industry 3.0 to become unable to keep up with the supply and demand. Industry 4.0 concept first emerged in 2011, leading to a rapid acceleration in digital transformation efforts. Making sense of data in Industry 4.0, which has the same meaning as smart factory, is an important beginning of this era [2]. While Industry 4.0, known as the fourth industrial revolution, is often associated with cyber-physical systems, no universal definition has been established. Santhi and Muthuswamy describe Industry 4.0 as a revolution centered on data systems, integrating digital technologies into operational production processes [3]. These digital technologies include the Internet of Things (IoT), machine learning, artificial intelligence (AI), cyber-physical systems, cloud computing, and cybersecurity. In the manufacturing sector, Industry 4.0 aims to ensure transparent monitoring of cyber-physical data while enabling companies to analyze their current state and protect themselves from unexpected situations. As Industry 4.0 transitions to Industry 5.0, industrial revolutions continue to evolve for human welfare, therefore Industry 5.0 is also known as Society 5.0.

Modern industry faces significant challenges, including raw material shortages, energy scarcity, supply chain disruptions, and rising costs, all of which directly impact companies' sustainability goals. These issues have heightened interest in developing production innovations, optimizing existing resources, identifying effective solutions, and implementing the latest digital transformation trends. The traceability, analytics, and reporting capabilities provided by Industry 4.0 enable manufacturers to monitor and analyze data in real time. In this landscape, three prominent solutions have emerged: MES, PM, and EM. According to Dyk and Schoor, MES is a system that integrates automation systems with production processes, enabling seamless production [4]. MES software aims to manage process operations, monitor shop floor activities, identify bottlenecks, and ensure interdepartmental coordination. This concept has evolved through advancements in production strategies, control systems, and data analytics technologies. By enhancing operational traceability, MES supports quality improvement, cost reduction, and efficiency enhancement. Maintenance in industrial facilities is essential for ensuring production continuity by preventing unexpected downtimes of equipment, machinery, and infrastructure. Maintenance processes became conceptualized after the 1950s, beginning with the corrective maintenance approach, followed by preventive maintenance and productive maintenance strategies. The maintenance management concept has evolved alongside technological advancements, aligning with companies' efficiency goals [5]. PM is the latest trend in maintenance management solutions. Timofeev and Denisov defined PM as a technology which aims to maximize the efficiency of industrial equipment by predicting maintenance needs, analyzing the current state of machines, and forecasting their future conditions [6]. Energy resources have played a crucial role in industrial development. Each new industrial revolution has been driven by the adoption of new energy sources, including water, steam, coal, oil, and electricity. Today, the management of energy resources has become a priority, leading to the

development of specialized EM software. According to Capehart et al., EM is the process of using energy in the most efficient way to maximize profitability and competitiveness [7]. According to Samadifshar and Ghorbani, EM is a model that involves monitoring, analyzing, and optimizing energy consumption with the aim of reducing costs while ensuring that the management of resources is automated and planned [8].

It can be seen in the literature that many factories worldwide have invested in these three key areas. Previous studies like Al-shami and Abdullah's one is called Halal Food Industry Certification And Operation Challenges And Manufacturing Execution System Opportunities or Kanungo's study is called Future Trends In Energy Management Systems: Opportunities And Predictions For Energy Efficiency and the others have demonstrated that, across various industrial sectors, MES, PM, and EM solutions have provided significant value in the Industry 4.0 era. These three solutions play a critical role in industrial digital transformation, enabling factories to manage machinery, production lines, robots, personnel, and administrative processes end-to-end. However, despite extensive investments, many digital transformation projects fail due to a lack of understanding of these solutions' benefits, insufficient comparisons between solutions in literature, and uncertainties regarding their future evolution in upcoming industrial revolutions. This study aims to overcome these challenges by the factory which wants to invest in these three solutions and also it should be a road map for them.

The Republic of Türkiye, with over 67,000 active factories, continues to invest in new technologies. Leadership in digital transformation, a green and digital transformation-focused service approach, and innovation-driven, technology-oriented strategies are highlighted as key priorities in the strategic plans for 2024–2028 of Turkish Ministry of Industry and Technology [9]. The government of Türkiye has also made commitments to provide support for companies undergoing digital transformation. To this end, new national regulations and mandates are introduced each year to facilitate industrial digitalization [9].

This study aims to serve as a guide for manufacturing facilities in Türkiye undergoing Industry 4.0 transformation, providing insights into the future of industrial production in the Industry 5.0 era. To transition into Industry 5.0, industrial concepts must be clearly defined, and companies must take strategic steps based on their tailored needs. In 2024, Türkiye established a Digital Transformation Consultancy Unit to assess companies' digital maturity levels. Currently companies are now required to consult this unit to receive digital transformation investment incentives. This ensures that companies' efforts regarding digital transformation are targeted investments rather than misguided ones [9]. A lack of clear understanding of key digital transformation concepts has resulted in misguided investments in manufacturing. In this study, the benefit criteria of the three key solutions were identified through literature review and vali-

dated with expert opinions. Currently, there is a gap in literature tackling these three solutions collectively based on expert insights. By analyzing added value of these solutions, this study aims to identify the leading digital transformation solution for Türkiye's industry and explore the future developments of industrial production in the industry 5.0 era. To achieve this purpose, existing literature and global applications regarding digital transformation and Industry 5.0 have been reviewed and a roadmap for the Turkish industrial developments have been developed.

Method

Fuzzy set theory, introduced by Zadeh in 1965, is an extension of classical set theory where elements have membership degrees rather than definite boundaries [10]. In fuzzy sets, each element has a membership function, and membership degrees range between 0 and 1. Integrating fuzzy sets into MCDM minimizes data loss while maximizing the accuracy of weight assignments [11]. According to Guitouni and Martel, MCDM methods involve three fundamental evaluation approaches: selection, classification, and ranking. Selection aims to identify the best alternative among options that are difficult to compare or have close weights [12]. Classification sorts alternatives based on predefined criteria, while ranking orders them from best to worst based on measurable parameters. MCDM methods solve highly complex problems with conflicting criteria by calculating criterion weights, enabling a quantitative or definitive ranking. In this study, the SWARA analysis, one of the multi-criteria decision-making (MCDM) methods, was combined with fuzzy sets.

Fuzzy SWARA

The Step Wise Weight Assessment Ratio Analysis (SWARA) method was developed by Kersuline et al. as an MCDM approach where experts or decision-makers step-bystep evaluate the importance of ranked criteria [13]. A key challenge of the classical SWARA method is decision-making in the presence of missing, uncertain, or inaccessible data. To address this, the Fuzzy SWARA method was introduced, which integrates the flexibility of fuzzy logic into SWARA by replacing definite values with fuzzy expressions. Mavi et al. extended the classical SWARA method into Fuzzy SWARA (BSWARA) [14]. The steps of B-SWARA method is as follows [15]:

Step 1: Experts or decision-makers rank the identified criteria from most to least important.

Step 2: Each criterion is compared with the preceding criterion, and its importance degree (s) is determined. It is the percentage importance ratio of a criterion to the previous important value. For the first criterion, the s value is assumed to be zero.

Step 3: The coefficient values (k) are determined using Eq. 1.

$$1, \quad j = 1$$

$$\tilde{k}_j = \{\tilde{s}_j + 1, \quad j > 1\}, \quad (1)$$

where $\tilde{k}_j$ is the coefficient value of j^{th} criterion, $\tilde{s}_j$ is the importance degree of j^{th}

criterion, and j ($1, \dots, n$) is the number of evaluated criteria.

Step 4: The importance vector (q) is calculated using Eq. 2.

$$1, \quad j = 1$$

$$\tilde{q}_j = \{q_{j-1}^{\tilde{k}_j}, \quad j > 1\} \quad (2)$$

where $\tilde{q}_j$ is the importance vector of j^{th} criterion, $\tilde{q}_{j-1}$ is the importance vector of $(j - 1)^{th}$ criterion, and j ($1, \dots, n$) is the number of evaluated criteria.

Step 5: The fuzzy weight values (w) for each criterion are then computed using Eq. 3 where n is the number of criteria.

$$\tilde{w}_j = \frac{1}{\sum_{n=1}^n \tilde{q}_j} \tilde{q}_j \quad (3)$$

where $\tilde{w}_j$ is the fuzzy weight value of j^{th} criterion, $\sum_{n=1}^n \tilde{q}_j$ is sum of all importance vector values from 1^{st} to n^{th} of $(j - 1)^{th}$ criterion, and j ($1, \dots, n$) is the number of evaluated criteria.

Step 6: The values are normalized using Eq. 4.

$$w_j = \frac{w_{jl} + w_{jm} + w_{jr}}{3} \quad (4)$$

where w_j is the normalized value of j^{th} criterion, w_{jl} is the left weight value, w_{jm} is middle weight value and w_{jr} is right weight value of j^{th} criterion, and j ($1, \dots, n$) is the number of evaluated criteria.

Application

Studies on MES, EM and PM in manufacturing facilities are analyzed, focusing on recent publications. According to Hu, emerging technologies and the Industry 4.0 revolution have transformed traditional methods into smarter solutions (Hu, 2024). The reviewed studies examined the impact of these solutions in the Industry 4.0 era, focusing on their benefits for manufacturing operations. These benefits mean the expectations of end users. It is aimed to obtain enlightening results for companies that do not understand these solutions correctly in the Turkish industry. At the end of this application, it is desired to provide reference results to a company that exists in the Turkish industry. In the studies examined each solution is

evaluated individually, and benefit criteria are identified for each. These benefits are then categorized into main and subcategories.

Research Finding and data Analysis

A review of the existing literature identified performance, cost, efficiency, process planning, real-time data analytics, and direct impact on KPIs as the key benefits of all three solutions. Each main criterion has corresponding sub-criteria, and all sub-criteria are interconnected. For example, the production performance improvement sub-criterion under the performance category is directly linked to reducing production losses. Similarly, the improvement of operational production costs under the cost category is supported by sub-criteria in the performance category. This interconnectedness highlights how all criteria influence one another. A notable finding is that the “direct impact on KPIs” criterion is a common main criterion for all three solutions. Studies indicate that these innovative solutions affect companies’ strategic mission and vision goals.

To apply to Fuzzy SWARA, 15 experts were selected. Their roles and expertise are detailed in Table 1. These experts are industry professionals from leading domestic and international firms in Türkiye’s manufacturing sector.

Table 1. Experts that are used to collect data

Expert	Explanation
Expert-1 (K1)	Country project manager of a local software company with important references in Turkey in Digital Transformation projects and three related solutions
Expert-2 (K2)	Türkiye business development leader of a local and global hardware and software manufacturer specialized in data collection from production.
Expert-3 (K3)	Professional and integrated services business unit manager at one of Türkiye's leading communications companies
Expert-4 (K4)	Sustainability & energy management manager of a large-scale and multilocation fiber textile industry manufacturer
Expert-5 (K5)	Production planning engineer in a medium-sized chemical liquid manufacturing company
Expert-6 (K6)	Product design and production planning project manager at a large-scale global industrial automation, electri-

	fication manufacturer
Expert-7 (K7)	Large-scale multi-location global automotive industry sub-industry manufacturer company in Europe Region IOT Expert
Expert-8 (K8)	Türkiye oil and gas segment manager in a global and world-leading automation and software company
Expert-9 (K9)	Automation manager at a large-scale, multi-location local and leading glass manufacturing company in Europe and the Middle East
Expert-10 (K10)	Global product manager in a global and world-leading automation and software company
Expert-11 (K11)	R&D engineer of a large-scale and multi-location fiber textile industry manufacturer
Expert-12 (K12)	Production maintenance engineer in a medium-sized metal manufacturing company
Expert-13 (K13)	Technical purchasing manager at a large-scale multi-location local and leading glass manufacturing company in Europe and the Middle East
Expert-14 (K14)	Production manager of a global and multi-location paper manufacturing company
Expert-15 (K15)	Maintenance and automation manager of a large-scale and multi-location fiber textile industry manufacturer

Then, experts score each criterion between 0 and 100 in increments of 5, with 100 representing the highest importance and 0 representing the least important. This scoring process constitutes the first step of the Fuzzy SWARA method, which involves ranking the criteria based on expert evaluations.

The arithmetic means of the 15 experts' scores for each criterion determines its overall score. Standard deviation is then calculated to identify outlier values. Based on the standard deviation, minimum and maximum values are determined. If an outlier exists, it is examined to prevent data loss. In such cases, minimum, average, and maximum values are calculated for all data points. For example, in the cost criterion, the experts' evaluations resulted in an average score of 84.333 with a standard deviation of 13.8701. Expert 9 assigned a score of 55, which is considered an outlier

based on the standard deviation but remains a valid and essential evaluation from the expert's perspective. Since neglecting these values would lead to data loss, the minimum, average, and maximum value method is applied to incorporate all expert scores in relation with their experience in the domain. This ensures data integrity and maintains the accuracy of the analysis. The Fuzzy SWARA method is then applied sequentially to all criteria using the equations provided in previous sections. Criteria evaluations were collected from

experts. Criteria were ranked according to their importance and shown with

$\tilde{s}_j$ value. The $\tilde{k}_j$ value was obtained with equation 1. The importance vector q was obtained with equation 2. As a result of the findings, weights were found with equation 3.

Equations 1, 2, 3 were made with fuzzy sets and finally the fuzzy $\tilde{w}_j$ value was normalized with equation 4. As a result, importance weights for each criterion are determined. These importance weights are presented in the average column at the end of the tables. Table 2 presents the final results for the main criteria after applying the Fuzzy SWARA method.

Table 2. Fuzzy SWARA results for the main criteria

	s	k	a	w	$Av.$
Efficiency	1.000	1.000	1.000	1.000	1.000
	0.286	0.209			
Performance	0.000	0.015	0.198	1.000	1.015
	0.139	0.173	0.286	0.199	
Direct Impact on KPIs	0.000	0.022	0.221	1.000	1.022
	1.000	0.114	0.169	0.286	0.190
Real-time Data					
Analytics	0.000	0.031	0.290	1.000	1.031
	0.164	0.286	0.179		
Cost	0.000	0.024	0.771	1.000	1.024
	0.286	0.165			
Process Planning	0.000	0.000	1.000	1.000	2.000
	0.160	0.286	0.157		
<u>Av.: Average value of the fuzzy importance weights or normalized value</u>					

According to the results in Table 2, the most critical criterion for a digital transformation project in production is efficiency. This means that among the three solutions analyzed, the most important factor is the system's ability to enhance efficiency. Following efficiency, the criteria are ranked in order of importance as follows: performance, direct impact on KPIs, real-time data analytics, cost, process planning.

The weights of these criteria are relatively close to each other, indicating that each criterion represents a significant benefit for industrial software solutions. Moreover, these criteria reflect what end-users expect

from digital applications in production. When making an investment, an end-user prioritizes the following objectives in sequence: real and measurable efficiency improvements, performance enhancements, positive impact on company's various KPIs, real-time transparent monitoring, cost reduction, optimization of process planning.

The same steps were applied to the sub-criteria, and their respective weights were determined. The calculated weights for the MES are presented in Table 3. The subcriteria have been ranked in order of importance, and their final weights are provided based on the analyses conducted.

