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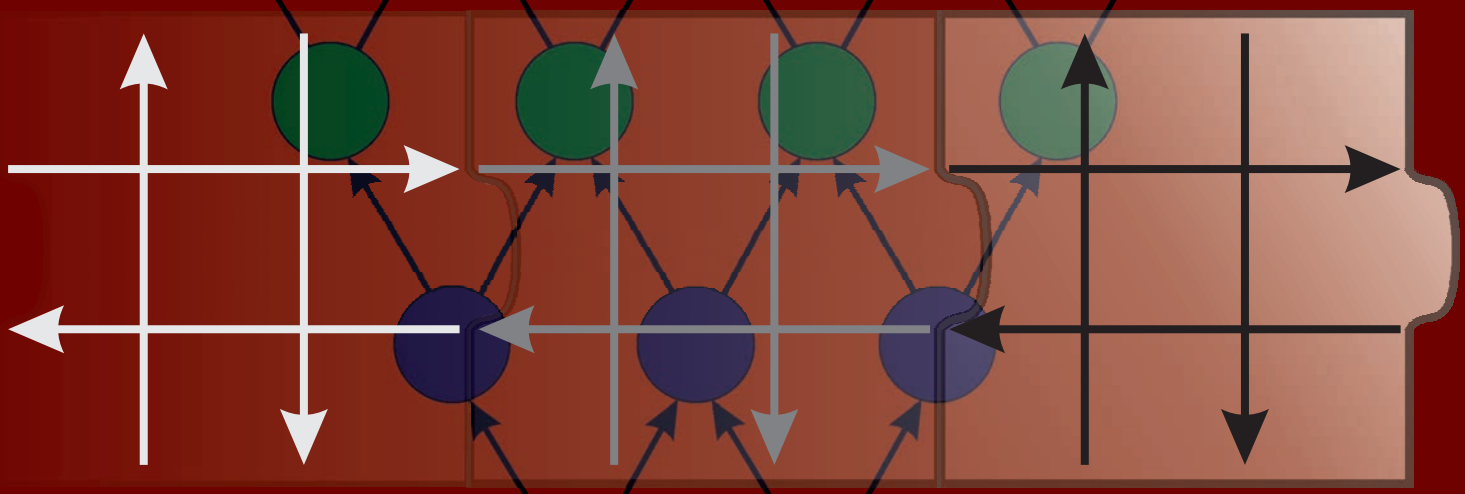

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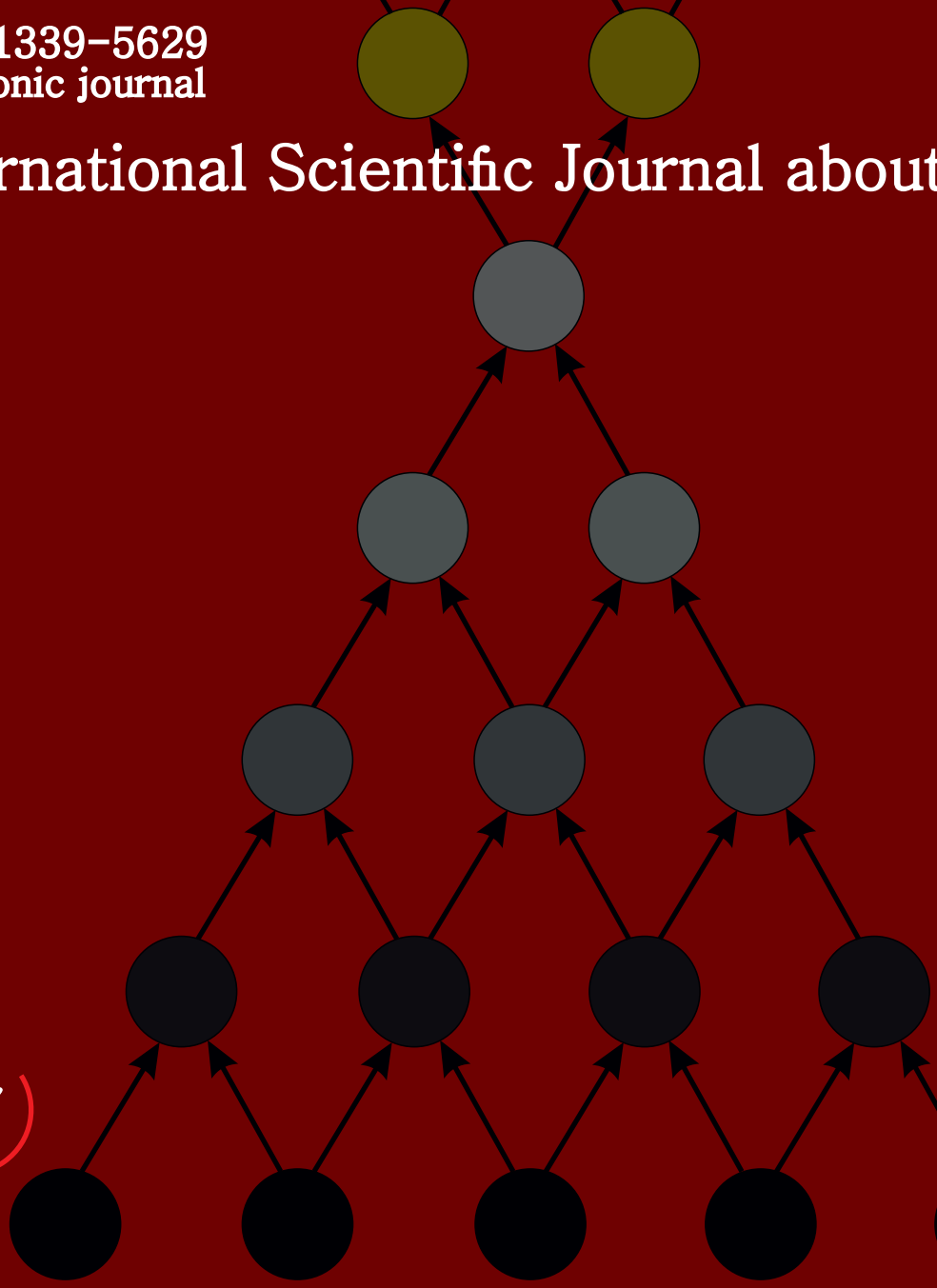

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Examining the impact of informal contract between delivery of package by agents and their customers on shipping

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Keywords: missing packages, delivery delay, damaged packages, informal contract.
Abstract: Given the challenges that businesses have when it comes to adjusting to current circumstances and improving their door-to-door delivery processes, it has been observed that delivery agents are the primary cause of troubles. Ensuring reliable transportation of air-to-sea cargo on a global level continues to provide a significant and difficult obstacle. The absence of a formal contractual arrangement between worldwide air and sea freight intermediaries and their clients has resulted in the prompt settlement of various concerns, such as missing merchandise, shipment delays, and damaged goods. The current study used a quantitative research approach to examine three hypotheses by considering four variables: "Assurance," "Legal Risk," and "Informal Contract" as the independent variables, and "Delivery of package by agents" as the dependent variable. The results of the study demonstrate that all of the independent variables exerted a significant influence on the dependent variable. The study revealed that "assurance" and "perceived legal risk," exert a beneficial influence on the establishment of informal contracts between Malaysian international air and sea cargo-agents and their customers in the context of shipping. The variable of "assurance" has a notable influence on the “Delivery of package by agents". The findings also carry substantial significance for customers, as it offer valuable insights into the uncertainties and obstacles associated with the informal agreements between Malaysian international air and sea cargo agents and their customers pertaining to shipping.