Table 3. Manufacturing execution system sub-criteria weight

Performance	Av. Cost	Av. Efficiency	Av.
Reducing Production Losses	Product Unit Cost Reduction 0.243	Increased Efficiency 0.228	Operational 0.196
Improving Production Performance	Improvement in Production Operational Costs 0.226	Reduction in Production Cycle Time 0.217	0.186
Monitoring and Analyzing Performance	Reduction in Maintenance Costs 0.213	Machine and Line Efficiency 0.206	0.179
Improving Personnel Performance	Reduction in Energy Consumption Costs 0.205	Increased Quality Management and Product Quality 0.198 0.170	
Preventing Unplanned Downtime	Improvement in Warehouse Raw Material Costs 0.188	Labor Efficiency 0.186	0.165

		Shift and Per- sonnel Effi- ciency Tracking	0. 16 0
Real- time Data Ana- lytics	Av. Process Planning	Av.	
Anomaly Root Cause Detection	Inter- Software Integra- tion 0.147	0.177	
Correct Data Collec- tion	Production Planning 0.143	0.169	
Data Monitor- ing and Manage- ment	Opera- tional Plan- ning 0.139	0.163	
Data- Based Estima- tion and Forecasts	Re- source Man- agement and 0.134 Planning	0.156	
Emer- gency Alarm Manage- ment	Delivery Time Planning 0.130	0.150	
Data Reporting	0.127 Work- flow Man- agement	0.145	
Seamless Integra- tion with Other Software Visualization with User-Friendly Interface	Personnel and Shift Rec0.122 ords 0.137		

In Table 3, the sub-criteria related to the MES are ranked in order of importance under their respective main criteria. The normalized weight scores for each sub-criterion have been added. Similarly, the same methodology applied to the MES has also been implemented for the EM sub-criteria. The results of this analysis are presented in Table 4.

Table 4. Energy management sub-criteria weight

Performance	Av. Cost	Av. Efficiency	Av.
Reducing Energy Losses	0.302	0.276	0.242
Improving the Energy Performance of Equipment/Devices	0.283	0.260	0.228
Energy Performance Monitoring	0.253	0.248	0.213
Improving Personnel Performance	0.230	0.237	0.201
Real-Time Data Analytics	0.163	0.246	0.185
Data Monitoring and Management	0.155	0.230	0.218
Accurate Data Collection	0.149	0.218	
Emergency Alarm Management			

Seamless Integration with Other Software	Inter-Software Integration	0.144	0.204
Anomaly Root Cause Detection	Workflow Management	0.139	0.185
Visualiza- tion with UserFriend- ly Interface		0.134	
Data-Based Estimation and Fore- casts		0.129	
Data Re- porting		0.125	

In Table 4, the EM sub-criteria are listed in order of importance. As in Table 3, the normalized weight scores have been added for each sub-criterion. Finally, for the three solutions analyzed, the results for maintenance management are presented in Table 5. All sub-criteria are ranked according to their importance, and the normalized values have been included.

Table 5. Maintenance management's sub-criteria weights

Perfor- mance	Av. Cost	Av. Efficiency	Av.
Providing Uninterrupt- ed Perfor- mance	Reducing Maintenance Costs 0.283	Operational Effi- ciency Increase 0.263	0.232
Increasing Machine Performance	Reducing Operational Costs 0.269	Device Life Span In- crease 0.248	0.220
Increasing Production Performance	Reducing Production Costs 0.258	Production Effi- ciency Increase 0.221	0.207
Improving Personnel Performance	Energy Con- sumption Cost 0.221 Gain	Labor Effi- ciency 0.206	0.198
	Stock Man- agement Spare	Machine Energy Effi-	

	Material Cost Gain	0.202 Management	ciency 0.190
Real-Time Data Analytics Av. Av.			
Data-Based Forecasts and Predictions	Maintenance Planning	0.146	0.235
Emergency Alarm Management	Preventing Unplanned Downtime and Rapid Intervention	0.141	0.225
Accurate Data Collection	Software Integration	0.137	0.212
Anomaly Root Cause Detection	Workflow Management	0.133	0.199
Data Monitoring and Management	Resource Management and Planning	0.130	0.180
Data Reporting		0.127	
Seamless Integration with Other Software		0.123	
Visualization with User-Friendly Interface		0.115	

It is evident from Tables 3, 4 and 5 for the solutions that the sub-criteria under each main criterion are closely related. While every criterion is crucial for production facilities, certain key criteria stand out. The sub-criteria under the common main criterion, “Direct Impact on KPIs,” have been evaluated collectively for each solution.

A review of the literature confirms that similar findings have been reported across various studies for each solution. Based on expert opinions, these three solutions have been evaluated on a single table. The final evaluation results are presented in Table 6.

Table 6. Sub-Criteria weights of common main criterion

Direct Impact on KPIs	Av
Return on Investment	0.168
Economic Development	0.161

Influencing	Deci-	0.156
sion Making		
Innovative	Solu-	0.151
tions		
Competitiveness		0.147
Technological	Im-	0.144
provements		
Carbon	Emis-	0.129
sions/Footprint		
Reduction		

According to Table 6, the normalized weights of the sub-criteria are quite close to each other. The “Direct Impact on KPIs” main criterion is identified as the third most important criterion in Table 2. The fact that the weights of its sub-criteria are similar indicates that this criterion plays a crucial role in new investments made by end users.

Conclusion

The concept of digital transformation, which is used more frequently with the fourth industrial revolution, is far beyond digitalization. It is a revolutionary process where the importance of data has been clearly understood, and data analytics has become the center of focus. The production execution system, energy management and maintenance management solutions brought to the forefront with Industry 4.0 are among the most recent investments made by the companies. Despite the undeniable rise of digital transformation in the manufacturing industry, there is a lack of research for evaluating these three solutions together. This study offers a comprehensive evaluation of these solutions by determining relevant criteria, performing benefit analyses and determining their advantages for the end users.

Findings indicate that all the main criteria in digital transformation efforts in the manufacturing sector are important. These criteria from literature review also meet the expectations formed when a project is implemented. In the Industry 4.0 era, end users want to benefit from all of these main criteria in their manufacturing projects. In other words, when a digital transformation investment is made, the end user expects the following from the project: increased productivity, performance improvement, cost reduction, ease of process planning, transparency of real-time data, and a positive impact on company KPIs.

Analysis of the sub-criteria for the main criteria for the three solutions shows that the results in each clustered sub-criterion are quite similar. Although there are some common sub-criteria, the rankings of the sub-criteria differ in each solution demonstrating that the expectations change depending on the relevant solution. When the tables are examined, important results are revealed. One of them is as follows, looking at the

results in Tables 3, 4 and 5, the sub-criteria of real-time data analytics are shown for three solutions. In Table 3, anomaly root cause detection is the most important subcriterion for the MES. The MES tracks a production line from end to end, managing the process of turning raw materials into products and their exit from the factory. A chronic error in this area can cause significant damage, which is why anomaly root cause detection is important. For EM, data monitoring and management is the most important sub-criterion as can be seen in Table 4. The current trend in EM solutions is energy monitoring. Companies, when investing in these solutions today, request software that can track energy sources first. In Table 5, for maintenance management, datadriven forecasting and predictions are the most important sub-criteria. PM has become a new trend in the Industry 4.0 era. With the utilization of AI modeling, more accurate predictions are essential for selecting the most appropriate criterion for maintenance management solutions. Software providers emphasize predictions in their solutions, and end users can prevent unexpected downtime by having accurate forecasts. Hence, each solution has its own unique dynamics.

When the weighted results of the KPI impact sub-criteria in Table 6 are examined, companies prioritize return on investment (ROI) when they decide to make an investment. The two leading sub-criteria in this area are the short-term return on investment and economic development.

This study reveals the feasibility of the manufacturing sector in Türkiye during the Industry 4.0 revolution while creating a roadmap for the Industry 5.0 transition. The aim of this study is to support companies in their transformation processes. The added values of these three important solutions have been presented to prevent companies from making wasted investments. Making the right investments based on needs is crucial. For future research regarding application of the fuzzy TOPSIS method to support in selection of the most accurate and meaningful solution and criteria. In addition, investigation of how these three solutions will affect ongoing production phases and how these solutions will evolve into the Industry 5.0 era.

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Recognition of Facial Emotions Through Convolutional Neural Networks

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Abstract. Facial Emotion Recognition is now a prominent area of research due to its extensive range of applications. With advancements in the science of deep learning, facial emotion recognition has emerged as a prominent topic in the commercial realm. Since 1960, there has been rigorous scrutiny of it; however, it remains a challenging task for industry analysts. Acknowledgment of feelings is used to recognize an individual's emotions. Diverse ways have been developed to identify an individual's emotions from static images and live footage. The face recognition exam aims to identify each distinct facial expression and categories it according to its emotional classifications. It has extensive applications in the domains of entertainment, education, e-commerce, health, and security. We have presented a way to recognize emotions by using facial information as data. It will predict the individual's emotional state, such as happiness, sadness, or astonishment, and will continually display the output. We used TensorFlow and OpenCV to develop the model. Using the suggested strategy is shown to be feasible by the outcomes of the experiments. Our technique, in contrast to previous research, combines TensorFlow and OpenCV to improve real-time face emotion identification. This allows us to achieve higher levels of accuracy and efficiency by streamlining the feature extraction and classification procedures for both dynamic and static photos.

Keywords: Face emotions recognition, deep learning, CNN, Tensor Flow.

11 Introduction

It is believed that one's outward look can reveal their inner state of mind. In order to provide us with an accurate picture of how a person looks when they're under a lot of stress in the real world, since emotions provide a unique perspective, observers can easily gauge a person's spiritual condition to react to or assist their outward demeanor, suggesting that this perception is truly more linked with an individual's internal state. Mental healthcare facilities are a good place to find these kinds of tools, as they help

doctors create more approachable treatment plans for their patients. A thorough understanding of emotions—what they are, how they work, and why we feel the way we do—is crucial in many contexts, including decision-making, healthcare, relationships, schools, and therapy offices. Facial recognition systems can detect expressions on the face. Among the most perplexing computer vision tasks, this one might rank high. Considering the challenges of creating a unique model, the model must be able to identify the characteristics that differentiate different emotions as Joy, Fury, Depression, Surprise, etc [1].

Initially, ensure that you possess the correct template according to the dimensions of your paper. This template has been adapted for use with the [2]. The fundamental goal of human emotion detection is to determine a user's feelings based on particular data given. Emotions are transient responses that last for a brief duration. An emotional state signifies an individual's current condition (arousal, mood, or personality) independent of external stimuli [3]. The above goals may be achieved via the various divisions within the model identification domain. This technique examines many stages of taxonomy development, including data collecting, attribute extraction, Labeled data, and training sets are crucial to taxonomic practice. Using a computer video camera as a usual input device will make multimodal emotion identification simpler, as demonstrated in Figure 2. This approach offers comprehensive data and statistics on the identification technique since several information sources may provide significant associated details while mitigating possible inaccuracies for each input. The primary objective of this effort is to develop a facial recognition system that can evaluate a student's understanding of the entire system of distant learning. Present in this paper is a model for sensory learning that encompasses three stages: emotion classification, feature extraction, and feature detection. Fig. 1 contains an illustration of this model.



Fig. 4. Human Facial Expressions of Emotion.

Fig. 1 depicts many different facial expressions of a woman's face, each labeled with an emotion, such as "happy," "sad," "fear," "neutral," or "surprise." The picture is the

result of a facial expression recognition system, as shown by the green bounding boxes that emphasize the faces that have been recognized and the blue text labels.

By using TensorFlow and OpenCV, the suggested approach improves the reliability and real-time effectiveness of facial expression identification, proving its practical usefulness in a variety of fields, including e-commerce, security, and healthcare.

12 Related Work

Wang and Kawka [4] presented, GiMeFive, an interpretable facial emotion categorization model. Deep CNNs were used to categorize six facial emotions and interpret them using layer activations and gradient-weighted class activation mapping to improve emotion identification systems' transparency and reliability. Convolutional Neural Networks (CNNs) have improved face emotion identification accuracy and efficiency.

Additionally, research [5] highlighted the efficacy of a unique deep convolutional neural network in extracting data from facial expressions by introducing an improved face emotion detection model based on the network. The Emognition dataset, which contains 10 different emotions, was used by Agung et al. [6] to broaden the use of deep learning in this field. They achieved a 96% accuracy rate and an average F1-score of 0.95 on test data by using a combination of data preprocessing and transfer learning to create CNN models using Inception-V3 and MobileNet-V2 [7]. In a similar vein, Islam [8] carried out an extensive investigation on CNN-based facial expression recognition, emphasizing the technology's usefulness in fields like affective computing and human-computer interaction. The research highlighted how CNNs may detect emotional states by evaluating facial features. An improved CNN combined with an Extreme Learning Machine (ELM) classifier was suggested by Banskota et al. [9] in a different research in order to decrease processing time and increase recognition accuracy. Real-time analysis was made possible by their model's 2% accuracy gain and 65 millisecond processing time in each frame.

Additionally, Qu et al. [10] used the PyTorch package to create a CNN-based model for real-time face expression identification. Their implementation offered important insights into deep learning applications for emotion detection and concentrated on optimizing space complexity. The effectiveness of CNN-based methods in developing face emotion detection technology is shown by these research taken together. For simultaneous face identification and facial attribute categorization, including emotion recognition, Savchenko [11] investigated multi-task learning using lightweight CNNs. The research demonstrated how well models may be adjusted for certain tasks to enhance performance in related applications.

13 Existing Structure

No specific paradigm exists for a thorough knowledge of human emotional levels. We use several organic methods to assess internal temperature, pulse, ECGs, and others.

Parameters to determine fitness or, at times, to evaluate whether the mood is in an unacceptable condition. The estimate fundamentally relies on the varying limits of the real factors influencing human tendencies to evaluate emotions. Several methodologies have been delineated in the literature for the automated identification of facial features [12].

Certain contemporary frameworks explicitly identify 68 facial landmarks in the principal framework, whereas the rest of the system uses the Active Appearance Model (AAM) for these landmarks. In some operational contexts, it may not be possible to get accurate characteristics. Shawn asked about face recognition using LBP. Articulation verification uses SVM classifiers using Local Binary Pattern (LBP) features. The developers have physically designated the eye locations for universal use because it is not feasible in the majority of working situations. This is the Computer Expression Recognition Toolbox (CERT) that Larry presented to the audience. CERT forbids the use of face photos and allows for the extraction of facial characteristics via the use of Gabor filters.

Emotion identification uses SVM and MLR algorithms. Lyons proposed a technique for encoding exterior appearances that makes use of clustering for class expansion and 2D Gabor wavelets for feature extraction. These approaches clearly need efforts for both computing costs and programming efforts. We use several organic methods to assess internal temperature, pulse, ECGs, and other parameters to determine fitness or, at times, to evaluate whether the mood is in an unacceptable condition. The estimate fundamentally relies on the varying limits of the real factors influencing human tendencies to evaluate emotions. Several methodologies have been delineated in the literature for the automated identification of facial features. Certain contemporary frameworks explicitly identify 68 facial landmarks in the principal framework; the Active Appearance Model (AAM) is used for these markers by the rest of the system. There are times when it might not be possible to get the correct characteristics. Shawn asked about how LBP could be used for face identification. In this context, articulation verification is performed using Support Vector Machine (SVM) classifiers with support Local Binary Pattern (LBP) features. The developers have physically designated the eye locations for universal use because it is not feasible in the majority of working situations. This is the Computer Expression Recognition Toolbox (CERT) that Larry presented to the audience. CERT forbids the use of face photos and allows for the extraction of facial characteristics via the use of Gabor filters. SVM and MLR algorithms are used to identify emotions. Lyons proposed a technique for encoding exterior appearances that makes use of clustering for class expansion and 2D Gabor wavelets for feature extraction. These approaches clearly need efforts for both computing costs and programming efforts.

14 Proposed Methodology

This research utilizes DCNN features for the automated identification of facial expressions. The project will utilize the Google search image collection. One of the datasets described before is used for face recognition in the pre-processing phase. We use OpenCV21 to crop the faces up front. The Caffe library extracts features on a GPU. Face characteristics are collected by Image Net 15 to train a convolutional neural network for object identification. ImageNet has eight learned layers. The first five layer properties are shown in Fig. 2 in this research..

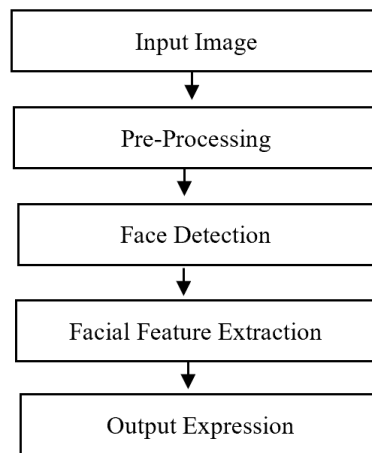


Fig. 2. Procedure for Classification.