1 Introduction

Informal contractual agreements and direct-to-home delivery services are prevalent in diverse regions across the globe, including Malaysia. The utilization of an informal commerce and distribution technique might yield both benefits and drawbacks [1]. This paper explores the notion of informal contractual agreements and direct-to-home delivery services, and their ramifications in many geographical contexts, with a specific focus on Malaysia. Informal contractual agreements pertain to business arrangements that lack formal legal documentation, instead relying on unwritten understandings or verbal agreements [2]. These agreements frequently depend on trust and interpersonal connections among the involved parties. The terms that may be incorporated encompass aspects such as pricing, delivery, payment methods, and product specs. Although lacking the legal enforceability typically associated with formal contracts, these agreements often retain binding power in numerous instances as a result of prevailing social and moral values. Direct-to-home delivery services refer to the practice of transporting goods directly to the households of clients, hence circumventing conventional retail channels [3]. The adoption of this methodology has garnered attention as a result of developments in e-commerce and logistics technologies. E-commerce offers clients enhanced convenience and enables businesses to expand their reach to a broader demographic, eliminating the necessity of a brick-and-mortar establishment [4].

Personal relationships and trust are key factors in corporate dealings across various cultural contexts. Informal agreements may be more prevalent in such circumstances [5]. The rise of the informal sector can be influenced by various economic factors, such as the presence of small firms or cottage industries. These enterprises may face limitations in terms of their capacity to participate in formal contractual agreements [6]. The informal economies of Malaysia have played a key role throughout history, notably within areas such as agriculture and small-scale retail. Local marketplaces, street vendors, and certain online platforms are characterized by the presence of informal agreements and conventional distribution systems. Informal agreements have the potential to cultivate strong connections between customers and suppliers, thereby facilitating individualized customer experiences [7]. Direct-to-home delivery is a convenient solution for clients, as it enables them to receive products directly at their place of residence, hence minimizing the need for additional time and effort.

The research problem associated to delivery services and their agents, lies with the absence of adequate legal safeguards and the ability to enforce them may result in conflicts or violations of contractual obligations. Inconsistencies in quality control have the potential to impact consumer satisfaction and the overall reputation of

the market. Insufficient market openness and competitiveness may result in inefficiencies. The dynamic nature of the environment is associated to the proliferation of e-commerce platforms has led to a progressive integration of digital tools for transactions and deliveries, even among informal firms [8]. Governments in different nations, such as Malaysia, may endeavour to achieve a harmonious equilibrium between promoting informal economies and ensuring legal safeguards for consumers and enterprises. Furthermore, the prevalence of informal contractual agreements and direct-to-home delivery services is observed in diverse countries, with their dynamics being influenced by cultural, economic, and technological variables. Although these methods include certain advantages, they also present issues that have the potential to influence market dynamics and consumer experiences. The delicate equilibrium between informal and formal procedures necessitates a sophisticated evaluation encompassing factors like as trust, legality, and the general efficiency of the market.

In order to gain a full understanding of the prevalence, characteristics, benefits, problems, and socio-economic repercussions associated with informal contractual arrangements and direct-to-home delivery services in various geographical regions, this study specifically focus on the context of Malaysia. The objective of this study is to offer a comprehensive understanding of the intricacies of informal contract associated to delivery services. The study also provides some implications for both firms and consumers, and the prospects of integrating informal activities with formal legal structures toward delivery services provided by delivery agents. Through an investigation into delivery services influence on informal contractual agreements and direct-to-home delivery services in various ways, this research contributes in analysing the variations in practices and identify common trends. By doing so, it also contributes to a comprehensive understanding of the dynamics of these agreements and services, their impact on different regions, and potential strategies for optimizing them within legal, regulatory, and technological frameworks.

2 Related work

The generalizability of findings pertaining to the evaluation of informal contractual agreements and direct-to-home delivery services, together with their consequences in different areas, such as Malaysia, may not be readily transferable to other contexts. Thorough examination of contextual elements is required in order to derive more comprehensive results. Several significant difficulties and obstacles that require attention have been discovered in the investigation. This paper aims to give a review of past empirical research pertaining to delivery services and informal contracts.

It has been determined that the optimization of cargo transportation efficiency is of paramount importance within the shipping business [9]. The study was conducted to determine how shipping businesses make efforts to optimize their operations with the aim of minimizing costs. The finding reveals that decreasing transit times, and enhancing the overall efficiency of the supply chain improve the delivery services entirely. This encompasses several elements such as route optimization, container usage, port handling processes, and inventory management [10]. The optimization of cargo transportation not only yields advantages for the companies involved but also facilitates streamlined global trade patterns and mitigates carbon emissions [11]. The shipping sector is facing mounting pressure to embrace environmentally sustainable methods as a result of growing apprehensions regarding the detrimental effects of air and water pollution, greenhouse gas emissions, and their consequences on marine ecosystems [12].

According to Cichosz et al. [13], recent advancements have enabled the generation of more precise forecasts pertaining to the stochastic nature of cargo quantity and freight. Consequently, this has facilitated the handling of a larger volume of ships and cargoes within a given time frame, leading to enhanced efficiency and profitability in shipping systems. Furthermore, according to Broekhuis and Scholten [14], the social contract existing between buyers and suppliers has a significant impact on the formal contract and contract management. The authors argue that contract concerns pertaining to customer focus and buyer-supplier relationships play a crucial role in aligning the interests of buyers, suppliers, and customers. The study conducted by Saka et al. [15] examines the comprehension of material management and post-contract waste minimization among quantity surveyors, with the aim of optimizing value for money. The study employed a material management process model and employed a quantitative research approach. The findings suggest that quantity surveyors have a significant role in the management of materials within the context of informal contracts.

A previous study in this domain was undertaken by Susanty et al. [16]. The research was conducted within the context of small and medium-sized enterprises (SMEs) and provided evidence to support the notion that a considerable challenge encountered by several firms is the absence of effective coordination throughout their supply chain. The small and medium enterprises (SMEs) who specialize in Batik production, situated in Pekalongan, an area in Central Java, have faced challenges resulting from the influence of information exchange and informal contracts on the level of trust created between them and their raw cotton fabric supplier within the batik industry. The study adopted a mixed-methods approach, incorporating both qualitative and quantitative research tools. The results suggest that the practice of exchanging information and forming informal agreements has a significant influence on strengthening the degree of trust among small and medium-sized enterprise (SME) owners in the batik sector and their suppliers.

As stated by Benítez-Ávila [17], there is a barrier related to the sequential operation of contractual and relational governance elements, as well as the incorporation of trust and relational standards. The research utilized the theoretical framework of contract design theory and employed a quantitative research approach. The results of the investigation indicate that the successful facilitation of contract agreements can be achieved by employing informal, social, and economic incentives. In their study, Vasan and Chavan [18] employed the concepts of "Vessel dwell time," "Terminal dwell time," and "Street dwell time" to examine the process of Indian customs green channel clearing within the jurisdiction of India. The researchers adopted a qualitative case study approach to analyse this phenomenon. The scope of this study is limited to examining the delivery time in India, with a specific focus on the duration it takes for a shipment to reach a port or airport within the country. The discovery implies that it would be beneficial to assess the performance of other nations both individually and collectively, in accordance with the Trade Facilitation Agreement (TFA) of the World Trade Organization (WTO), in future evaluations.

The main research gap in the context of both theoretical and practical perspectives pertains to the lack of a comprehensive comprehension and empirical evidence concerning the ramifications and outcomes of the widespread utilization of informal contracts associated to direct-to-home deliveries within Malaysia's commercial environment. The research gap may pertain to a more specific area or topic. An additional area of research that might be explored pertains to the insufficient investigation of the interplay between informal transactions and established legal frameworks, particularly with regard to the protection of consumer rights. Moreover, it is imperative to comprehend the various opportunities and problems that arise from informal commerce. The research gap may pertain to an insufficient investigation of the ways in which established enterprises may effectively adjust to or capitalize on these practices, as well as the means by which potential obstacles, such as quality assurance or legal conflicts, can be effectively managed. This study aims to investigate the effects of informal contracts between package delivery agents and their customers on the shipping process.

3 Research methodology

The current investigation employed a quantitative research approach, characterized by the systematic examination of hypotheses derived from a theoretical framework [19]. This procedure entails the gathering of data on particular variables assisted by the utilization of standardized instruments. In contrast to qualitative techniques, which entail active engagement between the researcher and participants, quantitative methodologies adopt a more detached approach, allowing participants to be passive observers in the research process.

3.1 Conceptualization and development of hypothesis

The basic paradigm proposed for this current research is depicted in Figure 1. This model is predicated on the premise that the research aims to construct a novel framework that incorporates factors derived from previous empirical studies. This study proposed the utilization of four key variables, specifically referred to as "Assurance **(AS)**," "Legal Risk (**LR)**," "Informal Contract (**IC**)," and "Delivery of package by agents (**DE**)" The study examines the relationship between the independent variables of "Assurance" and "Legal Risk," the mediating factor variable of "Informal Contract," and the dependent variable of "Delivery of package by agents".

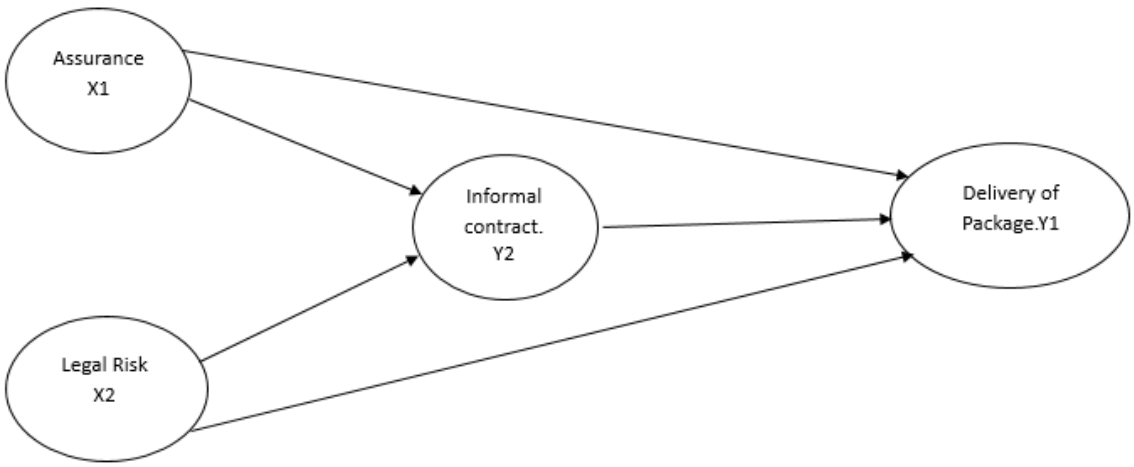

Figure 1 The proposed conceptual model

The operational definition of the variable "Informal Contract" refers to an agreement between customers and cargo agents that is not documented in writing and is not legally binding.

The operational definition of the variable "Assurance" refers to the degree to which a customer is confident that his or her shipment will arrive at its destination on time and without experiencing any complications.

The operational definition of the variable "Legal Risk" Represents the level of potential legal complications or risks associated with formal contracts or transactions. It influences the decision to opt for an informal contract due to the desire to avoid legal complexities.

The beginning of the process known as "delivery of packages by agents" occurs when a customer and an agent come to an agreement regarding the delivery of a customer's package from the customer's country of sources to the country in which the package is to be delivered. This is the last variable.

3.1.1 The level of assurance associated to the delivery of package by agents

In the context of assuring the quality of delivery of package by agents, this study examines the relationship between the amount of assurance connected with the delivery process. The establishment of particular standards would enhance the level of confidence and certainty between clients and cargo brokers about package delivery. When dealing with a situation governed by an informal contract, it is necessary to thoroughly analyse the procedures involved. This research aims to examine the relationship between the level of assurance and the delivery of packages by cargo agents, which is considered a significant concern in this study. The rationale for this assertion stems from the notion that, in the context of package delivery, there exists a prevailing preference for a heightened degree of certainty, as it engenders a greater sense of confidence in the successful achievement of the intended outcomes [20]. The present study is driven to examine the impact of certainty levels on package delivery by utilizing informal contracts.

Furthermore, it is crucial to acknowledge that when the act of delivering anything is closely linked to a substantial degree of assurance, it indicates that appropriate steps, evaluations, and precautions have been put in place to minimize potential hazards, guarantee the excellence of the service, and bolster reliability. Nevertheless, it is crucial to evaluate the possibility of extending the scope of assurance to include scenarios in which it is relevant. This involves assessing the various processes, verifications, and protections that have been put in place to ensure the dependable transportation of commodities via informal contractual agreements. Kilic et al. [21] utilized the theoretical construct of "Assurance" to evaluate its impact on the perceived superiority and quality of assurance services rendered by accounting companies with official accreditation in comparison to those without such recognition. This study recognizes the presence of both registered and unregistered firms within the Air and Sea freight agent industry, hence justifying the consideration of "assurance" as a variable for examination.

According to Kilibarda et al. [22], the sub-construct of "Assurance" can be classified as a constituent element of the broader construct of "Service Quality" within the domain of goods forwarding enterprises. These companies frequently offer a variety of services that demonstrate differences in their organizational structure and level of quality. The quality of service in this specific instance can be ascribed to the agent's level of skill in carrying out their tasks. The logic of the present study is consistent with the notion that conceptualizing Assurance as a determinant of service delivery is equivalent to asserting that Assurance has an impact on service quality, as posited by Kilibarda et al. [22]. Based on the aforementioned reasoning, the hypothesis 1 to 3 are formulated as follows:

H1: The level of assurance is positively associated with delivery of package by agents.
H2: The level of assurance is positively associated with informal contract between delivery of package by agents and their customers.
H3: Informal contract mediate the relationship between the level of assurance and delivery of package by agents.

3.1.2 The level of legal risk associated to delivery of package by agents

The concept of "legal risk" refers to the probability that an organization or an individual would face legal difficulties or unfavourable consequences due to their failure to comply with applicable laws, regulations, or contractual obligations [16]. The rationale behind examining the correlation between legal risk and package delivery stems from a recent study endeavour that has investigated the difficulties faced by Freight Forwarding Agents in meeting client expectations. According to Narunart and Panjakajornsak [23], the study has specifically identified legal concerns, such as disputes pertaining to delivery and parcel damage, as noteworthy elements that contribute to customer discontent. Insufficient decision-making and operational procedures, encompassing substandard logistic practices and inaccuracies in service delivery, equipment management, cost estimation, and booking and delivery services, have the potential to result in financial losses for all stakeholders [24]. Hence, it is crucial to optimize logistical operations, including responsibilities such as organizing deliveries, sending freight, and selecting transportation modes. Dua and Sinha [25] argue that the achievement of market domination necessitates the prioritization of low cost and responsiveness as crucial factors for attaining success.

The contractual agreement between the logistics service provider and the client acknowledges the existence of product liability as a potential legal and financial risk that might affect both parties. Product liability pertains to

the legal accountability associated with defective goods. The hypothesis that can be derived from the aforementioned argument is as follows:

H4: Legal risk is positively associated with delivery of package by agents.
H5: Legal risk is positively associated with informal contract between delivery of package by agents and their customers.
H6: Informal contract mediate the relationship between the legal risk and delivery of package by agents.

3.1.3 Informal contract relationship to delivery of package by agents

The consideration of the correlation between informal contracts and the delivery process holds significant importance within the domain of courier services. Previous research study underscored the need of cultivating trust between suppliers and customers to foster a connection between informal contracts and delivery [16]. This highlights the importance of the level of informality in contractual agreements. Despite the absence of legal enforceability, informal contracts can exert a substantial influence on the transportation of parcels through many mechanisms. From another perspective prior research uses this type of relation on the comprehension of delivery terms, which was revealed that casual agreements can establish a reciprocal comprehension between the courier agent and the customer concerning the delivery conditions [26]. This includes factors such as the time taken for delivery, instructions for handling, and any specific requirements or preferences. In situations where a formal written contract is not present, the participating parties may nonetheless choose to abide by an informal agreement as a guiding framework for their behaviour during the course of the delivery process. The utilization of informal contracts can facilitate the establishment of the expected level of service and performance in service expectations. According to Atiku et al. [27], it is possible for the courier agent and the client to develop a shared understanding of the expected standard of service quality. The required information for delivery of package by agents include the designated state of delivery, the chosen method of delivery, and any additional services that may be desired, such as signature confirmation or insurance.