Convert all photos to greyscale, recognize frontal faces, and then crop just the facial area to identify facial emotions. Deep Convolutional Neural Network (DCNN) can extract POOL5 features (256x6x6) from cropped faces. Set face expression labels for each picture using the provided dataset. Use the 9216-dimensional POOL5 vector for tenfold and leave-one-out cross-validation with an SVM classifier to recognize facial emotions.

14.1 TensorFlow

Google's team is responsible for the creation of TensorFlow in order to accomplish research and development goals. It exists as a framework that is open to the public. TensorFlow is frequently utilized in the domains of machine learning and deep learning methodologies. It is one of the frameworks that is used in machine learning and is among the most uncomplicated. A mathematical library that was constructed via the use of differentiable programming is what it is primarily. The deep neural networks are the primary focus of TensorFlow's attention. Keras is a framework that centers on TensorFlow 2 as its foundation.

On top of that, it is written in the programming language known as Python. In order to construct deep neural networks, TensorFlow makes use of data flow graphs. Data flow graphs are used in the process of developing multi-layer neural networks. The purposes of classification, recognition, and forecasting are the primary applications of TensorFlow.

14.2 Open CV

In the year 2000, OpenCV was introduced. It is a library that supports open-source software, and anybody may contribute to it in order to improve its applicability. Computer vision, image processing, and machine learning are some of the areas that now make use of OpenCV. There are a number of programming languages that may be used with it, including Python and Java. In order to identify the faces or things that are included inside an image, it is used to analyze both static and dynamic photographs. An open-source library for computer vision and machine learning, OpenCV is what you're looking for.

In particular, it gives apps like computer vision and machine learning a consistent way to interact with each other. Its main job is to recognize things and face emotions. OpenCV is free to use in business and is meant to be shared. It is licensed under the BSD 3-Clause License.

14.3 Using Haar Cascade

The Haar Cascade is used to teach the algorithm what to do. This is a machine-learning technique for spotting objects that is used to find things in pictures and videos. A lot of pictures, both good and bad, are used in this method to teach the model predictor, which only looks at the important parts. This method for recognizing objects works very well and is used in current apps. With this method, a large number of positive and negative photos are used to make a "cascade function," which is then used to find things in more photos. There is a Haar cascade called the "Haarcascade_frontalface_default.xml" file that is used to find frontal faces. You can get to this Haar cascade through the internet. The Haar cascade may pick up traits from the source. The development process may make use of a wide variety of Python libraries and frameworks, which are easily accessible for direct application.

The comprehension of human facial expressions and their analysis encompasses several facets:

- a) Computational analysis
- b) Emotional recognition
- c) Polygraphs
- d) Airline security

This research examines several aspects of emotion. It has five categories:

1. Happiness
2. Sadness
3. Anger
4. Surprise
5. Clam

This model has been taught to look at five groups to figure out what feelings people are showing on their faces. If it is probable that the expression will be happy, then the output will be joyful; however, this may not be the case depending on the input expression of the value that is being entered by the webcam [13]. For the purpose of distinguishing the continuous articulation, there will be no need for any external equipment. It does not need a significant amount of processing power and may be operated on a simple personal computer. For the purpose of predicting the outer look, it is a basic and typical prepared preparation model. Due to the fact that it does not need any external source, this project is merely an improved version. In order to collect input, it will make use of a plain ordinary webcam, and in order to generate output, it will make use of the screen of the computer. The result will be shown in the form of a square with a colored frame and a more composed appearance on the right-hand side of the square. It begins by using Open CV to recognize the face, and then it will proceed to develop a subsequent method to convert the RGB image into a dim-scale picture. As a result of this growth, the image is almost ready to be able to sense the facial feeling.

Given that the model will be taught to accept an appropriate reward to adjust its value, the present action being undertaken is to decrease the picture size. To make the model, we use the CNN design. In order to build this model, we are using the tensor stream as a way to get a normal high estimate level. This investigation utilizes various techniques to develop the model, equipping it to incorporate the knowledge base and facilitate the identification of facial expressions of emotion using Python. In recent years, face detection and identification have emerged as the approach to biometric authentication that has gained the greatest popularity. To put it simply, it is the use of facial characteristics inside a biometric system. It is the face Section that is the focus of the problems that arise with face recognition. For further classification, It is possible to further subdivide face recognition into two categories: photos and real-time face detection. For the purpose of identifying faces in still photos, we will implement a number of distinct picture modifications as part of our face detection project. we will be done in an attempt to identify faces. The article [1] describes one of the first automated facial detection systems that was ever developed. The construction of a vector feature was accomplished by the use of marker points in [8].

Additionally, this is used widely in cameras for the purpose of recognizing several occurrences that are included inside the frame. Social networking platforms use facial recognition algorithms to identify faces in photos, as shown by Facebook. Various approaches are used in face detection, enabling high-accuracy identification of faces.

15 Facial Detection Utilizing Python

Overfitting caused images not in the database to be rejected, large and high-resolution images took too long to compute, input images needed to be higher than 6"6 resolution, classifiers mistakenly identified many non-facial entities, and when combined with skin classifiers, dissent from mouth and eye classifiers was also rejected. We are going to use the Haar cascade and the MTCNN in order to generate datasets of faces that have been cropped. It is important to note that the face dataset will consist of photographs of a single human being by themselves. Let us examine the processes required for face detection [14].

An image may have several faces of varying sizes, and their locations may be unknown. Rather than examining the whole picture, we will identify a face inside a narrow window that traverses a bigger image. We will verify the presence of a picture at each location on the image. Upon detecting a face, we will record its position and then relocate it; the sliding window classifier is the name of the operation that is being done . A common use of face detection is the use of algorithms that determine if a photograph contains a face (positive) or does not include a face (negative). [15] To ensure that the algorithms are accurate, they are trained on large datasets that include hundreds of photographs of people's faces. As soon as they have been trained, the algorithms could react to more inquiries. The first question is whether or whether the snapshot contains any faces, and if it does, the second question is when and where those faces are placed. When the algorithms determine that there are faces in the image, they will react to inquiries by drawing bounding boxes around the faces that have been positively detected. Changing lighting conditions and very steep head angles were some of the things that affected how well these machine learning-based methods worked.

16 Results and Analysis

Through the use of deep learning, we investigated the architectures of CNN and ResNet50 in order to recognize facial expressions. This dataset is focused on evaluating approaches for emotion identification using physiological responses and facial expressions, including a range of emotional expressions.

This dataset has around 24,000 photos annotated with five fundamental emotions: happiness, fear, sorrow, disgust, and rage. It was developed to address deficiencies in prior datasets and is appropriate for real-time face emotion detection research. These datasets were selected due to their ability to balance real-world application, variety, and annotation quality, guaranteeing excellent accuracy in real-time face emotion identification.

Table 1 shows how well a model for recognizing facial emotions did on three different sets of data (FER-2013, CK+48, and 3RL dataset), including how well it reported, how well it tested, and how well it predicted. The 3RL dataset did the best job of pre-

dicting feelings generally as shown in Fig. 3. However, FER-2013 made some mistakes when it came to different emotion classes, and CK+48 had trouble understanding emotions other than anger.

The Fig. 4. illustrates seven facial expressions—Angry, Disgusted, Fearful, Happy, Neutral, Sad, and Surprised—each designated above the respective face, exemplifying the categorization output of a facial emotion detection system.

Table 4. Datasets DL Comparative.

Dataset	Accu- racy	Test Ac- curacy	Prediction
FER-2013	99.8%	89%	Recognize happy, neutral, fear and sad emotion with misclassification in other classes.
CK+48	99.9%	95.9%	Only disgust emotion was recognized correctly
3RL dataset	99.9%	91.4	Best prediction results between all experiments



Fig. 3. FER predicting result.

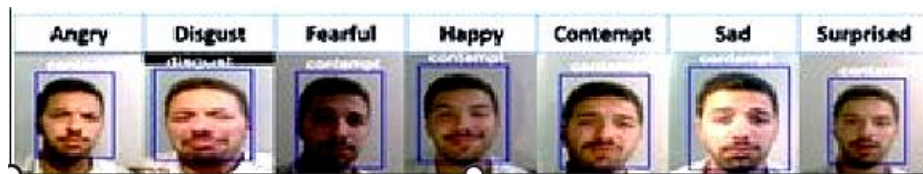


Fig. 4. Data sets.

The 'sick' feeling is seldom seen in conventional emotion identification datasets. To include this category, consider the following strategies.

16.1 Creation of Custom Datasets

Compilation of Images: Collect photographs of humans displaying symptoms of disease or pain from medical image libraries or stock photo websites. Annotate these photos manually using the 'sick' category with annotation tools like LabelImg or VGG Image Annotator (VIA).

16.2 Data Augmentation

Approaches to augment the diversity of the 'patient' category allow the model to acquire robust features.

17 Conclusion

This study introduces a face emotion detection system that offers a versatile model by correlating behavioral traits with physical-biological attributes. Many feelings, like happiness, sadness, fear, anger, surprise, and disgust, are represented by different parts of the face. These parts are connected to geometric shapes that have been rebuilt and used as the recognition system's main matching pattern. The results received show that the suggested method works. In order to increase accuracy in real-time circumstances, future work may concentrate on strengthening the model's resilience by including cutting-edge deep learning approaches, such as transformer-based architectures. Furthermore, adding multimodal data—such as speech and physiological signals—could improve emotion detection even further and provide a more thorough comprehension of human emotional states.

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Multimodal Deep Learning Integration and Loss Value Analysis

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Abstract. This paper proposes a multimodal deep learning architecture by integrating clinical text reports and medical image data to which the diagnoses in the reports are mapped. Mean squared error (MSE) is used to optimally measure the performance of the missing value in unimodal and multimodal systems. A long short-term memory network (LSTM) is used for feature extraction of clinical text reports and a convolutional neural network (CNN) is used for feature extraction of medical image data. In the final training phase, the loss value of the LSTM model was measured as 4.4758 and the CNN model as 0.0041. Feature vectors obtained from heterogeneous data were combined on a multimodal system to create a common representation. The loss values of the multimodal system during the training process were analyzed and the loss value was determined as 0.0011 in the last stage of training. The obtained results were visualized for each model by expressing the loss values graphically and the advantages of multimodal systems were emphasized. The use of multimodal systems with minimum error margin is expected to increase in future studies.

Keywords: multimodal deep learning, feature extraction, loss function, medical images, clinical reports, CNN, LSTM.

This research discusses the difficulties encountered by single-mode systems and how loss values vary when medical images and clinical text reports are integrated into a multimodal deep learning network. This research presents a paradigm that incorporates heterogeneous data formats into a multimodal system architecture. Highlighting the essential importance of multimodal deep learning systems in the medical industry, this study discusses the design principle and experimental results of the model in depth.

Multimodal systems are artificial intelligence systems that combine multiple data to process them. As a result of the growing interest in these systems, many datasets and techniques exist to represent and integrate data from various modalities [1].

These methods include creating datasets, preparing data, training models and integrating data. Each method makes it possible for multimodal systems to integrate data from various sources to perform more comprehensive and precise analysis. However, recent advances in technology and the increase in data volume have significantly reduced the capabilities of unimodal systems and built the technology era on multimodal systems [2]. Multimodal systems, which can collect more information by integrating data from different modalities, provide a significant advantage over unimodal systems [3]. This advantage has a significant impact on the performance of multimodal systems. With the combination of different data sources, more comprehensive and accurate analyses are performed, thus minimizing the margin of error by achieving lower loss values. In this study, we focus in particular on the loss values of unimodal and multimodal systems and detail the extent to which the margin of error is reduced. With the use of multimodal systems, especially in the medical field, lesions are better understood and the quality of the diagnosis and treatment process is significantly improved [4]. By increasing the accuracy of the diagnosis and treatment process, the error margins of the systems are greatly reduced. Medical images play a major role in modern diagnostic and therapeutic methods. A variety of medical image data, including radiology, ultrasound and pathological images, are constantly emerging as a result of ongoing advances in medical imaging technology. The domain of medical image reconstruction and enhancement has encountered both novel opportunities and challenges due to the swift advancements in deep learning technology, particularly with the advent of models like Convolutional Neural Networks (CNN) [5]. In this scenario, because to the dataset's richness and complexity in medical images, the model employs a convolutional neural network (CNN) as a feature extractor. CNN is capable of adaptively extracting high-dimensional features from images using multichannel convolution and pooling procedures and accurately capturing texture features, detailed features, and spatial distribution information of lesions [6].

Long Short-Term Memory networks (LSTM), a subset of Recurrent Neural Networks (RNN), have significant potential in the field of machine learning. Their design can handle text and other sequential data in innovative ways. LSTMs can capture the temporal dynamics of language, comprehending its ebb and flow, by storing information from previous data points and applying it to predict the future. Prediction approaches for these structures necessitate a thorough methodology, especially when data from several sources is used [7]. The LSTM technique was chosen for deep semantic analysis of clinical report texts based on their raw structure. LSTM can efficiently identify temporal dependencies and contextual correlations in disease-related utterances while also leveraging all textual contextual information [6].

In summary, this study integrates a multimodal deep learning model to integrate clinical reports and text. In the context of this integration, especially the loss values of the model are analyzed, compared with single-mode systems and its advantages are emphasized. In this context, the use of multimodal deep learning mechanisms in the medical field is expected to increase in the future due to its advantages such as low loss rate.

There are numerous works on image categorization using CNN in the literature. Since Alex Krizhevsk et al. published AlexNet in 2012, many conventional CNN architectures have emerged, including VGGNet, GoogLeNet (Inception), ResNet, DenseNet, MobileNet, and EfficientNet. Most of these structures are widely utilized in medical image categorization. Despite its effectiveness in many computer vision applications, CNN's use in medical picture categorization presents numerous obstacles. These issues include limited datasets, tiny structural lesions, unbalanced sample categories, low model generalization power, lack of explainability, and so forth. The research community is continually looking for adequate answers to these difficulties in order to develop AI models that are better suited to medical picture classification. From a different angle, each study examined the existing literature. As an example, Muhammad et al. surveyed every existing CNN-based method for classifying brain tumors, then created a suite of pre-trained CNN models for this task using two datasets—one without data augmentation and one with—and evaluated their efficacy. In order to identify coronavirus infection in images like X-ray and CT scans, Subramanian et al. performed an extensive evaluation of different deep learning methods. Majtner et al. investigated several strategies for identifying medical and biomedical photos, including CNNs and transfer learning as feature extractors. [8]. In another work, MSE, RMSE, and MAE characteristics were utilized as loss functions in a CNN model designed to improve skin cancer diagnosis. These characteristics are critical for determining the forecast accuracy and margin of error. The developed CNN model had an MSE of 0.375, an RMSE of 0.612, and an MAE of 0.5 [9].

Recently, LSTM has emerged as an effective method for understanding long-term dependencies and accurately representing the relationship between recent and historical events. To detect abnormalities in time series, Malhotra, Vig, Shroff, and Agarwal proposed using stacked LSTM networks. Next, a multi-sensor anomaly detection technique based on the LSTM encoder-decoder scheme is expanded. One disadvantage of these two studies is that the authors assume a multivariate Gaussian distribution for the error vectors, which may not be valid in practice. Tran, Du Nguyen, and Thomassey developed a kernel quantile estimator in a control chart-based technique to overcome this assumption. Schölkopf, Platt, Shawe-Taylor, Smola, and Williamson claimed that their LSTM-based approach outperformed a machine learning-based approach [10]. For example, in a study conducted in Turkey, various models such as LSTM and CNN were developed to predict the number of Covid-19 cases and deaths, and performance evaluations were made based on metrics. In the LSTM model, according to the MSE metric 16670823,040, according to RMSE 4082,991, according to MAE 2543,651 and according to R2 value 0.975 values were obtained. For the CNN model, the MSE metric is 34253568,270, the RMSE metric is 5852,655, the MAE metric is 3820,487 and the R2 metric is 0.931 [11].