The utilization of informal contracts can provide a certain level of flexibility and allow for alterations to be made during the course of the delivery process. In the case of unforeseen circumstances, such as a change in the designated delivery location or a delay in the recipient's availability, the informal agreement can provide a basis for negotiating alternative arrangements or developing solutions that accommodate the interests of both parties [16]. Informal contracts can be utilized as a reference point for settling disagreements or difficulties that may occur during the delivery process within the framework of dispute resolution. Although informal agreements do not possess legal enforcement, they can nonetheless be valuable in clarifying the objectives and expectations of all parties involved. This can facilitate productive discussions and negotiations with the goal of reaching a mutually agreeable resolution [28].

It is important to acknowledge that informal contracts may have some limitations when compared to formal written contracts, as they lack legal validity and may lack specified terms and conditions. Therefore, it is advisable for courier agents and clients to consider formalizing their agreements through written contracts to guarantee improved legal protection and clarity [16]. Generally speaking, while informal contracts may not possess the same level of legal enforceability as formal contracts, they can nonetheless significantly impact the delivery process by setting mutual expectations, adaptability, and a basis for addressing possible issues. The aforementioned argument gives rise to the development of a hypothesis below:

H7: Informal contract is positively associated with delivery of package by agents.

3.2 Instrumentation, research population, sampling and data collections

This research employs questionnaires as a method of data collection from participants in relation to delivery service agents and clients. When constructing a survey, it is crucial to offer respondents a diverse range of possibilities for option choice and to restrict the number of questions per variable to ensure a meaningful interpretation of the variable [29]. To deal with that, the present study employed the Likert scale ranging from 1 to 5 (1=strongly disagree – to - 5 = strongly agree). According to Hair et al. [19], it is advisable to ensure a sufficient number of items per variable prior to doing factor analysis. This measure is implemented to mitigate any potential adverse effects on the overall study instrumentation in the event that it becomes necessary to exclude specific items throughout the analysis. Consequently, the questionnaire was constructed to encompass all the variables adopted from the previous studies, namely Informal Contract, Legal Risk, and Assurance. Additionally, a separate set of questions was formulated specifically for the variable "Delivery of package by agents" The questionnaire consists of a range of 6 to 10 questions per variable. The study utilized the questionnaire developed by Susanty et al. [16] to evaluate the prevalence of informal contracts in delivery service involving agents and consumers. These contracts encompass implicit agreements between agents and customers that prioritize the preservation of a favourable reputation characterized by integrity and fairness for both sides, as opposed to asserting undue dominance. The variable known as "Legal Risk" encompasses situations where there is a lack of regulation or uncertainty regarding legal status, which has the potential to undermine the protection and well-being of all

parties engaged in an air and sea cargo transaction. The variable in question has been derived from the research conducted by Wasiuzzama et al. [30]. The variables within the category of "Assurance" pertain to the quantification of the degree of certainty both customers and agents possess regarding the successful and punctual delivery of shipments to their intended destinations, free from any complications or difficulties. These items were derived from the research conducted by Kilic et al. [21].

The survey instrument includes a section that addresses demographic information, covering questions that are essential for comprehending the respondent's traits and overall opinions. The other part of the survey question involves a “variables questions”. The questions sets underwent pre-testing, followed by a pilot test, in which the validity and reliability of the questions were assessed prior to proceeding with final data collection.

The concept of a "study population" encompasses all individuals or subjects that are the central focus of a research investigation, and from whom a subset, known as a sample, will be selected for the purpose of the study. This study focuses on those who utilize the services offered by delivery service agents and their clients. To obtain an approximate figure for the population in question, it is noteworthy that the number of delivery services and their agents be extracted first, hence, in Malaysia in 2022 there are out 6000 delivery agents from a total of 115 courier licenses listed in the "List of Non-Universal Service Licensees." An approximate of 10 to 30 customers per year per agents was estimated. As a result, this study estimated a total population of 180000 people from which a sample as extracted.

Simple random sampling technique was chosen for this study based on the fact that it is sampling design procedure, where in each member of the population has a nonzero chance of being chosen for sample, that is there is an equal opportunity for every member of the population to participate in the research [31]. Krejcie and Morgan's sample size formulation technique was chosen for extracting the sample size required, because previous studies frequently cited as a reference for establishing the appropriate sample size in educational research [32] From the Krejcie and Morgan's sample size determination table, which presents a comprehensive analysis of population sizes and their corresponding sample sizes for different confidence levels the sample size for this present study should consist of 384 samples as the target. This is because from the table any population that is more than 100,000 should use a minimum sample size of 384.Immidetely after setting up the target samples, an online data collection questionnaire was developed. Delivery of package by agents are invited as well as requesting them to forward the question to their customers. Furthermore, the questionnaire is broadcasted through emails, social media platforms and to related groups.

4 Analysis and presentation of the results

The assessment of collected data is a critical step in extracting significant insights and reaching informed conclusions pertaining to the topic or intervention being investigated. The choice of analytical techniques and methodologies is dependent on the specific characteristics of the research inquiry and the data that has been collected. The utilization of the analysis employed in the present study is in accordance with the specific research objectives. The study employed descriptive analysis for the demographic variable and inferential analysis for the research variables as recommended by Hair et al. [19]. It is suggested that a comprehensive variable analysis should commence with the administration of reliability tests and factor analysis, then proceeding to the examination of the interrelationships among the variables. The user provided a numerical reference without any accompanying text.

4.1 The profile of the respondent and response rate

The analysis of response rate and participant characteristics was conducted using a descriptive statistical approach, and the findings have been clearly delineated. A total of 411 valid replies were gathered for the purpose of conducting analysis. The demographic profile of the participants indicated that a majority of the respondents, around 62%, belonged to the age group of 25 to 34 years, making it the most prominent segment. In contrast, approximately 20% of the participants fell into the age category of 34 years and older. This discovery indicates that individuals belonging to the younger age group demonstrate a higher degree of receptiveness towards these matters. In the context of gender, it was observed that male participants shown a greater rate of response in comparison to their female counterparts, comprising around 57% of the overall responses. The bulk of participants, namely more than 82%, hold a Bachelor's degree level of education.

The results indicated that a significant majority of the participants, around 87%, agreed with the proposition that utilizing a deliberate and planned approach is essential for effectively encouraging and promoting the acceptance and utilization of delivery services among agents and their consumers. In a comparable manner, the findings of the study demonstrate that a substantial majority, precisely 91%, exhibited endorsement for delivery services conducted through informal contracts as it serves as an indication of reliability and should be cultivated with meticulous attention to the customer's requirements, inclinations, and challenges. This suggests that the implementation and use of Informal contract on delivery services require a more substantial advancement beyond subjective viewpoints or beliefs.

4.2 The reliability and factor analysis

The analysis of the relationship among the variables was performed. It begins with an extensive evaluation of

variables by the implementation of reliability testing and factor analysis. This is followed by the analysis of the interrelationships that exist among these variables. The research conducted an analysis to assess the reliability of the study's variables, resulting in a Cronbach's alpha coefficient of 0.821 when all variables were aggregated. The resultant Cronbach's alpha value obtained from the analysis can be viewed as a measure of the degree of internal consistency. Consequently, given that this signifies the preliminary phase following the gathering of data, the reliability analysis was also conducted on the four main variables. The Cronbach's coefficient values found in this study are as follows: IC (0.916), LR (0.926), AS (0.823), and DE (0.787) (see Table 1). At present, the variables IC, LR, AS, and DE contain 7, 8, 7, and 7 items correspondingly. The subsequent stage entails the execution of factor analysis.

Table 1 The result of the reliability study

Latent	Cronbach's	Cronbach's Alpha Based on	No of
IC	0.916	0.922	7
LR	0.926	0.928	8
AS	0.823	0.831	7
DE	0.787	0.798	7

The Exploratory Factor Analysis (EFA), was carried out, by assessing the results of the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's sphericity test on the variables AS, LR, IC, and DE. The findings of these tests are provided in Table 2. Hair et al. [19] suggest that the appropriateness of values for exploratory factor analysis (EFA) can be assessed by evaluating the Kaiser-Meyer-Olkin (KMO) values, which should exceed 0.55. In the present investigation, all variables exhibited KMO values exceeding 0.5. Furthermore, the Bartlett's test of sphericity yielded statistically significant findings ($p < 0.001$), providing additional evidence for the dependability of the model's fit.

Table 2 Results of examination of constructs for exploratory factor analysis suitability

Construct	KMO (> 0.50)	Bartlett's Test of Sphericity
IC	0.792	0.00
LR	0.841	0.00
AS	0.799	0.00
DE	0.828	0.00

Table 3 displays the outer loading values for all variables, this is the baseline indication of the factor loading required (see Figure 2). The validity of the items was determined based on their factor loadings, which were considered acceptable if they were within the range of 0.50 and above, as suggested by Hair et al. [19]. Additionally, the items were also evaluated based on their eigenvalues, which were required to be greater than 1, as indicated by the same authors. All the variables evaluated had an explanatory capacity of 61.909%, above the recommended threshold of 60% total variance elucidated by Hair et al. [19]. Nevertheless, any value below the specified threshold is deemed unacceptable, resulting in the exclusion of items falling inside that range.

Table 3 The results of the outer loading values

	Assurance	Delivery of package by agents	Informal Contract	Legal Risk
AS1	0.851			
AS2	0.884			
AS3	0.800			
AS4	0.812			
AS5	0.845			
AS6	0.765			
DE1		0.921		
DE2		0.937		
DE4		0.907		
DE5		0.846		
IC1			0.682	
IC2			0.672	
IC3			0.647	
IC4			0.785	
IC5			0.778	
IC6			0.788	
IC7			0.682	
LR1				0.878
LR2				0.825
LR3				0.774
LR4				0.712
LR5				0.756
LR6				0.849

In nearly all instances, there exists a set of elements that are excluded, with the exception of the data pertaining to the ICC variables (see to Table 4). The objective of conducting factor analysis was to enhance the overall accuracy and interpretability of the factor structure. This was achieved by the removal of specific components. However, the omission of these components from the measurement has the potential to impact the credibility and reliability of the instrument. Therefore, it is crucial to acknowledge this aspect. Subsequently, following the completion of the Exploratory Factor Analysis (EFA), an additional iteration of the Reliability test was administered.

Table 4 Reliability analysis results for all the variable after EFA

Variables	Number of Items (Before items deletion)	Cronbach's Alpha	Number of Items (After items deletion – EFA)	Cronbach's Alpha
IC	7	0.916	7	0.916
LR	8	0.926	5	0.941
AS	7	0.823	6	0.886
DE	7	0.787	4	0.897

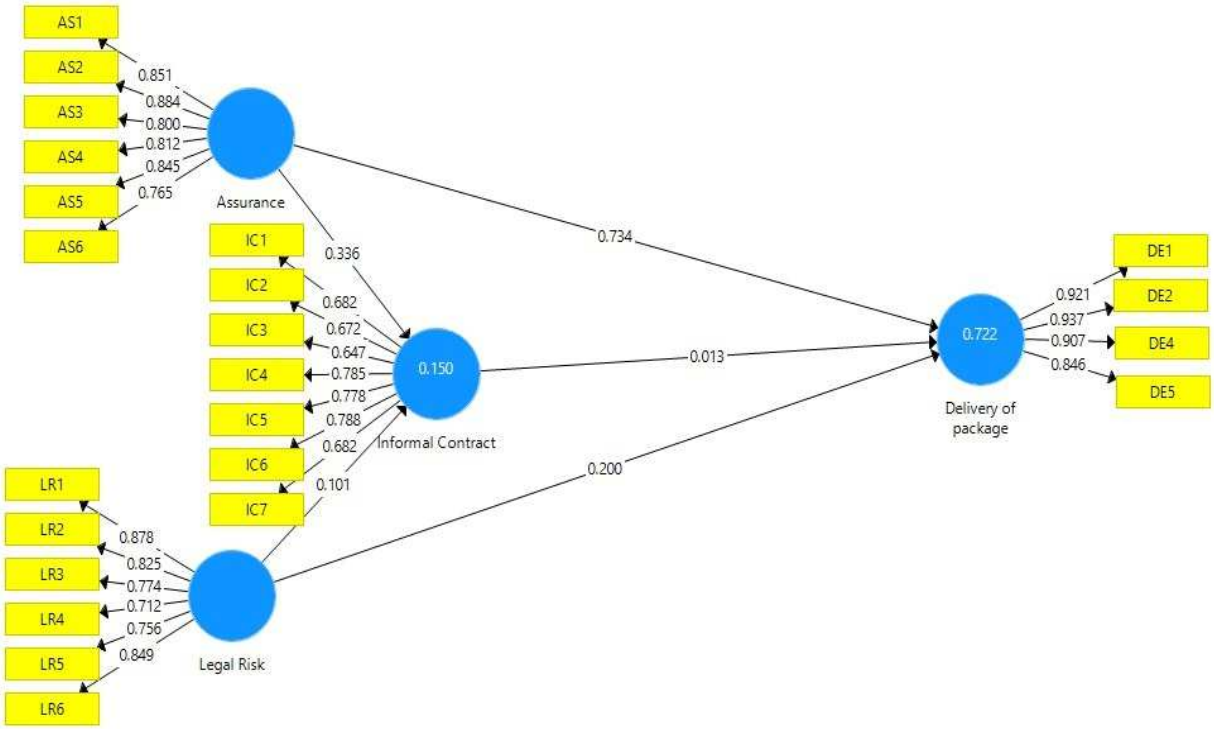

Figure 2 The results of the outer model

4.3 The analysis of the hypothesis testing

The findings demonstrate if there are statistically significant associations between the variables in question (see Table 5. The column labeled "Relationship Status" provides information regarding the nature of the relationship, indicating whether it is positive or negative. On the other hand, the column labeled "Hypothesis" serves to determine whether the null hypothesis is accepted or rejected, with the decision being based on the p-value. There is a statistically significant positive correlation between Assurance and delivery of package by agents. This finding implies that there is a positive correlation between the level of Assurance and the utilization of delivery of package by agents. The statistical analysis reveals a substantial positive correlation between Assurance and Informal Contract. This suggests that there is a positive correlation between an escalation in Assurance and a rise in the prevalence of Informal Contract agreements. Moreover, the impact of informal contracts on the association between assurance and delivery of package by agents has been found to diminish the strength of the relationship, resulting in a lack of statistical significance. The responsibility of reducing the relationship status falls within the purview of the mediator. Consequently, the hypothesis is deemed valid, suggesting that the association between Assurance and delivery of package by agents is mediated by an Informal Contract.

There exists a statistically significant positive correlation between Legal Risk and delivery of package by agents. This implies that there is a positive correlation between the escalation of Legal Risk and the growth of delivery of package by agents. The statistical significance of the positive association between Legal Risk and Informal Contract is observed in a similar manner. This suggests that there is a positive correlation between the escalation of Legal Risk and the prevalence of Informal Contract arrangements. Moreover, the presence of an Informal contract has been found to moderate the association between Legal risk and Delivery of package by agents, resulting in a decrease in the strength of the link. However, this moderation impact is not statistically significant. The responsibility of reducing the relationship status falls upon the mediator. Consequently, the hypothesis is deemed valid, suggesting that the association

between Legal risk and Delivery of package by agents is mediated by Informal Contract.

The statistical analysis reveals that there is no significant correlation between the Informal Contract and Delivery of package by agents, indicating a lack of meaningful association between Informal Contract and Delivery of package by agents, however it is positive. This implies that but customers and agents are quite satisfy with their transaction, but are aware anything can happen that is not right.