The previous work discussed in this section demonstrates significant gains in medical image and medical report classification, as well as the impact of loss functions on performance. It focuses on how effective loss function parameters such as MSE, RMSE and MAE are in determining the accuracy of medical imaging. Similarly, in this study, the MSE loss function is used to combine multimodal data and evaluate the performance. Future research suggests that loss functions should be optimized and

multimodal techniques should be applied to build more flexible and generalizable models in the field of medical image classification and prediction.

20 Theoretical Foundations

20.1 CNN

A convolutional neural network (CNN) shown in Fig. 1, a deep learning model used to interpret pictures and other multidimensional data, is made up of artificial neurons that respond to specific adjacent units in their receptive fields. In addition to machine learning, these networks excel at computer vision tasks like object detection, speech recognition, and image categorization. Convolutional algorithms are especially beneficial for gridded data because they help capture local characteristics and spatial correlations in the input data [12].

However, in order to achieve better predictive performance and meet more challenging goals, CNN architecture is becoming deeper and more complex. High-resolution image acquisition devices allow more pixels to be collected simultaneously in a single image. CNN training and inference is therefore computationally extremely expensive and of limited use due to its low speed. Although CNN optimization and acceleration has been studied since the topic was introduced, it has recently received more attention due to its positive industrial impact [13].

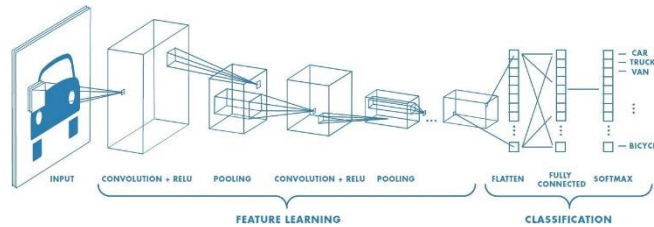


Fig. 1. Convolutional Neural Network Architecture [14]

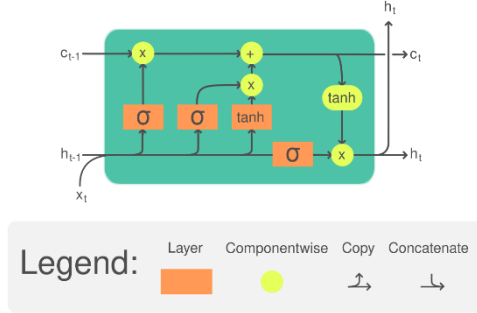


Fig. 2. Long Short-Term Memory Network Cell [16]

Long short-term memory (LSTM) networks (see Fig. 2) help with typical recurrent networks' issues with gradient bursting, gradient fading, and long-term data retention. Its basic structure makes it possible to record changes in temporal input characteristics, which is essential for understanding complex time series interactions. Using this capability, the model can learn complex temporal correlations of time series data [15].

A type of recurrent neural network (RNN), called a Long Short-Term Memory (LSTM) network, was created to address the vanishing gradient and bursting problems in traditional RNNs. It shares structural similarities with a typical RNN. LSTM offers gating devices to improve performance[10].

20.3

Loss Function

A widely used loss function in regression and time series forecasting, the MSE represents the sum of squared distances between a target variable and its predicted values. Below is a summary of the MSE calculation [17]:

$$MSE = \frac{\sum_{t=1}^n (Y_t - \bar{Y}_t)^2}{n} \quad (1)$$

According to this equation, the actual value of a point in time period t is denoted by Y_t , the expected value for period t is denoted by $\bar{Y}_t$, and the total number of installed points is denoted by n [17].

20.4

Feature Extraction

Feature extraction uses the object's features to find, process and identify regions of interest. In this process, algorithms are created using either unsupervised learning (clustering) or supervised learning (classification) approaches [18].

PCA (Principle Component Analysis) is a method for reducing dimensions. It stands for principal component analysis. PCA extracts information from a variety of datasets. The purpose of PCA is to generate a feature set with fewer dimensions than the original dataset. Determining the number of primary components is critical in PCA. The principle components that best explain the data should be chosen from all principal components using a p-value. The appropriate number of principle components is determined using criteria such as the broken bar model, cross-validation, Velicier's partial correlation process, Kaiser's criterion, Barlett's test for eigenvalue equality, Cattell's screen test, and cumulative variance percentage [19].

21 Multimodal Deep Learning Architecture

Fig. 3 shows the results of the study's multimodal deep learning model, which combines CNNs with LSTMs. During model building, CNN and LSTM-based networks are used for feature extraction for each data type separately and the resulting loss values are analyzed. These different models are then combined in a multimodal system to optimize the loss values.

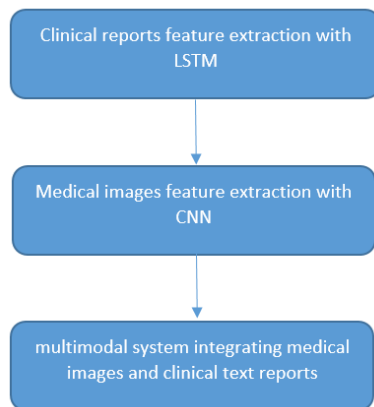


Fig. 3. Multimodal System Stages

21.1 Feature Extraction From Clinical Text Data

In this study, a comprehensive heterogeneous dataset was chosen for clinical text data. In the dataset, each disease information is paired with relevant images and includes demographic information such as disease symptoms, age and gender of the patient. In the first stage, the relevant dataset was checked and the most frequently occurring words were analyzed as shown in Fig. 4 below. Then, basic preprocessing steps such as case conversion, punctuation and removal of stop words were performed. The clinical text data were converted into numerical vectors and feature vectors of the first sample were extracted. With the LSTM model, contextual information was captured and the model was trained through a deep semantic understanding process. The per-

formance of the model during and after training was evaluated based on the loss values. After model training, predictions were made on the first five samples. The extracted features were visualized with principal component analysis (PCA).

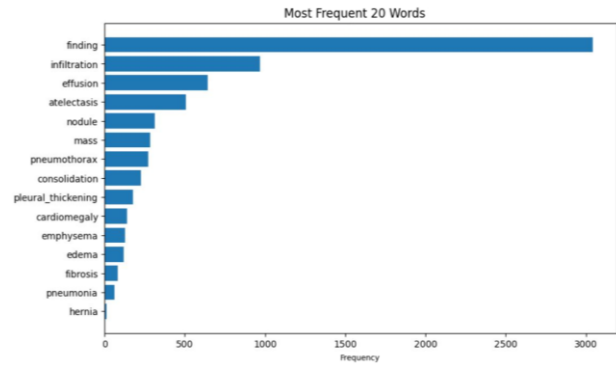


Fig. 4. The 20 Most Frequent Words in Clinical Text Data Analysis

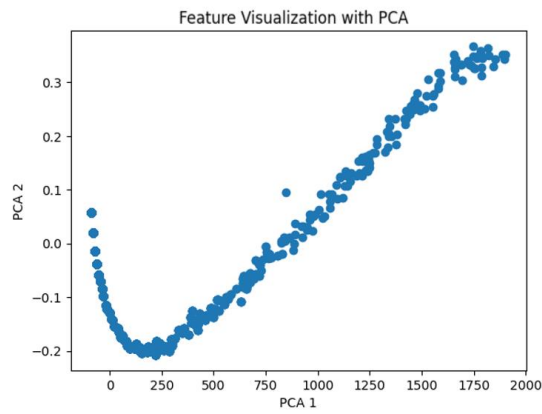


Fig. 5. PCA Plot of Clinical Text Data Feature Vectors

Fig. 5 represents the visualization of the feature vectors of the LSTM model using PCA. PCA graphs can accurately and efficiently capture the most important variances in the data [20]. High-dimensional data can be reduced to lower dimensions, allowing for visualization. It provides detailed information about the distribution and interrelationships of the features learned by the model. In this context, the regions where the data are concentrated represent the regions with the highest number of similar features. The proximity or macro distribution of the points indicates how similar the features are to each other. Parts that fall farther away from other points indicate outlier or noisy data. The majority of the data is distributed along a distinct curve, proving that there is a strong relationship between them.

21.2

Feature Extraction from Medical Image Data

The medical images in this study consist of X-RAY format. Convolutional neural networks (CNN) are used to capture the details and spatial distributions of the medical images. All of the medical images were reduced to the same dimensions to ensure consistency of the model processing. CNN architecture is designed for powerful feature extraction with layers such as convolution and pooling. The model was trained by reducing the processed images to vector dimensions. The performance of the model was analyzed based on the loss values. Visual feature vectors learned in the trained model were visualized with PCA.

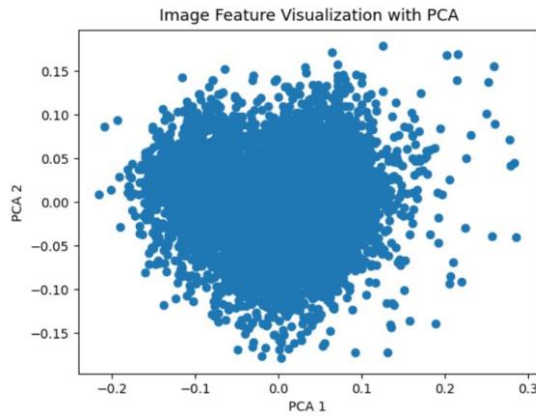


Fig. 6. PCA Plot of Medical Image Data Feature Vectors

In Fig. 6, the features extracted from the output layer of the CNN model with PCA are reduced to two dimensions and visualized. In this context, regions where data are gathered in a macro cluster represent data with similar characteristics. In the figure, the data are mostly similar to each other as this cluster is gathered in a prominent area. Since the model performs feature extraction, the most focused features are represented in this region. Sparse regions represent data with different features. Some points that fall away from the cluster indicate that there is outlier or noisy data in the model. Since outliers are not very frequent, it is clear that the image data is clean and consistent.

21.3

Multimodal System Design

A multimodal system design is used for feature extraction and integration of medical image data from the LSTM model and clinical text reports from the CNN model. This system provides a multimodal deep learning architecture by combining features from both modalities. The fusion layer combines these features into a single vector representing the data for both modalities. The fused feature vector is processed through various layers to add depth to the model. The final layers of the model were optimized with appropriate activation functions to provide better feature representation.

21.4

Data Set

This study favors a comprehensive dataset of chest X-ray pictures and their corresponding clinical descriptions. The proposed framework utilizes a compilation of chest radiographs from the NIH Chest X-ray dataset of the National Institutes of Health Clinical Center. In 2017, Wang et al. created the “Chest-Xray8” dataset. The images are utilized to diagnosis 14 distinct diseases depending on their presence or absence, including atelectasis, cardiomegaly, consolidation, edema, effusion, emphysema, fibrosis, hernia, infiltration, mass, nodule, pleural thickening, pneumothorax, and pneumonia. Every image is accompanied by a radiology report containing additional information regarding both the patient and the image [21].

21.5

Loss Function

Since the aim of the study is to monitor the performance of the models through their loss values and to evaluate their stabilization in this context, “MSE (mean-squared-error)” was preferred as the loss function.

22

Experimental Results

Fig. 7 shows the change in the loss values of the models throughout the training process. Looking at the figure, it is observed that the LSTM model starts with a very high loss value at the beginning of the training and decreases rapidly throughout the training process. In the final stages of the training process, it stabilizes and reaches an optimal point. The final loss value of the LSTM model with the MSE loss function is 4.4758. The CNN model started the training with a very low loss value and maintained the stabilization in the loss value throughout the training process and its final value is 0.0041. When the loss values of the multimodal system are analyzed, it started from a low level and experienced a normal decrease in the training course and continued to maintain its stability in the later stages of the training. The final value was 0.0011. In this context, the LSTM model did not perform as well as the CNN and multimodal system architecture. Although the loss values of the CNN model and the multimodal system at the beginning of training were close to each other, they did not provide as strong representation learning as the multimodal system.

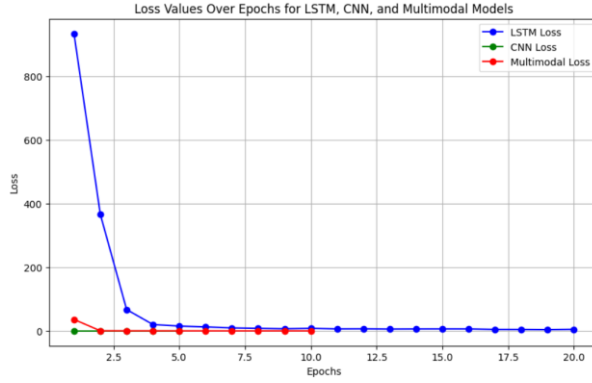


Fig. 7. Loss Value of Models over Epochs

Fig. 8, shows the loss values of the models from the last training on a logarithmic figure. With the logarithmic figure, the high-scoring loss values can be analyzed more clearly. Looking at the figure, it is seen that the LSTM model has a significantly high loss value. The CNN model outperformed the LSTM model, achieving a lower loss value. The multimodal system achieves a much lower loss value than both LSTM and CNN, demonstrating that it successfully integrates different data types and performs more powerful representation learning.

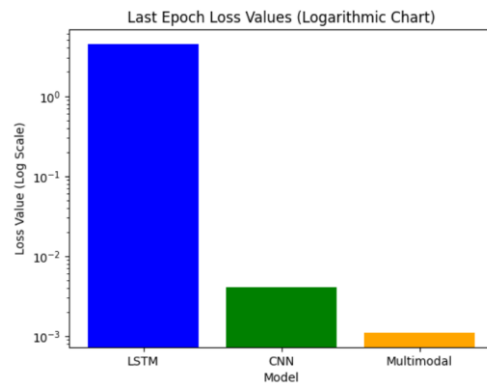


Fig. 8. Last Epoch Loss Values of Models

23

Conclusion

In this study, a multimodal deep learning architecture is designed using a comprehensive dataset that includes medical images and clinical reports to which each medical image is mapped. Medical image data were designed with CNN and feature extraction was performed and loss values were analyzed at each stage of the training process. Clinical disease description reports were trained with the LSTM model and feature extraction was performed and loss values were analyzed during the training process. The two feature vectors obtained were integrated into the multimodal system, a new

architecture was designed, a common data representation was created and the training process was carried out. The loss values of the multimodal system in the training process started at a lower level compared to the other models and progressed in a stabilized manner. It has achieved superior success and advantages compared to the single-mode systems used in the study. In this context, the model proposed in this study demonstrates the effectiveness of multimodal systems in the medical field. It is predicted that clinical reporting procedures will become more effective in the future thanks to the richer and more complete representation capabilities of such multimodal systems, which combine heterogeneous data types such as clinical reporting and medical imaging. Developments in this area are expected to facilitate more precise analysis of medical data, leading to more accurate and faster decisions in the healthcare industry.

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A Multimodal Deep Learning Architecture for Diabetic Retinopathy Diagnosis

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Abstract. This paper proposes a multimodal deep learning architecture that integrates text and image data for the diagnosis of diabetic retinopathy. This architecture aims to improve diagnosis and diagnostic processes by integrating information from different data types. In the related study, image data were preprocessed, data dimensions were optimized and trained on the convolutional neural network model. The training accuracy of the model was measured as 64.97%. Text data containing disease diagnoses were preprocessed by natural language processing steps and the training process was carried out with the recurrent neural network model. The accuracy value obtained as a result of the training is 63.94%. A hybrid model was obtained by combining the data obtained from both models on a multimodal deep learning architecture. This model outperformed the unimodal systems by reaching 66.77% accuracy in the training phase. The findings show that the proposed multimodal architecture efficiently exploits the complementary nature of the data types and offers higher accuracy compared to unimodal structures. This study demonstrates that multimodal deep learning techniques enable more comprehensive analysis and more reliable medical diagnosis results. In future studies, it is envisioned that it can be applied as a standard procedure for many medical data and disease classifications.

Keywords: multimodality, disease recognition, deep learning, CNN, RNN.

24 Introduction

This study proposes a multimodal deep learning architecture that integrates medical image and clinical data for the detection of diabetes in the eye. Compared to unimodal systems where medical image and clinical data are processed separately, multimodal systems have higher accuracy rates. This proves that multimodal systems achieve promising results in the detection of diabetes in the eye.

Diabetic retinopathy (DR) is an ocular condition induced by diabetes mellitus. The condition results from damage to blood vessels in the photoreceptive regions of the retina, ultimately resulting in blindness. Research indicates that the Western Pacific Region has a greater prevalence of diabetes, with 152.2 million cases, compared to

South East Asia's 78.3 million cases. In India, 69.2 million individuals have diabetes, with over 36 million remaining untreated. Diabetes cases are anticipated to reach 109 million by 2035, heightening the risk of ocular impairment and blindness in the foreseeable future. Statistics indicate that 6 million diabetics in India suffer from a sight-threatening variant of diabetic retinopathy. Fundus pictures of suspicious patients commonly exhibit abnormalities including microaneurysms, exudates, neovascularization, cotton wool patches, hemorrhages, and vitreous hemorrhages. It may also be associated with other conditions, including cardiovascular risks. This ailment is predominantly asymptomatic. Precise identification of the condition necessitates proficient medical practitioners, and contemporary diagnostic tools are both time-intensive and expensive. Timely diagnosis of the condition can diminish the probability of vision impairment. This is unfeasible due to the asymptomatic nature of the condition [1].

Much of the recent work has focused on the use of deep learning approaches to improve the classification of eye diseases. These advantages are focused on the development of a convolutional neural network (CNN) based disease detection system for image data in this study. The performance of the network is usually determined by the CNN hyperparameters. Consequently, choosing the right hyperparameter plays an important role during the CNN training phase. Moreover, CNN hyperparameters need to be optimized for improved training and performance [2].

In addition to the fundus images processed with CNN, clinical text data, with which the images were labeled and matched, were processed with Long Short-Term Memory (LSTM), a variant of recurrent neural networks (RNNs). LSTM networks, a specific kind of RNN, have proven to be exceptionally promising. Their architecture is well designed for processing sequential data, including text. LSTMs can encapsulate the temporal dynamics of language by preserving information from previous data points to guide future predictions [3].

In medical practice, multimodality fusion has become increasingly important in the detection of difficult conditions such as eye disorders, especially diabetic eye diseases, which increase the risk of blindness and vision loss. Eye diseases are difficult to diagnose with a single modality and often miss important disease markers. To improve diagnostics, experts support multimodality-based strategies [4].

In summary, in this study, a multimodal system is proposed considering the difficulties of single-mode systems in eye disease detection. While the image data is processed with CNN architecture, the clinical data related to the disease to which each image is mapped is processed with LSTM. When the accuracy values obtained from the modalities are compared, the results obtained by multimodal systems are higher than unimodal systems. Based on this context, multimodal systems are promising in the field of medicine, especially in disease detection and classification.

25 Related Work

The remainder of the paper is structured as follows. Section 2 delineates the multimodal systems that have been developed in the extant literature for the diagnosis of diabetic retinopathy. Section 3 provides information regarding the models that were utilized in the study. Section 4 describes the methodology of the study. Section 5 contains and

analyzes the experimental results. Finally, Section 6 is the discussion section, and the future work section presents future research directions.

Numerous research exist in the literature about the detection of ocular disorders. In a work on eye illness classification utilizing CNN, Özbay introduced a CNN-based active deep learning (ADL) model to effectively differentiate and assess individual diabetic retinopathy lesions. During the preprocessing of the ADL system, the artificial bee colony (ABC) method is utilized to establish the threshold value for the segmentation of diabetic retinopathy images. The F1-score of the ADL-CNN model was 94.58% while utilizing the EyePacs dataset. Ou et al. examined a dual-stream interactive CNN model called BFNet for the classification of multi-label ocular diseases. They constructed a network with a CNN backbone module with residual blocks, a classifier module, a feature refinement module that enhances features, and a multiscale module that enriches the input data. The F1 scores of BFNet on the off-site and on-site datasets were 89.50% and 88.50%, respectively [5].

Another study included models including transfer learning, InceptionV3, VGG19, and ResNet50 for the identification of diabetic retinopathy (DR). The experimental findings indicated that the accuracy attained 60%. The acquired photographs originate from the Kaggle dataset for Asia Pacific Tele-Ophthalmology Society Diabetic Retinopathy Dataset (APTOS DR). In contrast to data parallelism (DP) strategies achieving a validation accuracy of 55.72%, the model parallelism (MP) strategy demonstrates faster convergence and a superior validation accuracy of 62.13% [6]. A different study suggested a hybrid model for ocular illness diagnosis by combining CNN and LSTM models. This model employed CNN to extract picture features and LSTM to discriminate among the extracted features. The AMDNet23 model demonstrated an accuracy rating of 96.50% [7].

A study on diabetic retinopathy indicates the utilization of deep convolutional neural networks for the rapid and automated categorization of dry and wet age-related macular degeneration. Performance data indicate that deep neural networks can identify dry visual impairment with more accuracy than wet visual impairment. When comparing the two models' classification abilities, the eighteen-layer ResNet model comes out on top. At each age related macular degeneration (AMD) stage, the ResNet model achieves an area under the receiver operating characteristic curve of 94% and 63%, respectively [8].

Nair et al. created an automated approach for evaluating color fundus images from the Ocular Disease Intelligent Recognition (ODIR) dataset. The primary goals are to improve the early detection of eye diseases and to reduce the time and effort required for clinical diagnosis. Merging and magnification are two preprocessing techniques used in tool-filtered pictures with a multi-label convolutional neural network (CNN). The images were later categorized into seven classifications using transfer learning. The efficacy of each design was evaluated with the Hamming Loss metric [9].

Lam et al. employed two distinct convolutional neural networks (lexNet and GoogLeNet) to implement transfer learning in their research. They employed Otsu's method to preprocess the data subsequent to its collection from two publically accessible datasets, EyePacs and Messidor-1. Furthermore, the authors utilized various boosting approaches to improve the model's efficacy. When it came to diabetic retinopathy (DR) picture classification, the proposed transfer learning models reached an accuracy of up to 74.5 percent [9].

In another proposed multimodal model for the detection of glaucoma in the eye, an accuracy of 97.2% was achieved by integrating support vector machine (SVM), LSTM and CNN. This model is capable of detecting complex data patterns and performing multi-class classification tasks [10].

Another study proposes a hybrid model for diabetic retinopathy diagnosis by considering the combination of CNN and LSTM. The one-hot encoding used in the models transforms each base into a matrix of the same size in the preprocessing stage. Each of the three convolution layers is embedded in a temporal distribution layer. The results show an accuracy of 96.3% [11].

In summary, the models used in the literature have various accuracy rates depending on the data sets. The data set greatly affects the accuracy of the model. In this study, a multimodal approach is proposed by integrating diabetic retinopathy images and related clinical disease diagnoses. The multimodal architecture achieves a higher accuracy rate compared to unimodal systems. Multimodal systems are promising for diabetic retinopathy detection in future studies.

26 Theoretical Foundations

26.1 CNN

CNN, also known as convolutional neural networks, is a type of deep learning model used to analyze data containing grid patterns, such as photographs. It is designed to automatically and adaptively extract hierarchies of spatial attributes from low-level patterns to high-level patterns. It improves categorization by automatically extracting features after training the model with raw pixel data of the image [12].

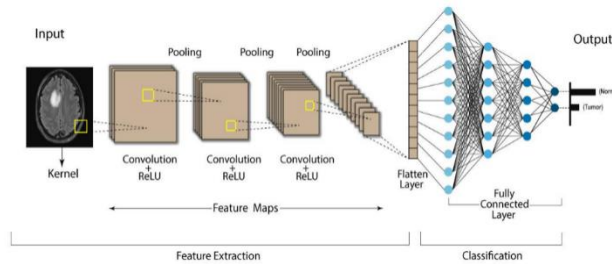


Fig. 1. Convolutional Neural Network (CNN) [13]

CNNs (see in Fig. 1) have exceptional efficacy in computer vision applications, including picture classification, object detection, and segmentation [14].

The analysis and interpretation of visual data is achieved through the detection of patterns within images. CNNs, akin to other models, undergo training and testing processes to learn and evaluate their performance. The forward propagation technique is employed during the training phase to process substantial amounts of data and make predictions. These predictions are then compared with the actual values to ob-

tain a result, and the model utilizes back-propagation to maximize accuracy. Following the training phase, the model undergoes a testing phase in which it processes data that was not included in the training dataset and is, thus, novel to the model. The testing phase serves to evaluate the model's generalizability and to ascertain the model's fit to the real world [15].

26.2 RNN and LSTM

The Long Short Term Memory (LSTM) method, a prominent form of Recurrent Neural Networks (RNNs) (refer to Fig. 2), is acknowledged for its capacity to process and comprehend sequential input with long-term dependencies. It is still difficult to initialize and optimize RNN-LSTM models correctly, which frequently compromises their performance and accuracy [16]. Despite these challenges, RNNs are a powerful neural network and the only form with internal memory. This positions RNNs as among the most promising networks currently employed [17].

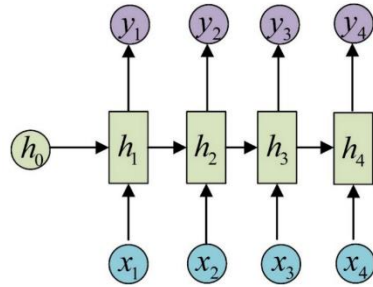


Fig. 2. Recurrent Neural Network (RNN) [18]

These networks have the capacity to process multiple data streams concurrently and have demonstrated a high degree of efficacy across a broad spectrum of subjects, despite the inherent challenges. LSTMs are comprised of chain modules that function as recurrent neural networks. These chain modules operate by providing the subsequent network with information regarding the output of the preceding network, thereby ensuring the persistence of information. Additionally, LSTM networks are capable of performing operations such as the addition or removal of information to a cell through structures referred to as gates, facilitating the transfer of information. The composition of LSTMs involves point-to-point multiplication and a sigmoid neural network, which enhances the number of control knobs and prevents information from being scrambled, ensuring optimal outcomes [19].

27 Multimodal Deep Learning Architecture Design

In this study, eye disease image data were modeled with CNN and clinical text data mapping related diseases were modeled with RNN. Both models are trained separately and their accuracy rates are obtained. Then, a CNN-RNN multimodal architecture was designed and the accuracy rate was compared with single-mode models.

27.1 Data Set

Shang Gong Medical Technology collected “real” patient data from hospitals and healthcare facilities in China to create the Ocular Disease Intelligence Recognition (ODIR) dataset. It consists of eight groups: normal (N), cataract (C), glaucoma (G), diabetes (D), hypertension (H), pathological myopia (M), age-related macular degeneration (A) and other abnormalities or disorders [20]. In this study, only diabetic retinopathy was used for classification. The relevant dataset incorporates both image data and clinical text data. Information such as patients' age, gender, right and left eye diagnoses is included in the clinical text data. In this study, only diabetic retinopathy disease is selected from the dataset, and the classification process is performed.

27.2 CNN Model with Image Data

In the related study, corneal images to be used for eye disease diagnosis were first subjected to preprocessing steps. Image data were integrated into 150x150 pixel dimensions and resized. The resized images were normalized in the range of 0-1 to optimize the learning process. The CNN model was constructed after allocating 80% of the data for training and 20% for testing. The model employed the Adam optimization algorithm and the binary cross-entropy loss function. The training outcomes of the CNN model are illustrated by the curves presented in Fig. 3.

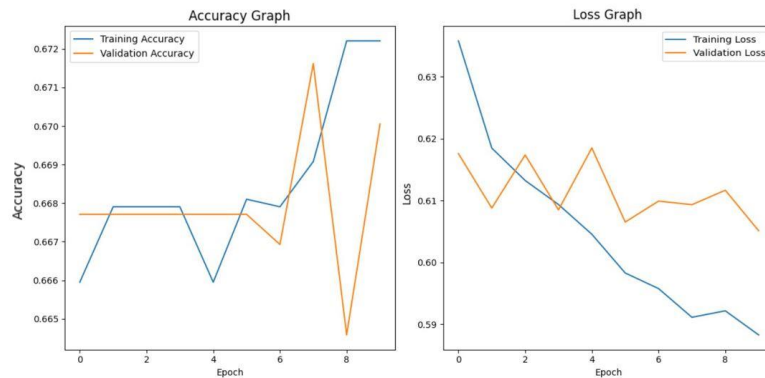


Fig. 3. Accuracy and Loss Curves for the CNN Model

Fig. 3 illustrates the accuracy and loss trajectories of the CNN model for both training and test datasets. The model exhibits greater variability in performance on the validation data compared to the training data. This may be due to the fact that the model learns some data faster. When we look at the loss values, the loss rates on training and test data show a significant decrease. In general, the CNN model shows an increase in accuracy and a decrease in the loss value during the training phase. After the training phase, predictions were made on the data and the overall accuracy of the model is 64.97%.

27.3 RNN Model with Text Data

The text data used in this study contains the disease diagnoses to which the image data in the corresponding dataset is mapped. Each image data has text data containing diagnoses in the right and left eye.

As with the image data, this column of the dataset was chosen for the text data as the classification process will be performed on diabetic retinopathy. For the text data, we focused on diagnostic values from the left eye. The text data was cleaned through various natural language processing steps and preprocessed to focus on meaningful words.

Each text was then broken down into words using Tokenizer and the words were then converted into numeric strings. These strings of numbers were formatted in a way that the model could understand. This was done to organize the input data for the model. A model based on RNNs was chosen to work with the text data. The dataset was partitioned into two segments: 80% for training and 20% for testing. The training methodology employed the Adam optimization algorithm and the binary cross-entropy loss function. At the conclusion of each epoch, the model underwent evaluation with validation data, while the training loss and accuracy metrics were consistently observed. Fig. 4 illustrates the accuracy and loss metrics of the model during the training process.

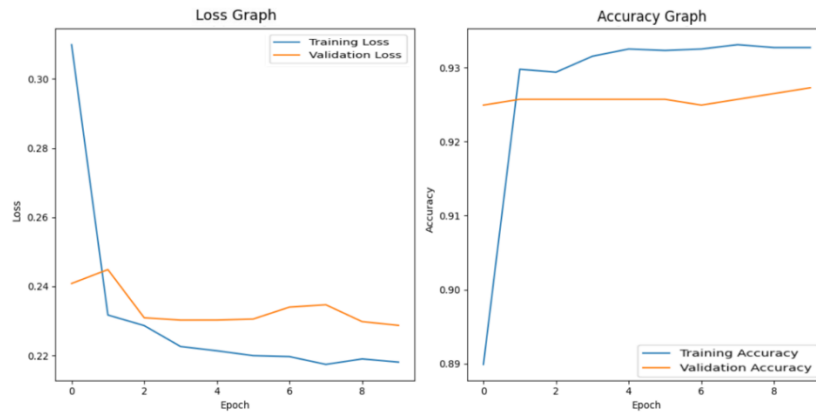


Fig. 4. Accuracy and Loss Curves for the RNN Model

Fig. 4 above illustrates the training and accuracy trajectories of the RNN model. The accuracy curve indicates a significant rise in training accuracy. This indicates that the model effectively learns from the training data. The validation accuracy, conversely, begins to stabilize after a specific juncture, suggesting that the model may enter an overfitting state during this training period. Looking at the loss curve, the loss values decrease significantly from the first stage of training. In general, the RNN model increased the accuracy and decreased the loss value during the training phase. After the training phase, predictions were made and the accuracy of the model was recorded as 63.94%.