Table 5 The result of the hypothsis testing

Types of Influence	Original Sample (R^2)	T Statistics	P Values	Relationship Status	Hypothesis
H1: AS->DE	0.734	7.676	0.000	Positive	Accepted
H2: AS->IC	0.336	3.282	0.000	Positive	Accepted
H3: AS->IC->DE	0.004	0.041	0.046	Positive	Accepted
H4: LR->DE	0.200	2.341	0.000	Positive	Accepted
H5: LR->IC	0.101	1.563	0.001	Positive	Accepted
H6: LR->IC->DE	0.001	0.013	0.325	Positive	Accepted
H7: IC->DE	0.013	0.185	0.061	Positive	Accepted

5 Discussion and implication of the study

This study examined assurance, legal risk, informal contracts, and delivery of package by agents. It has provided many valuable insights on these interrelated elements in commercial settings. This study's findings include: Influencing Factors: The study showed how assurance, legal risk, and informal contracts affect delivery of package by agents. This study quantifies and analyzes package delivery service quality and customer satisfaction aspects. Decision-Making: Empirical Evidence The empirical findings help package delivery sector decision-makers make strategic decisions. These insights can help organizations strategically deploy resources to assurance systems, efficiently manage legal risks, and tailor their informal contract strategy to service outcomes. Study outputs offer practical advice for improving operational performance. Organizations can improve assurance and legal risk management processes to meet consumer expectations and improve service quality.

The study examines the individual and group consequences of assurance, legal risk, and informal contracts to better understand their interplay. A holistic approach helps understand the dynamics of the package delivery sector. This study lays the groundwork for future investigation. This study provides a platform for investigating several factors that may affect package delivery services. Future studies could include technological integration, personnel training, and consumer engagement. Service Improvements: This research can help businesses optimize service delivery. Organizations may use the insights to create tailored plans to improve their package delivery services, boosting customer satisfaction and loyalty. Legal risk affects service outcomes, the study says. Businesses need this knowledge to anticipate and resolve legal issues. This reduces disagreements and improves service quality. Research may help organizations differentiate themselves from competition through strategic differentiation. Assurance and legal risk management can help package delivery companies build trust and credibility. The research provides significant insights into the intricate interaction of key factors that affect service quality and customer satisfaction. Academia and industry practitioners who want to understand and manage assurance, legal risk, informal contracts, and their effects in package delivery services will benefit from the above contributions.

The hypothesis testing results could inform assurance, legal risk, package delivery, and informal contract strategy. Assurance (AS) improves delivery of package by agents (DE) and Informal Contract (IC). This shows the importance of building company trust. Due to their commitment to quality and dependability, companies that reassure customers may increase consumer satisfaction and loyalty. Legal Risk: Legal risk management and compliance can improve package delivery services, according to the data. Proactive legal risk management can boost reputation, reduce future conflicts, and strengthen customer relations. Assurance and Informal Contracts did not affect delivery of package by agents (DE). This implies that while assurance can build trust, it may not directly boost service quality from informal contracts. Beyond these two requirements, organizations should prioritize service-enhancing components. The hypothesis on the combined impacts of Legal Risk and Informal Contracts on Delivery of package by agents (DE) was equivocal, suggesting that legal risk management may not significantly affect informal contract effects on service quality. Businesses should look beyond these affiliations to provide excellent service. The low impact of informal contracts on Delivery of package by agents (DE) implies that while informal agreements may help create business ties, other factors may have a greater impact on service quality. Organizations must prioritize service performance and client happiness. The findings show that assurance, legal risk, informal contracts, and delivery of package by agents are interconnected. Businesses must assess how these factors affect their operations, customer interactions, and organizational effectiveness. To make strategic decisions, you need a complete understanding of the service delivery ecosystem. The research sheds light on

assurance, legal risk, informal contracts, and delivery of package by agents. However, restrictions may alter the generalizability and interpretation of these results. The study may have occurred in a specific location or industry. Thus, these research may not apply to numerous places or industries with different regulatory frameworks, cultural norms, and commercial practices. The study illuminate's assurance, legal risk, informal contracts, and delivery of package by agents services. However, it is important to acknowledge and account for these limitations when interpreting and extrapolating the results to wider contexts. Future research should aim to overcome these constraints and better understand the sector's complex dynamics.

6 Conclusion

The study examined the complicated interactions between assurance, legal risk, informal contracts, and package delivery services. This study sheds light on the complicated dynamics of package delivery interactions. This study used empirical analysis and hypothesis testing to better understand how these factors affect service quality and customer satisfaction. The package delivery service sector now relies on assurance. The study found that a strong assurance structure improves package delivery and informal contracts, boosting customer trust and loyalty. This emphasizes the importance of organizations developing processes that represent reliability and quality to their customers. The research also showed how legal risk affects service quality and customer attitudes. Legal risk management can reduce disagreements and improve package delivery. The study found that informal contract relationships did not consistently affect service results. This suggests that while informal agreements shape commercial relationships, their impact on service quality may be more complicated than imagined. This study's constraints—context-dependent results and the difficulty of establishing causal relationships—must be acknowledged. This study only examined particular features, which may have excluded other important factors that could have affected the sector. This study has far-reaching effects. Package delivery companies can use their insights to make strategic decisions to improve service quality, trust, and legal obligations. The findings can also be used to study equivalent links in other sectors. As the package distribution business evolves, this study provides a foundation for future research. Adding more variables, studying more industrial dynamics, and using longitudinal studies to capture temporal oscillations could expand this research. These efforts will deepen understanding of the complex interactions between service quality, client satisfaction, and organizational success. This research expands the knowledge of assurance, legal risk, informal contracts, and delivery of package by agents. This research is useful for organizations trying to navigate the intricate interconnections that are essential to providing excellent services and building long-term client relationships in light of the changing business landscape.

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Enhancing road service compliance: a robust penalty model for efficient maintenance management
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Enhancing road service compliance: a robust penalty model for efficient maintenance management

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Keywords: late penalties, long segment scheme, penalty formula, road preservation, road service level compliance.
Abstract: The long segment scheme allowing contractors to oversee road maintenance still has drawbacks. For example, non-compliance, such as delaying preservation for road issues, persists due to small penalties. This leads service providers to neglect road performance without objection to fines. This research aims to provide sufficient incentives for contractors to comply with the implementation of the late delivery penalty rate of road service levels. This research used an experimental method to test two formulas for the late delivery penalty rate of road service levels on two road sections in Central Java and Special Region of Yogyakarta, Indonesia. During the experiment, the time taken by service providers to fulfill the road service level on the two different road sections was measured and recorded. In the first road section, the previously used formula resulted in a penalty of only $7.39, while the developed formula yielded $122.17. Furthermore, in the second road section, the government formula led to a penalty of $375.89, whereas the developed formula resulted in a fine amount of $1,468.99. The results showed that the penalty value given to contractors for two road segment trials using the research formula was 16 and 4 times higher than the formula used by the Directorate General of Highways. In addition, the developed formula takes into account other road performance indicators such as potholes with a diameter < 10 cm and depth < 4 cm, ponding, and uneven patching.

1 Introduction

Long segment pertains to a preservation effort carried out within the confines of a singular extended stretch, potentially comprising multiple segments, with the objective of establishing a consistent road condition [1,2]. The implementation of road preservation through the long segment scheme in Indonesia has been in effect for over six years (since 2016) [3]. Considering the length of the road, the most essential type of work is road maintenance [4]. Therefore, the handling type is the most important aspect of maintenance activities. The ability of service providers plays a crucial role in carrying out road maintenance activities under the long segment scheme. Service providers must be able to shift from a traditional construction executor to a road segment manager paradigm. This paradigm shift is essential for addressing various flows within logistics, such as material flow, information flow, financial flow, and human flows, thus optimizing the overall management of road segments.

Assessing user satisfaction and project success in road preservation (maintenance, rehabilitation, reconstruction, and widening) from a technical or non-technical aspect is challenging due to the lack of performance indicators. In long segment projects, the entire scope of work is incorporated into one contract, whereas in previous preservation activities, the scope of work is documented in separate contracts. In addition to the quality of work, the implementation of long segment projects must comply with the required road performance indicators. The contractor is obligated to submit weekly reports that compare the road performance indicators with on-site implementation results. The project management or technical management team reviews the weekly reports, and the verification results are used to calculate financial penalties if the road performance indicators are not met. Eventually, if the contractor fails to meet the road performance indicators, they are responsible for paying financial penalties by deducting them from monthly payments.