27.4 Multimodal Architecture

In the design of the multimodal architecture, data containing medical disease diagnoses from the RNN model and image data from the CNN model are integrated. After processing the two types of data separately, the model combines them. The processed features of the text and visual data are combined to form a single vector. The final output layer of the model receives this combination. A single neuron forms the output layer, which uses a sigmoid activation function to perform binary classification. The Adam optimization algorithm and a learning rate of 0.0001 are employed to train the model. Performance is assessed with the binary cross-entropy loss function as an indicator of accuracy throughout training.

After the training process, the model showed a better result compared to unimodal systems, achieving an accuracy of 66.77%.

28 Experimental Analysis

The values shown in Fig. 5-6 provide a comparison of the multimodal and unimodal systems. The models are compared based on their accuracy rates throughout training. These accuracy rates indicate the adequacy and categorization success of each model on the respective data type.

The accuracy obtained from the CNN model is 64.97%, the accuracy obtained from the RNN model is 63.94% and the accuracy obtained from the multimodal architecture is 66.77%. Figure 5 shows that the accuracy rates of the models are close to each other, but the multimodal architecture still gives better results than unimodal architectures.

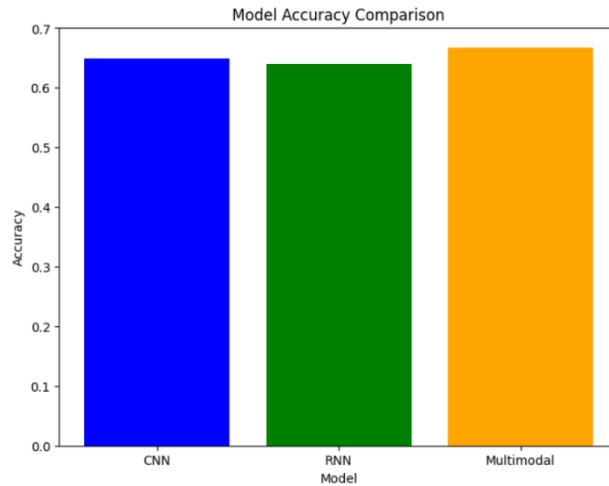


Fig. 5. Accuracy Comparison of Models

Fig. 6 clearly shows the difference in accuracy values between the architectures. Since the accuracy rates of the models are close to each other, this figure, in which the axis range is limited to 0.60-0.70, was also preferred in order to understand the difference

more clearly and to make more accurate comparisons. When the figure is analyzed, it is seen that the accuracy of the multimodal system is significantly higher than the uni-modal system.

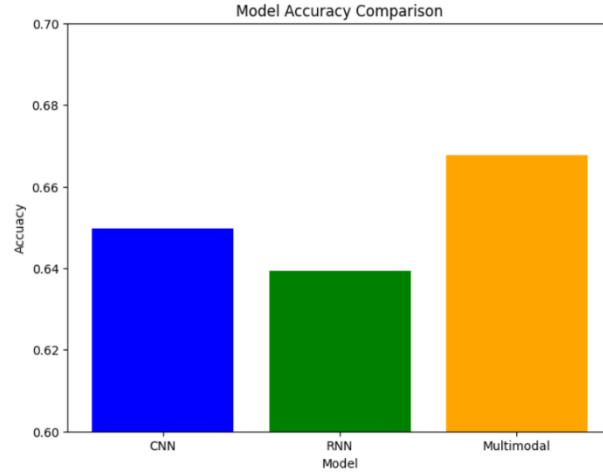


Fig. 6. Accuracy Comparison of Models in Limited Axis Range

29 Conclusion

In this study, a multimodal architecture is proposed for more accurate diagnosis of eye diseases. In the relevant dataset for diabetic retinopathy, CNN model is used to process image data and RNN model is used to process text data containing disease diagnoses. Both models were trained separately and accuracy metrics were calculated. The data from the models were integrated on a multimodal architecture. This architecture achieved a significantly better result than the single-mode architectures that were processed independently by going through the training phase and calculating the accuracy metric. This implies that wider learning and better classification performance is achieved through the integration of various types of data.

A significant discovery of the study is that the multimodal approach overcomes the disadvantages of unimodal approaches by skillfully exploiting the complementary nature of information in both text and image data. This proves to provide more comprehensive and reliable results, especially in medical applications.

This study shows that multimodal deep learning techniques provide a practical answer for analyzing medical data. By processing many types of data together, multimodal models improve the reliability of diagnostic and diagnostic procedures to higher accuracy rates. Future research is expected to be able to evaluate the potential of this approach for practical clinical applications and to more comprehensively examine how it affects various types of medical data and disease classifications.

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Digital Transformation and Managerial Management of Public Resources: A Systematic Review (2020-2024)

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Abstract. This study analyzes digital transformation in the managerial management of public resources between 2020 and 2024, aiming to identify emerging trends, assess technological and organizational challenges, and examine digital policies adopted to improve efficiency in public administration. The research aligns with Sustainable Development Goal 16 (SDG 16), specifically target 16.6, which seeks to strengthen effective, accountable, and transparent institutions. Methodologically, a systematic literature review was conducted following the PRISMA approach, selecting 30 articles from databases such as Scopus and Scielo. Studies on digitization in public management, resource optimization, transparency, and accountability were analyzed. The results reveal that digitalization has optimized fund allocation and increased public trust in institutions. However, challenges remain, including the lack of technological infrastructure, resistance to change, and the need for clearer regulations. The implementation of digital platforms and data-driven management has proven to be key strategies to address these obstacles. In conclusion, digital transformation is an essential tool for improving administrative efficiency and reducing corruption in public resource management. Strengthening inter-institutional collaboration and promoting policies that facilitate technological adoption are recommended. This study provides evidence on the importance of digital modernization in government administration and its impact on the transparency and efficiency of public management.

Keywords: Public administration, public finances, administrative efficiency, resource optimization, administrative management.

Introduction

Digital transformation and innovation in public administration are essential for ensuring efficient resource management, strengthening transparency, and enhancing accountability. The adoption of advanced technologies—including cloud computing, big data analytics, artificial intelligence, e-government platforms, blockchain for public finance, digital identity management systems, and cybersecurity

initiatives—improves service quality and optimizes the allocation of public resources, thereby fostering greater public trust. Digital platforms enable agile, real-time, data-driven decisionmaking, which in turn enhances governments' effectiveness in addressing economic, social, and environmental challenges (Van, 2024).

Process-based management in public administration, underpinned by digital transformation, is crucial for improving resource utilization efficiency. Digital tools help identify inefficiencies and structure activities in an organized and measurable manner, thereby promoting transparency and accountability. The implementation of digital platforms ensures more sustainable public administration and the proper allocation of resources for the benefit of citizens (Khanina et al., 2024).

This study aligns with SDG 16.6, which advocates for effective, accountable, and transparent institutions. It demonstrates how digital transformation enhances public resource management by improving efficiency, transparency, and accountability. The use of advanced technologies optimizes fund allocation, strengthens citizen trust, and reduces corruption, ultimately fostering a more equitable and modern public administration.

In countries such as Chile, digital public management faces challenges including excessive workloads and limited managerial participation in decision-making, which affect the effectiveness of educational processes. Digital transformation, when clearly defined and implemented through specific technologies, can bridge these gaps by facilitating more collaborative and efficient management practices. The integration of advanced technologies in education enhances resource accessibility and optimizes decision-making, ultimately leading to improved educational outcomes (Amushila & Bussin, 2021).

In the realm of human resource management, digitalization enables the personalization of talent management practices and enhances professional development. Digital platforms facilitate the recognition of individual employee needs, resulting in a more motivated and efficient work environment. The implementation of these technologies optimizes human resource allocation in the public sector, contributing to increased productivity and improved service delivery (Koo & Kim, 2024).

However, managerial pessimism and a lack of investment in corporate social responsibility in certain sectors hinder the implementation of sustainable strategies. The adoption of digital technologies can shift this mindset, aiding leaders in making more strategic, long-term decisions. A clearer definition of digital transformation and its associated technologies would further reinforce this argument by providing a focused analytical framework. This transformation is key to promoting policies that contribute to sustainable social and economic development, aligning organizational interests with community needs (Villarreal et al., 2021).

Managerial management and the execution of public resources face significant challenges—such as corruption and inefficiency—that limit their effectiveness. In a rapidly evolving global context, identifying best practices for optimizing resource allocation is crucial. Therefore, this study is guided by the following research questions:

- RQ1: What are the emerging trends in digital transformation for public resource management between 2020 and 2024?

- RQ2: What technological and organizational challenges do governments face in implementing digital transformation in public administration between 2020 and 2024?
- RQ3: What digital policies have countries adopted to enhance public resource management between 2020 and 2024?

The research is theoretically justified by integrating and synthesizing key theories on institutional effectiveness and performance, thereby contributing to the development of a broader conceptual framework. Practically, it provides policymakers with evidence-based tools to improve the efficiency and effectiveness of public policies by identifying challenges and opportunities in a critical context. Socially, it facilitates an analysis of the impact of public management on quality of life, promoting transparency, accountability, and citizen participation, thereby strengthening public trust and dialogue.

The research objectives are:

- To analyze emerging trends and practices in digital transformation applied to public resource management between 2020 and 2024.
- To evaluate the main technological and organizational challenges governments face in implementing digital transformation in public resource management from 2020 to 2024.
- To examine the digital policies and approaches adopted by different countries to improve efficiency in public resource management and execution between 2020 and 2024.

Methodology

A systematic review is a structured process for collecting and analyzing previous studies on a specific topic, using predefined criteria to ensure objectivity and comprehensiveness (Vizcaino et al., 2023). This method was employed in the present study to synthesize existing evidence and provide a clear and reliable overview of the current state of knowledge. By minimizing selection bias, it enabled the identification of patterns and gaps in the literature, thereby strengthening the study's arguments with a solid empirical foundation.

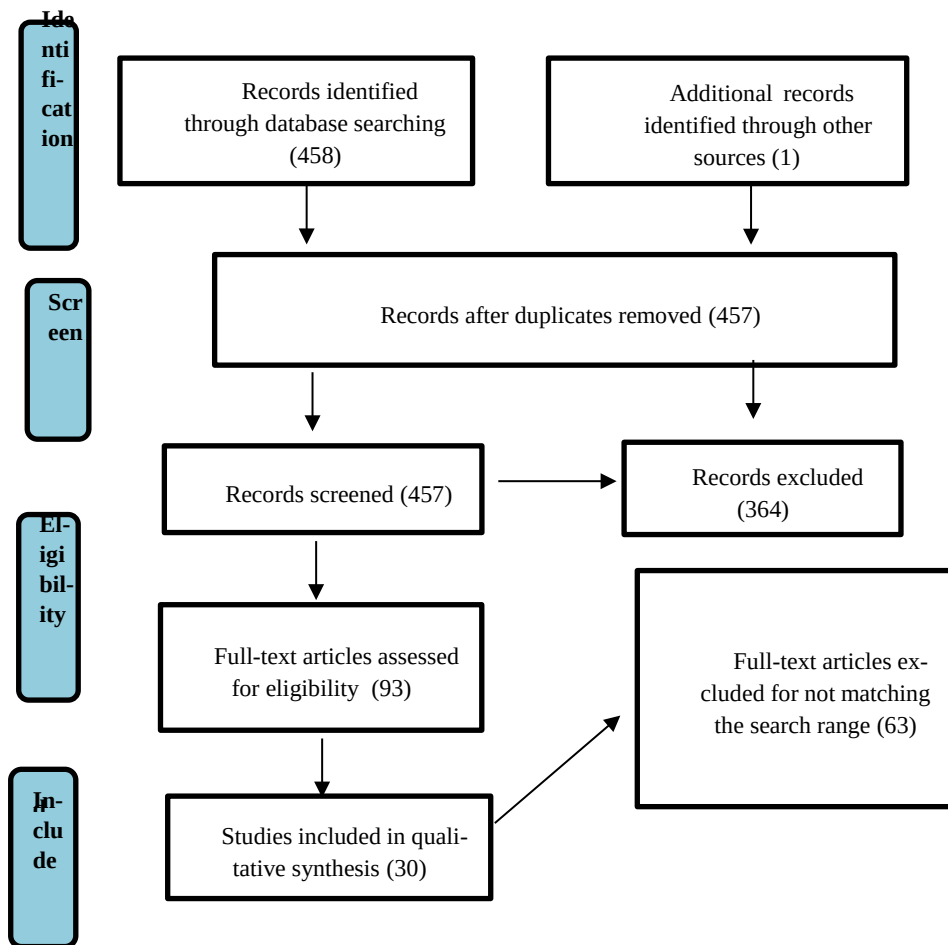
For this investigation, two primary databases were consulted: SciELO and Scopus. In SciELO, three records were initially identified, of which one study met the search criteria, while two full-text articles were excluded for not aligning with these criteria. In Scopus, a total of 457 records were identified; from these, 92 were selected for a more detailed review, and after a thorough screening of the full texts, 63 articles were excluded, resulting in 29 studies that satisfied the inclusion criteria. Overall, 30 articles were selected, providing valuable insights into key topics such as current trends and practices in public resource management, major challenges faced by governments, adopted policies and approaches, and the impact of efficient managerial practices on resource execution. Each of these studies contributed crucial elements to constructing a comprehensive perspective on public man-

agement and resources, which is essential for addressing the research objectives established at the outset of the study.

Figure 1 illustrates the flow diagram of the study selection process, clearly outlining the phases of identification, screening, and inclusion, thereby enhancing the transparency and reproducibility of the systematic review. Additionally, the ethical guidelines of César Vallejo University were strictly observed to ensure that the research was conducted with the utmost integrity and in compliance with ethical standards. These guidelines include respecting the rights of the authors of the reviewed articles, proper citation of sources following APA guidelines, transparency in the interpretation of results, and a commitment to data confidentiality when necessary.

To further ensure consistency and minimize bias, a standardized data extraction framework was implemented as part of the methodology. This framework included key fields such as the identification of the study (author and year), study design, population characteristics, keywords used in the search (e.g., public administration, egovernment, OR, AND), quantitative outcomes, and funding source.

Figure 1: PRISMA Method



Note: Adapted from the PRISMA method.

Additionally, Table 1 provides supplementary data by systematically detailing the numerical counts of records identified, those selected, the studies excluded, and ultimately the studies included. This integration of a flow diagram with a summary table enhances the verification of the methodological rigor applied during the literature selection process, offering a clear, step-by-step depiction of how the final sample was derived.

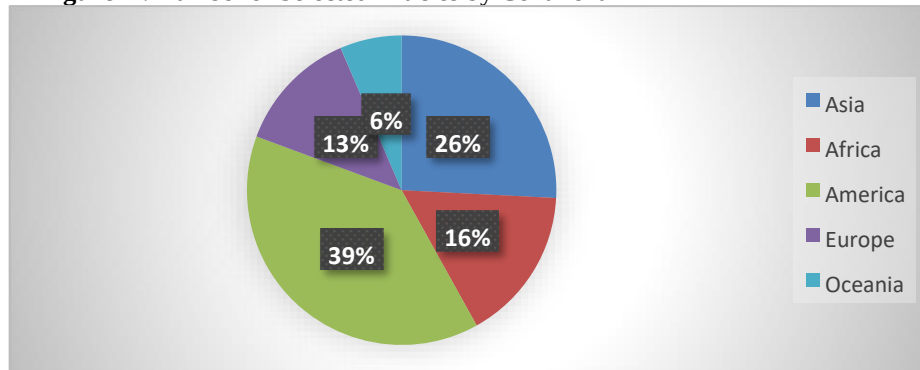
Table 1 : Databases and Data Collection Stages

Database	1. N° Items Identified	2. N° Items Selected	3. N° Full-text Articles Excluded (out of scope)	4. Items cluded
Scielo	3	1	0	1
Scopus	457	92	63	29

Note: Adapted from the PRISMA method.

Figure 2 illustrates the distribution of the reviewed articles based on their continent of origin. The data reveal that the Americas account for the largest share, comprising 36% of the total articles, followed by Asia at 27%. Africa represents 17% of the analyzed studies, Europe contributes 13%, and Oceania has the smallest representation with only 7%. These results suggest that a significant proportion of the selected articles originate from the Americas and Asia, which may reflect a higher research output or greater accessibility to studies in these regions.

Figure 2: Number of Selected Articles by Continent

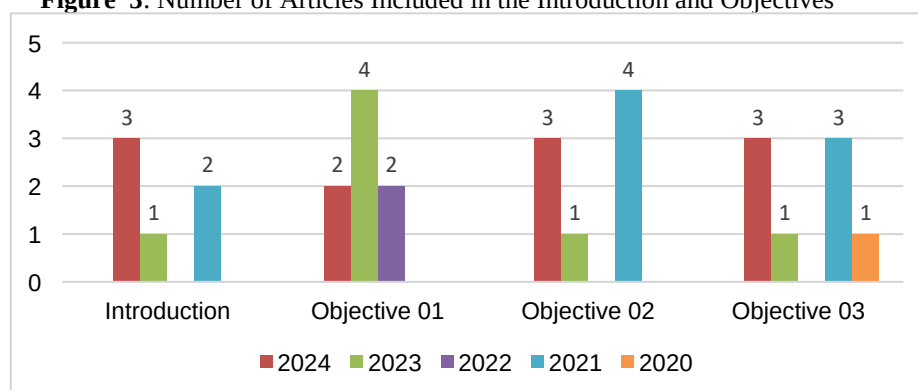


Note: Prepared by the researchers.

Figure 3 illustrates the distribution of articles utilized in the introduction and across the three research objectives, categorized by keywords such as public administration, public finance, administrative efficiency, resource optimization, and managerial management. In the introduction, six articles were employed to establish a general context for digital transformation in public management. For Objective 1, eight articles were selected to underscore the evolution of technologies and their applications in public administration. Objective 2 is substantiated by eight articles that address both technological and organizational challenges, providing a critical analysis of the primary obstacles encountered by governments during this process. Finally, Objective 3 is supported by seven articles that examine digital policies and approaches adopted by various countries, thereby reflecting international strategies aimed at enhancing the efficiency of public resource management. Collectively, each objective offers a critical perspective on digitalization in public

administration, ensuring that the analysis is both comprehensive and robustly supported by empirical evidence.

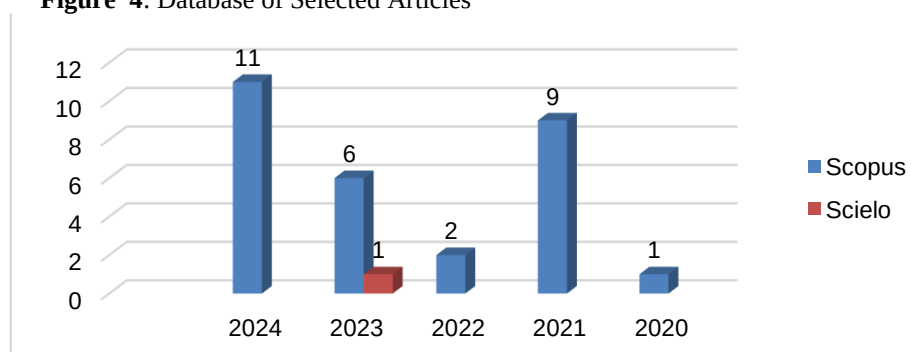
Figure 3: Number of Articles Included in the Introduction and Objectives



Note: Prepared by the researchers.

Figure 4 illustrates the percentage distribution of scientific publications by continent. Asia accounts for 66% of the total, reflecting its leading role in research output—likely due to its advanced academic infrastructure and substantial investments in research and development. Africa contributes 13%, emerging as a notable region in scientific production. Europe represents 10% of the publications, while the Americas and Oceania contribute 8% and 3%, respectively. This distribution highlights significant geographic disparities in research activity, suggesting that future efforts might focus on enhancing research capacity and visibility in underrepresented regions.

Figure 4: Database of Selected Articles



Note: Prepared by the researchers.

Results and Discussion

This chapter presents the findings of the study on digital transformation in public resource management between 2020 and 2024, structured around three key objectives. The results are detailed below along with a critical interpretation that acknowledges the study's limitations without overstating its significance.

3.1 Analysis of Emerging Trends and Practices in Digital Transformation Applied to Public Resource Management between 2020 and 2024.

The first objective aimed to identify emerging trends and key digital practices in public resource management during the specified period. The findings indicate that digital transformation has significantly improved efficiency and transparency in public administration. Heaton et al. (2022) emphasize the role of dynamic capabilities in the public sector, which enhance adaptability to rapid changes—crucial for resource optimization. Similarly, Bamba and Somé (2023) demonstrate that digitalization has improved project evaluation within UEMOA, leading to more sustainable public investments.

However, Darby et al. (2023) and Al-Assaf et al. (2024) report that challenges persist in integrating regulatory frameworks and ERP systems, particularly in sectors such as healthcare, where poor coordination and inefficient management hinder optimal resource use.

Regarding technological innovation, Salazar-Adams and Ramírez-Figueroa (2024) and Wali et al. (2023) identify advancements in areas such as waste management and climate change adaptation. Advanced technologies, including real-time monitoring systems, have proven essential for enhancing project sustainability. Additionally, Han and Wang (2022) highlight how autonomous management, combined with digital accountability, has promoted more efficient resource use—a trend also observed in NGOs, where enhanced transparency has strengthened donor confidence (Hengevoss, 2023).

These findings suggest that digitalization has positively impacted efficiency and transparency in public management, though significant challenges remain, particularly concerning regulatory integration and technological system adoption.

3.2 Evaluation of the Main Technological and Organizational Challenges Faced by Governments in Implementing Digital Transformation in Public Resource Management from 2020 to 2024.

The second objective focused on identifying the technological and organizational challenges that governments encounter in implementing digital transformation. The results reveal that governments face considerable difficulties in this process.

Todesco and Cardoso (2021) highlight poor coordination among government levels and inadequate infrastructure in Brazil, which limit project execution. Similarly, in Spain, Sarria-Pedroza and Fernández-Guadano (2021) note that insufficient collaboration between public agencies and private enterprises hinders effective

tive project implementation—a problem that could be mitigated through digital platforms enabling continuous monitoring and stronger public-private partnerships.

Furthermore, Erfani et al. (2023) and Tuggle et al. (2024) explore specific obstacles in U.S. transportation projects and public governance, respectively. The lack of digital tools for risk management and resistance to change within governmental structures are identified as key barriers. Additionally, Dimitriadis (2024) points out that in conflict-prone regions such as Nigeria, corruption and insecurity severely impact resource allocation efficiency, exacerbated by institutional distrust and the absence of digital oversight mechanisms.

Despite these obstacles, Tengblad and Oudhuis (2024) suggest that in Sweden, digital platforms could help mitigate ethical dilemmas related to efficiency and equity in resource allocation. Similarly, Acevedo and Ariza-Buenaventura (2021) and Muhtar et al. (2021) emphasize that in Colombia and Indonesia, unclear regulatory frameworks and ineffective monitoring systems remain significant challenges to accountability.

These results highlight the inherent difficulties in implementing digitalization, particularly in coordinating across government levels and overcoming infrastructural limitations, as well as addressing organizational and cultural barriers.

3.3 Examination of Digital Policies and Approaches Adopted by Different Countries to Improve Efficiency in Public Resource Management and Execution between 2020 and 2024.

The third objective analyzed the digital policies implemented by various countries between 2020 and 2024 to enhance efficiency in public resource management. The findings reveal a growing interest in digitalization as a strategy to improve efficiency and transparency in governance.

Roh et al. (2020) highlight that South Korea has made significant progress through digital regulatory frameworks that optimize public resource distribution. Despite challenges such as corruption, digital technologies remain essential for improving public administration efficiency. In Saudi Arabia, AlMunifi and Almutairi (2021) emphasize the importance of leveraging past experiences via digital platforms, thereby enhancing project planning and monitoring.

Likhacheva and Stepanov (2021) and Magued (2023) explore how Russia and developing countries are adopting digital approaches to manage resources in remote areas and foster innovation in the public sector. These policies have strengthened public-private cooperation and sustainability, although geopolitical and economic factors continue to pose challenges. In Australia, Buick et al. (2024) demonstrate that the digitalization of flexible work in the public sector enhances efficiency and employee satisfaction, contributing to greater administrative effectiveness.

Nevertheless, digital approaches also face challenges. Fana and Goudge (2024) indicate that in South Africa, austerity policies may create tensions with labor unions, complicating the implementation of digital reforms. Finally, McCannon (2021) and Wang et al. (2024) underscore the importance of digital transparency

and accountability mechanisms, particularly in contexts where inadequate oversight affects resource distribution efficiency.

These findings suggest that while many countries have adopted digital strategies to enhance public resource management, distinct challenges persist based on each country's socio-political and economic context. The successful implementation of digital policies depends on balancing advanced technologies with contextual factors and overcoming structural and cultural barriers.

Conclusions

Based on the analysis of the first objective, it is concluded that there is an increasing emphasis on improving resource management through the use of modern technologies and enhanced process efficiency. Transparency and interinstitutional collaboration emerge as essential elements for sustainable public management, while financial sustainability and the prioritization of strategic projects are key to resource optimization. It is recommended that future research further explore the implementation of innovative technologies that reinforce these aspects and that training programs on governance and sustainability be promoted for public administrators.

Regarding the second objective, the main challenges in digitalized public management include a lack of coordination between government levels and inefficiencies in resource allocation. Resistance to change and inadequate strategic planning further hinder the implementation of effective policies. Overcoming these challenges requires improvements in governance and strengthened interinstitutional collaboration. It is recommended to establish strategic planning mechanisms with multisectoral participation and to design integrity and control programs that foster public trust and prevent corruption.

For the third objective, it is concluded that public policies must balance transparency with the flexibility necessary to adapt to local realities. Persistent barriers such as bureaucracy and the lack of digital infrastructure continue to pose significant challenges. The success of these policies depends on flexible reforms and the active participation of stakeholders. It is recommended to promote reforms that prioritize process simplification and investment in key technological infrastructure, along with citizen participation platforms to adapt public policies to local needs through digital governance tools.

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The Role of Social media in Sharing Green knowledge in Small and Medium Enterprises of Kuwait: A Qualitative-Thematic Analysis.

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Abstract. In achieving the Sustainable Development Agenda comprising of sustainable development goals, businesses, especially SMEs, have to play a central and significant role. SMEs, which contribute the majority of value creation and employment, need to change their business practices. However, SMEs can align their business practices with sustainability in response to increasing demand due to sustainable consumption. Although government and other institutions are playing an active role in enhancing awareness about sustainability, the role of SMEs is being overlooked. SMEs, being in close proximity to consumers and other stakeholder networks, can play a significant role in promoting information and awareness with regard to sustainability. Thus, the purpose of present research is to explore the role of SMEs in promoting green knowledge through the widely used medium of social media. The current study, using a qualitative-explorative research design, collected data using semi-structured interviews with managers working in social media at SMEs in Kuwait. The thematic analysis of the data is proposed to be guided by Actor-Network Theory as a theoretical paradigm and its underpinnings. The initial results, based on 13 interviews, suggest an important role of education, government regulation, and with cautionary role of greenwashing. Furthermore, the results will be refined using the data from more participants and rigorous coding procedure. The research aims to provide in-depth knowledge on the issue of social media driven knowledge sharing by SMEs for sustainable consumption.

Keywords: Green Knowledge, SME, Social media, sustainability .

1 Introduction

The United Nations (UN) developed and adopted the 2030 Agenda for Sustainable Development [1]. The agenda consists of 17 major sustainable development goals (SDGs), which address the common global challenges, ranging from alleviating poverty and hunger to improving the overall quality of life on earth and sea. This 2030 agenda for sustainable development was subsequently adopted and ratified by all

members of the UN [2]. Although the SDGs are both ambitious and much needed, working and achieving these goals require both investment by governments and international organizations, such as the UN, and World Bank, as well as policy and regulatory changes [3]. Furthermore, it also requires much-needed cooperation from both individuals and businesses [4].

In this regard, cooperation from businesses is of critical importance [5]. Businesses can play an important role in supporting UN, governments, and other organizations to achieve such SDGs [6]. Secondly, an important element of SDGs addresses the problem of climate change and pollution [7]. The data suggests that value creation activities, which refer to the producing products and services by businesses, have both direct and indirect impacts on most climate change problems [6]. Thus, addressing the climate change component of SDGs requires comprehensive change and cooperation from businesses [5]. Additionally, sustainable value driven activities can play significantly important role in achieving SDGs [6]. Thus, it can be argued that businesses can play a significant role in achieving the 2030 sustainable development agenda through changing their value creation practices and aligning them with the objectives of SDGs [7].

The data suggests that Small and Medium Enterprises (SMEs) also play a significantly larger role in value chain activities at both local and international levels [8]. For example, data suggests that SMEs makes up 99.8% of total enterprises in the European Union [9], 99.9% in United States of America (USA) [10], and 90% in Gulf Cooperation Council (GCC) countries [11]. Furthermore, data also suggests that SMEs contribute almost half of value addition globally [12]. These figures clearly emphasize the importance of SMEs within larger context of business contributions towards the SDGs. Thus, it can be argued here that SMEs need to align their value chain activities with the SDGs.

Although it is important for SMEs to align their value chain with the SDGs, equally important are the sustainable consumption practices, which refer to the attitudes and intentions of consumers to buy and consume sustainable products and services aligned with SDGs [13]. Sustainable consumption can result from a comprehensive shift in behavior and patterns of consumption [14]. Further, to drive such shift in behavior and patterns of consumption, the role of knowledge towards environmental, social, and economic issues with respect of sustainability becomes crucially important [15]. Such kind of knowledge can help individuals develop awareness and understanding, which are necessary to change attitude and patterns of consumption [16]. SMEs not only provide necessary information and awareness but also bridge the awareness-action gap, as SMEs can effectively leverage their close and strong community relationships and influence [17]. Furthermore, social media platforms, as a means of SMEs' communication with consumer and community, can help to publish educational content, connect with a larger audience, and assist in meaningful conversations about sustainable practices [18]. By using social media to share success stories and real-world examples of sustainable consumption, SMEs can drive behavioral change in addition to increasing awareness of environmental challenges [19]. Alt-

though social media and sustainability are explored in the existing literature, little is known about how SMEs can raise awareness of green products and services. More specifically, since raising awareness may require sharing the cutting-edge scientific proven knowledge, SMEs can play an important role in disseminating such knowledge effectively. Thus, in order to close this gap, this study utilized qualitative methods, particularly interviews with SME managers and owner, to investigate their viewpoints, approaches, and difficulties while using social media to spread green information and knowledge with the aim of promoting sustainable consumption. By doing this, it offers a better comprehension of how SMEs actively encourage sustainable and ecologically conscious customer behaviour. This strategy will enhance knowledge of SMEs' participation in the shift to a greener economy by offering insightful information about how they use digital platforms to encourage sustainable consumption and raise environmental consciousness. The article proceeds with a brief overview of literature, research methods, and conclusion.

2 Theoretical review:

Green knowledge is considered to be an important research and theoretical construct in sustainability research [20]. Various studies have empirically tested and validated the role of green knowledge in key elements such as green innovation [21], green performance [22], supply and value chain [23], and various others [24]. Theoretically, green knowledge can be described and defined as awareness, understanding, and information related to broader environmental, social, and economic issues, directly addressing the broader sustainable development agendas [25]. Green knowledge also encompasses knowledge and information regarding key issues such as the efficient use of resources, energy conservation, waste management, sustainable production and consumption, and eco-friendly technologies [26]. Green knowledge, due to its fact-based information, can also significantly empowers individuals and organizations to undertake the decisions aimed at promoting environmental sustainability and achieving the SDGs [27]. Therefore, it can be confidently argued that green knowledge significantly promotes the transformation of value chains from traditional to sustainable, as well as shifting consumption patterns that continuously support such a transition of value chains [21].