The quality of road maintenance work in a long segment is one of the indicators of the success of the road pavement plan achievement program. Division 10 of the Directorate General of Highways of the Republic Indonesia requires contractors to meet the road service level based on road performance indicators [5]. The achievement of the road service level is applied to all work achievements within the scope of work, including road pavement, road shoulders, drainage, road equipment, complementary structures, and plant control. If the service provider fails to achieve the road performance indicators according to the specified repair response time, financial penalties in the form of daily payment reduction are

imposed based on Equation 1 (1). The purpose of applying penalties is to ensure the service provider's obligation to complete the work on time, thereby fulfilling the service users' rights.

$$D = 0.01 \times H \times \frac{Pjc}{Pjl} \times Nlp \quad (1)$$

where,
D: nominal payment reduction,
H: total number of days that the road repair is delayed in meeting the road service level according to the field inspection,
Pjc: the length of the road section that is defective or does not meet the performance indicators in the designated section of the road that has a minimum length of 100 m,
Pjl: the length of the road in the contract according to the scope of work,
Nlp: the contract's work scope value.

Based on the preliminary study results, the financial penalties for delayed road service currently in place are still inadequate [6]. This was evaluated from various indicators, such as response time, traffic volume (vehicles/day), public complaints/reports, length of road that does not meet the road performance indicators per 100 m, and the value of the work scope in the contract. In addition, the amount of the penalty is considered too small, which causes the service providers to neglect the road performance and have no objection to paying the fines. This is evident from the commitment maker officer who imposes penalties for delayed achievement of road performance indicators and the amount of fines imposed is still not significant, as shown in Figure 1.

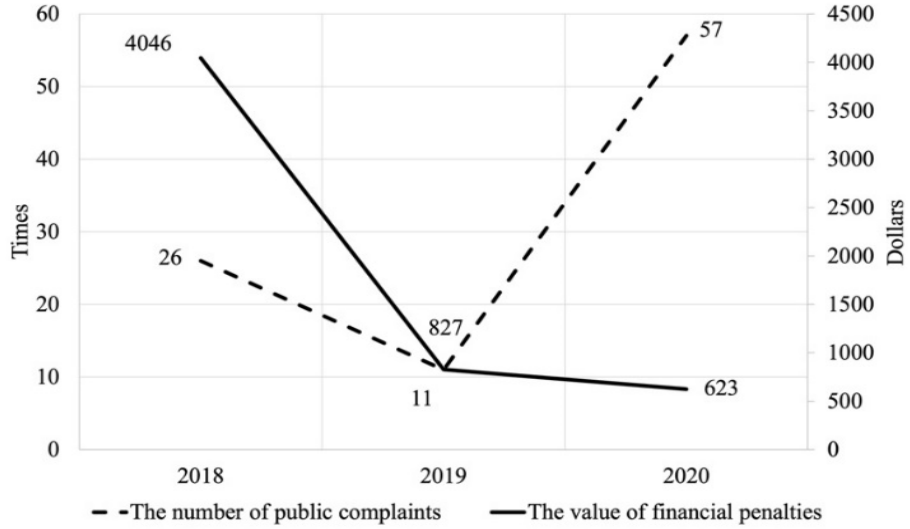

Figure 1 Relationship between public complaints and financial penalties for late fulfilment of road performance indicators in Central Java Region [7]

Service providers are currently neglecting road performance because they believe the penalties are not significant enough. The objective of this research is to address the shortcomings in the current penalty system for delayed road service. Specifically, the study aims to provide sufficient incentives for contractors to comply with the implementation of late delivery penalties through the development of a penalty formula. This formula is designed by considering various elements, with a primary focus on the flow or management of financial resources within the logistics framework. The originality of this research lies in its departure from conventional penalty frameworks for delayed road service. Unlike static systems, this study pioneers a dynamic penalty model that adapts to the nuanced dynamics of road service. Additionally, this research introduces novelty through its experimental approach in specific regions of Indonesia. Rather than relying on established formulas, the study develops and tests a penalty formula for late delivery of road service levels.

2 Literature review

2.1 Road maintenance concept

Road maintenance is the systematic set of activities aimed at preserving and enhancing the safety, quality, and functionality of public roads, with a focus on adapting to changing traffic conditions and evolving economic models [8,9]. Among the types of road maintenance, routine road maintenance is considered essential for preserving the level of road service and road capacity [10]. To implement the road maintenance system precisely and optimally, a road maintenance program with adequate and continuous planning and funding is necessary [11-13]. As noted by Vaitkus et al. [14], the performance of roads declines upon being put into service, intensifying the need for maintenance, particularly due to the significant impact of

increased traffic volume and climate change on road conditions. Therefore, road maintenance must be conducted by employing several integrated and cost-effective techniques [15,16]. These approaches aim to extend the service life of roads, enhance road safety, and fulfill the needs or desires of road users.

2.2 Penalty regulation

In the context of road maintenance, the application of financial penalties is often intertwined with the concept of performance-based contracts (PBC) [17-19]. PBC are agreements where contractors are held accountable for meeting specific performance indicators and achieving predefined outcomes [20]. Financial penalties serve as a mechanism within these contracts to incentivize compliance and deter deviations from agreed-upon standards. The occurrence of penalties in road maintenance contracts is typically linked to the failure of contractors to meet specified performance indicators within the stipulated repair response times. This aligns with the performance-based nature of the contract, where the focus is on achieving desired outcomes, such as road quality and timely repairs.

In PBC in Argentina, payments are not based on the unit price for each individual work item, but rather on the contractor's compliance with predetermined quality standards and specified outcomes [21]. This system permits the implementation of penalties or financial penalties if the desired quality or level of service is not met. The application of agreed-upon penalties or financial sanctions must be enforced in the event of contractor non-compliance with road performance indicators. According to the Asian Development Bank [22], if the contractor fails to remedy defective road conditions in a timely manner, automatic payment reductions will be implemented and will increase significantly in subsequent periods if the deficiency is not rectified. This system has been implemented in Ukraine, where the contractor must pay penalties in the form of greater payment reductions for failing to detect non-compliance if service users identify additional defects not included in the system. Additionally, it was found that there are concerns regarding the stringent enforcement of penalties in the Philippines, and the penalties applied under the PBC are relatively moderate. To increase the efficiency of PBC as a road service mechanism, it is recommended that the financial penalties for failing to meet road service levels are rigorously enforced. For non-compliance with performance standards, the expression "payment reduction" is used because the term "penalties" is not well received among contractors. The value of payment reduction must be sufficient to provide contractors with sufficient incentives to conform. If the payment reduction is insufficient, contractors tend to be less compliant; if it is excessive, contractors may add risk premiums to their bid prices. Therefore, it is essential to accurately determine the appropriate payment reduction for each instance of non-compliance.

In the following subsections, several references are presented regarding penalties or payment reductions implemented in various countries. This serves as consideration for implementation in Indonesia or for reviewing existing regulations in Indonesia operating under the long segment scheme.

2.2.1 Penalty framework in Argentine PBC

According to Silva and Liautaud [23], performance indicators should be as minimal and straightforward as feasible to facilitate observation and evaluation. Throughout the duration of the contract, the rehabilitation bundle for road thickness, maximum roughness level, groove depth, cracks, and raveling must conform to the specifications. For example, compliance with specifications entails the absence of visible potholes or exposed cracks, the absence of excessive wheel marks, and the maintenance of good conditions on shoulders, culverts, drainage channels, guardrails, vertical and horizontal signs, and the overall road environment. For each component, penalties for non-compliance are established and enforced to discourage contractors from failing to comply. For example, if a pothole is not addressed within the specified timeframe, the service provider will incur a fine of approximately $1,200 per day until the repair is completed (as indicated in Table 1). The total amount of penalties imposed is then subtracted from the monthly payment.