Green knowledge, as opposed to general environmental awareness, which concentrates on identifying environmental problems, includes practical insights and solutions that can help people and organizations adopt sustainable behaviors [26]. It also differs from green marketing, which primarily aims at promoting eco-friendly products to consumers. Instead, green knowledge empowers decision-making for sustainability-driven transformation, such as shifting from traditional to sustainable value chains [21] and integrating long-term ecological and economic strategies [27].

Although green knowledge has been widely researched and proven to be very important in key aspects such as green innovation [21], green performance [22], and

supply and value chains, [23], two key research gaps are highly visible in the existing academic literature. The first research gap pertains to the role of knowledge (green) in shifting attitude, intentions, and behavior patterns that promote sustainable consumption. The second research gap pertains to the role SMEs play in promoting green knowledge, with the aim to garnering support for their green value chain activities.

Marketing theories [28] and others, such as theory of planned behaviors (TPB) [29], have concluded the role of attitude in adopting certain behaviors [30]. This stream of research has also suggested that, in order to build such attitudes and behavioral intention, awareness plays an important role [31]. In the context of sustainable consumption, various studies have highlighted the role of environmental and sustainability awareness in influencing consumer behavior and decision-making [32]. It can be concluded that increasing knowledge and information about the issues addressed in the SDGs can lead to the development of positive attitudes towards overall sustainable development agendas [33]. Further, such knowledge and information on consumption aspects, such as sustainability, resource conservation, and eco-friendly choices, significantly leads to changing behavioral patterns [32]. However, the mechanism through which such knowledge is both produced and shared with consumers and other stakeholders is greatly missing from the existing academic literature [35]. According to the general theory of knowledge, sharing knowledge within an effective ecosystem can create a ripple effect, reaching a wide audience [36]. The widespread dissemination of such knowledge can enhance awareness, which in turn, can lead to changes in attitudes and consumption patterns [37]. However, insights regarding such mechanism of green knowledge sharing in a modern ecosystem of social and digital media are limited and need comprehensive exploration [35]. Thus, addressing this gap may provide insights that can positively contribute to the sustainable consumption patterns.

Additionally, SMEs can be more interested in and positively affected by the widespread existence of green knowledge in society, as increasing exposure of such knowledge can create a demand for sustainable products and services [38]. Thus, it can be argued that SMEs, due to their close network proximity with consumers, can play a role in sharing such green knowledge with both consumers and stakeholder, with the aim of developing positive attitude [39]. In this context, larger corporations are often credited for their sustainability initiatives and public awareness campaigns [40]. However, SMEs, in the age of digital and social media, play a more specific and effective role as compare to larger corporation's public awareness campaigns [38]. SMEs have distinct benefits that may be used to effectively promote sustainable practices, such as strong community links and a more individualized approach to consumer interaction [41]. As argued earlier, SMEs may be more motivated to share green knowledge, as doing so can have the immediate effect of demand creation [40]. Although arguments have been made, limited studies have examined role of SMEs in sharing green knowledge with the aim of influencing the consumer behavior and gaining support for their eco-friendly value chain activities. Closing this gap can reveal important information about how SMEs increase consumer loyalty, raise environmental awareness, and make their green activities seem more credible

3 Research methods

The aim of present research is to qualitatively explore the role of SMEs in sharing green knowledge with consumers and key stakeholders, such as consumers using social media platforms. Since insight on this perspective of knowledge sharing is limited regarding SMEs and social media as a tool, the present research is proposing a qualitative and explorative research methodology using interpretative paradigms. The qualitative method will be effective in investigating the ways in which SMEs use social media to disseminate green knowledge, comprehending the obstacles and enablers in this process, and evaluating its influence on encouraging sustainable consumption behavior among their target audiences. Using an interpretive approach, this research will concentrate on comprehending SME managers' perceptions and experiences about social media use and knowledge sharing in the context of sustainability [42], [43].

3.1. Data Collection:

Since the current research is aiming to explore the role of SMEs in green knowledge sharing using social media to influence sustainable consumption practice, the research has employed the qualitative data collection instrument, i.e., semi-structured interviews. More specifically, the present study has aimed to collect data using semi-structured interviews from managers working at SMEs in Kuwait [44]. Since research is an ongoing process, table 1 depicts the profile of managers who have been targeted for data collection so far. The table also shows the industry of SMEs owner, their timeline of establishment, and their social media following. Since semi-structured interviews are aimed at collecting the experiences, viewpoints, and insights of the managers about the issue of green knowledge sharing, data saturation was determined when no new themes, insights, or variations emerged from additional interviews, indicating redundancy in responses [45].

Table 1: Participant Profile

Partici- pant ID	Posi- tion	Social Media Follow- ers	Industry	Gen- der	Estab- lished
P1	SME Owner	1k – 5k	Manufactur- ing/recycling	Male	Since 2020
P2	SME Owner	6k – 10k	lifestyle products	Male	2020
P3	SME Owner	1k – 5k	Consulting agency	Male	2022
P4	SME Owner	11k – 15k	lifestyle products	Male	2020
P5	SME Owner	31k – 35k	Consulting agency	Fe- male	2019

P6	SME Owner	16k – 20k	Sustainable building consulting	Fe- male	2018
P7	SME Owner	31k -35k	Food industry	Male	2021
P8	SME Owner	16k – 20k	Environmental Con- sulting	Fe- male	2018
P9	SME Owner	6k -10k	Fashion industry	Male	2021
P10	SME Owner	1k – 5k	Health and beauty	Fe- male	2017
P11	SME Owner	41k – 45k	Agriculture	Male	2018
P12	SME Owner	21k – 25k	lifestyle products	Fe- male	2022
P13	SME Owner	6k – 10k	Manufacturing/recycling	Male	2018

The current study has employed the purposive sampling strategies to collect the data from SME managers who have experience in social media usage as tool of strategy and sustainability practice [46]. This semi-structured nature of the data collection tool has assisted us to be both specific to the context of social media use in green knowledge sharing and to ask open-ended questions, which are intended to delve into important topics, including the kinds of green knowledge shared and exchanged, the usage of social media as a platform for knowledge sharing, and the possibilities and problems encountered by SMEs in advancing sustainable practices. Appendix 1 illustrates the interview guide that has been used to undertake the interviews [47].

3.2. Data Analysis:

The current research recorded and maintained the audio file of the interviews with permission and consent from all participants. Afterwards, the interviews were further transcribed utilizing best practices, such as resolving the verbatim, which can help us ensure the proper contextualization of the data. The research has employed thematic analysis, which is a widely used qualitative research technique, in order to examine the data after it has been transcribed [48]. This thematic analysis will make it possible to find, examine, and understand patterns or themes in the data, offering insights into the main variables affecting SMEs' dissemination of green information and the function of social media in this process [49]. The themes are generated based on the coding procedure, which entails identifying a core concept and construct in the data and connecting such code to develop meaningful patterns (themes) [49]. The research has employed the actor-network theory (ANT) to develop the code and themes from the collected data. The ANT, as underpinning theory, will help to examine the relationships between SMEs, managers, social media, and green information. Therefore, ANT

will be supporting this study [50]. It makes it possible to comprehend how these actors—both human and nonhuman—affect and mold the network's knowledge-sharing and sustainable practicepromoting processes.

The present study, in order to analyze the transcribed interview data, has employed NVivo 15.0 software. The NVivo software is considered to be an effective tool for qualitative data analysis with the help of data organization, coding, and visualization. We employed a systematic coding process using NVivo to ensure consistency in thematic analysis. Inter-coder reliability was assessed, and detailed reporting on coding techniques and reliability measures will be provided in the final stage [51]. Finally, the study will interpret the codes and their themes to comprehend the underlying trends and relationship between SMEs' usage of social media for sharing green information and sustainable consumption using ANT [52]. The current research's intention of employing the ANT theory is based on the idea that SMEs, due to their closer network proximity with both consumers and related stakeholders, can play an important role in acquiring and disseminating important knowledge regarding the SDGs.

We intend to carry out further interviews, bringing the total to about 32, in recognition of the sample size concerns. Our findings will be stronger as a result of this growth, which will enable a wider variety of viewpoints from other SME sectors. The data saturation concept informs our choice, making sure that no noteworthy new information is discovered prior to the end of data collecting. Furthermore, we want to consider input from the research community at every stage, improving our strategy in response to helpful academic criticism in order to enhance the study's contributions.

4. Analysis of the data:

Since the present research is an ongoing process, this study has started to collect and analyze the data. Table 1 shows the participants profile of 6 initial interviews conducted for the current study. The section provides initial analysis of interview data undertaken with managers managing the social media and are interested in the sustainability aspect of the SMEs business.

4.1. Data preparation:

This research, by following the best practices, has prepared the interview data using the proper transcription of each of the interviewees' responses using verbatim. Following the transcription, Microsoft word files has been prepared for each interviewee response separately. Each of the file has been labelled as '*participants*' along with a number. All six files have been uploaded to NVivo software for further in-depth thematic analysis.

4.2. Coding procedure:

The study has employed the open coding procedure to inductively allocate a code to the emerging themes and concepts from the interview data. The interview transcripts were methodically examined line by line, and such codes were assigned to pertinent phrases or sentences. Based on commonalities and trends found in the data, these codes were further categorized into more general groups, which have helped us to develop and identify important themes about the way SMEs may share green knowledge using social media. Table 2 shows the results of codes developed with regard to the interview data analyzed.

Table 2: Initial Codes developed				
S.No	Code	Description	No. of references	Files
1.	Education	The code capture the theme of the role of educational initiatives in promoting sustainable practices	22	6
2.	Government Support and Regulation	The code capture the role of Policies and government intervention in the influencing green practices	26	5
3.	Greenwashing	The code capture the concerns regarding to practice promoted as green, and ecological friendly but it's actually otherwise.	5	1

4.3. Content analysis of codes

Figure 1 shows the content quantity analysis of codes generated as a result of open coding procedure. The results have clearly highlight that opportunities for collaboration exists, which can help SMEs enhance their performance towards the SDGs. The results strongly suggest the role of social media in spreading awareness and information with regard to sustainability, and need to implement the sustainable development agenda. Further, an interesting aspect of the results is said to be the role of laws, government support, and formal education, which can significantly help in the provision of knowledge regarding sustainability related issues. The results have also shed light on the cultural origins and orientation towards sustainability. Such dynamic interaction emphasizes that sustainability is a socio-political undertaking that calls for concerted effort from institutions, communities, and individuals. Therefore, concerted efforts using all such key issues are necessary. Finally, an important insight have also been developed with regard to greenwashing, and efforts are needed to tackle such important issue by corporations.

4.4. Cluster analysis of codes:

The results of cluster analysis have revealed interrelations among topical codes, which helped our understanding with regard to the SMEs activities of sharing green knowledge through social media for sustainable consumption promotion. The results have revealed an interesting pattern and themes of education and awareness which address public participation and knowledge transmission as key instruments to develop a behavioral pattern, consistent with sustainability objectives. It can also be employed as a tool to counter false information and promote moral behavior. Furthermore, an important role of social media is presented, which tends to increase and

enhance awareness and behavioral patterns. Finally, government support and regulations are closely related to greenwashing and social media, suggesting that government support and regulation can provide significant support for social media awareness activities undertaken by the SMEs. The streamlining of regulatory practices can also lead to countering any dishonest tactics that could potentially negatively impact behavioral patterns. Thus, the dual function of social media lies in its role in providing education and awareness, and countering any such misconduct like greenwashing.



Figure:1 The Thematic and content analysis of codes.

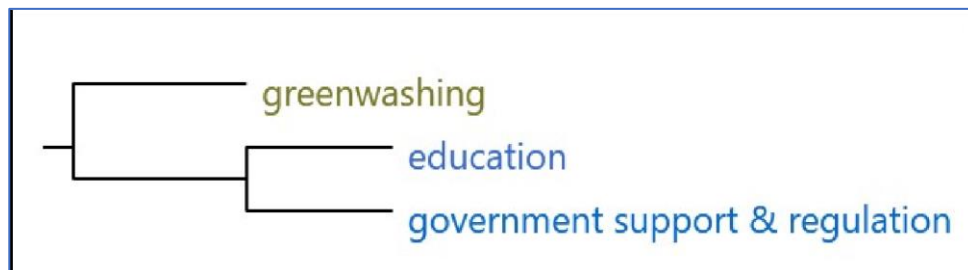


Figure:2: Thematic evolution of codes

4.5. Discussion

The cluster analysis's findings have revealed complex relationships between different thematic codes. The results suggested that fundamental themes such as awareness and education are important in influencing consumer behavior to make more envi-

ronmentally friendly decisions. The importance of social media, as a vehicle for consumer awareness, has emerged as a significant contributor, as one of the interviewees argued that *"We use social media not just to promote our products but to help our customers understand the environmental impact of their purchases. It's a way to raise awareness and foster responsibility"* (Interviewee 3). Thus, SMEs, using social media by providing informative content, can foster a deeper understanding of sustainability issues, which can drive consumer behavior toward more sustainable patterns.

Furthermore, the findings suggest that although social media is being used as a tool for raising awareness, it can also be used as a tool for increasing greenwashing, as one respondent has argued that, *Social media gives us the power to provide information quickly. But, due to social media being a low cost medium of advertising have also allowed actors to promote product which actually don't possess any component of sustainability*" (Interviewee 6). This emphasizes how crucial social media is in upholding credibility and openness, establishing it as a powerful tool for dispelling myths and encouraging moral consumption.

The influence of government assistance and regulation on SMEs' behavior and usage of social media to promote sustainability was another important issue found in the research. The foundation for what is considered appropriate in terms of environmental claims and green marketing is mostly established by government rules and regulations. According to one SME manager, *"Regulations are essential for ensuring that we're all on the same page. Without clear guidelines, there's always a risk of falling into greenwashing. Government support helps validate our sustainability efforts and ensures we don't mislead consumers"* (Interviewee 7). The danger of greenwashing, in which businesses deceitfully present themselves as environmental friendly in order to lure customers, can also be reduced by government regulations. Regulations may encourage ethical marketing and increase customer trust in the veracity of sustainability promises by establishing explicit standards and guidelines.

Furthermore, our study indicates that government rules might help SMEs use social media as a more effective tool if they are well-supported and simplified. One respondent mentioned that *"The government's role in enforcing sustainability standards makes it easier for us to communicate our green initiatives without fear of backlash. If everyone is adhering to the same rules, we can use social media with confidence to spread our message"* (Interviewee 2). In conclusion, social media's role in promoting sustainability becomes more evident: it acts as a forum for public education on sustainability as well as a weapon against false information and greenwashing. SMEs may actively interact with customers on social media and share their knowledge on various sustainable initiatives. Furthermore, government regulations are essential to guaranteeing the legitimacy of these initiatives and holding businesses responsible for their environmental promises

5. Conclusion:

The current study has attempted to explore the role of SMEs in the larger context of sustainability initiatives. In the present research, by problematizing the need for sus-

tainable business models which can help to create demand for green products and services, it has been argued that role of green knowledge is very important. It has been further argued that SMEs, due to their close proximity with consumers and other key stakeholders, can play a highly significant role in disseminating green knowledge and information, which can serve as a basis of decision-making by consumers to change their consumption patterns toward sustainable and green products and services. Due to the lack of available insights in existing academic literature, the present research is attempting to employ explorative research to uncover and explore the role of SMEs in green knowledge sharing that can influence the sustainable consumption. This research, by using data collection method of semi-structured interviews, which allows for uncovering in-depth opinions, views, and insights from participants, has attempted to examine such role of SMEs in green knowledge sharing with managers. The subsequent and initial analysis of the data, based on the Actor-Network Theory-guided thematic framework using NVivo software, has allowed us to uncover the important role of education and government support with the cautionary role of greenwashing. The initial analysis points to these factors playing an active and overlapping role with both social media and sustainability. The initial analysis and conclusions have provided impactful insights with regard to the role of SMEs employing social media to advance sustainability and the difficulties they encounter in doing so. These findings will be extended further, with more interviews, data, rigorous thematic analysis, and conclusions to explore the use of social media in knowledge sharing for sustainable behaviors by SMEs.

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