Table 1 Penalties for late fulfilment in road performance criteria in Argentina

Parameter	Fulfilment Conditions	Penalties (USD)
Rehabilitation		
Pavement roughness	IRImax = 3 (Asphalt Concrete/AC) IRImax = 3.5 (ST/RC)	600/week/km
Pavement rut depth	Maximum 1 cm	1,200/week/km
Pavement edge reduction	0 cm	1,200/week/segment
Pothole diameter > 2.5 cm	100% patched	1,200/pothole/day
Cracking	100% closed	600/week/km
Concrete pavement joint cracks	100% closed	600/week/km
Raveling	0%, and < 2% if road maintenance	600/week/km
Routine Maintenance		

Parameter	Fulfilment Conditions	Penalties (USD)
Uneven road	Maximum 3 cm	1,200/week/ segment
Cracking	100% closed for type 4	600/week/km
Pothole	100% patched	1,200/pothole/km
Raveling	100% pathced	600/week/km
Shoulder hardened	Pothole/raveling = 0 Shoulder drop = 0 Rutting < 12 mm Cracking closed (100%)	1,200/week/km
Shoulder not hardened	There is no erosion, no channeling, and good cross slope; edge drop < 2 cm; width ≥ 3 m	1,200/week/km
Roadside vegetation/brush clearing	Brush height < 15 cm of 15 m	1,200/week/km
Cleaning box culverts/drainage/bridge	Clean/no clogging	600/day/km
Right-of-way area cleaning	No dirt, green area maintenance	600/day/km
Sign	Preserved, clearly visible during both day and night	150/day/sign
Lightning	Preserved	150/day/lamp
Road markings	Preserved, clearly visible during both day and night	300/day/line/km
Guardrail	Good condition	1,200/week/location

Source: [23]

2.2.2 Penalty framework in CAREC member countries' PBC

As per the Central Asia Regional Economic Cooperation (CAREC), not meeting road performance indicators will lead to payment reductions. This includes scenarios where reports are not processed within the specified timeframe, the average roughness of a road section surpasses the specification, or potholes exceed the maximum size. Payment deductions are determined in local currency or as a percentage of the total monthly flat sum payment per km. When service users discover non-compliance, payment reductions are implemented, and additional payment reductions are implemented when damage is not repaired within a predetermined timeframe. If response times have been routinely missed, payment reductions may increase. Table 2 provides an example of the application of payment reductions in CAREC member countries.

*Table 2 Example of reduction in payment for failure to meet road performance indicators in CAREC member countries**

Criteria	Performance Level	Reduced payment on first inspection	Reduced payment for follow-up inspection
		(% of monthly lumpsum/km)	
Pothole on the road surface	The pothole shall not be wider than 10 cm from any direction.	5% for every 1 km of road section with potholes	15% for every 1 km of road section that has potholes until the potholes are fixed
Rutting	Depth of groove does not exceed 20 mm with a length of 3 m, every 100 m.	10% every 100 meters that do not meet the criteria	20% on every 100 meters that do not meet the criteria until rutting is addressed
Vertical sign	One or more traffic signs are not damaged, unreadable, misplaced, or not functioning.	5%	10% until the sign is repaired or replaced
Vegetation	The maximum vegetation height measured anywhere within a 100-meter stretch is above the threshold value limit.	5% every 100 m	10% for every 100 meters until vegetation is cut to the allowed height

Note: *CAREC countries: Afghanistan, Azerbaijan, China, Georgia, Kazakhstan, Kyrgyz Republic, Mongolia, Pakistan, Tajikistan, Turkmenistan, and Uzbekistan.
Source: [22]

2.2.3 Penalty framework in World Bank-funded projects' PBC

According to the World Bank [24], payment reductions are applied for failure to meet road performance level requirements. The results of road performance level inspections and criteria are documented in a memorandum, which includes the categories and locations of non-compliance, especially those listed in the standard table

included in the service provider's monthly report. Each instance of non-compliance will be assigned a correction deadline. Therefore, site visits are required on the specified dates to confirm that the contractor has addressed the road performance level non-compliance findings. If the contractor has not corrected the non-compliance by the deadline specified in the memorandum, payment reductions will be imposed. Service providers who fail to remedy the cause of previously applied payment reductions will see the amount of reduction increase from month to month, without limit, until the road performance level is achieved. The initial payment reduction calculation for the first month ranges from 10% to 50% of the monthly lump sum, depending on the type of road components [19]. Meanwhile, late handover beyond 30 days is determined by Equation 2 (2).

$$PR = 2^n PR_u \quad (2)$$

Where>

PR: payment reduction, which is the reduction in payment calculated if non-compliance is not rectified within 30 days,

$n = \frac{J-1}{30}$ (n is rounded to the nearest whole number, without decimals),

J: the number of days of non-compliance,

PR_u: the unit rate for payment reduction, which applies during the first 30 days of non-compliance.

3 Methodology

This research utilized an experimental method to test the formula for road service delay penalties. Two formulas were tested on two road segments managed by the National Road Implementation Center of Central Java and Special Region of Yogyakarta, Indonesia. The first formula was the one used by the Directorate General of Highways since 2020, while the second formula was developed in this study. Initially, the study identified the needs and conducted a literature analysis related to the penalty for road service delay. To capture survey data, questionnaires are distributed to a sample of respondents in order to collect primary data. There are two options for completing questionnaires: printed copies or *Google Forms*. Indicators for each factor that contributes to penalties for late fulfillment in road service level were used to develop the questionnaires. The new formula was tested on two different road segments with varying conditions. During the experimental stage, the time taken to fulfill the road service level by the contractor/service provider was measured and recorded for the two road sections. The results obtained were then calculated using the two formulas mentioned earlier, which led to the determination of the penalties for both road sections.

4 Result and discussion

4.1 The developed penalty formula

The current formula for calculating penalties only considers a limited set of factors, including the duration of the delay, the length of the defective road segment, the length of the road under contract, and the value of the scope of work. In this study, a mathematical model was developed to provide a more comprehensive framework for calculating penalties for late fulfillment of road service levels. This model is based on the idea that formulas represent a physical representation of mathematical concepts and can be used to understand the correlation between different variables in an intuitive and straightforward way. To validate the model, tests were conducted on two road sections in Central Java and Special Region of Yogyakarta, which revealed valuable insights into the nature and extent of the errors that may arise when using the formula. Equation 3 was derived as the formula for calculating penalties for late fulfillment in road service levels.

$$S = Koef\ x\ T\ x\ F_V\ x\ N\ x\ F_A\ x\ J \quad (3)$$

Where:

S: the amount of financial penalty for failing to meet the road service level,

Koef: the coefficient value for each road component, as shown in Table 3,

T: the delay in responding to road performance in days,

F_V: the traffic volume factor, where Primary Arterial Roads (PAR) has a factor of 1 and Primary Collector Roads-1 (PCR-1) has a factor of 0.9,

N: the multiplier value for the penalty/cost of routine road maintenance,

F_A: the community complaint factor, where no complaints have a factor of 1, verified complaints by National Road Implementation Center or National Road Service have a factor of 1.5, and accidents have a factor of 2,

J: the length of the road that fails to meet the criteria, which is determined by dividing the length of the faulty or poor-performing road segment (minimum length of 100 m) by the length of the road covered in the contract.

Table 3 Factor score weight

Component	Factor score weight (*Koef*)
Road Pavement	0.027
Road Shoulder	0.020
Drainage	0.011
Road Equipment	0.001
Complementary Structures	0.006
Clearance	0.017

4.1.1 Coefficient variable (*Koef*)

The coefficient in the formula currently applied to the long segment scheme is 0.01 for all types of road damage. Meanwhile, the formula resulting from this study applies different coefficient values for each road component (see Table 3). These coefficient values are derived from factor score weights obtained during the analysis, representing the intercorrelation between manifest and latent variables. The final model produces a set of factor score weights, serving as regression coefficient estimates for predicting latent variables based on observed variables. The term "factor score weight" denotes the proportional influence of variable X on variable Y—when X changes, it proportionally impacts Y. The initial coefficient value (*Koef*) of 0.01 undergoes variation for different types of damage influencing the penalty value. For instance, the coefficient acting as a multiplier for road pavement damage (such as potholes) is 0.027, surpassing other components like clearance (road cleanliness, etc.), which carries a value of 0.017.

4.1.2 Variable *T* (delayed response time)

In this study, the response time for each type of road performance indicator damage considered in the delayed penalty formula is outlined in Table 4. Each day of delay is factored into the formula as a multiplier. For instance, if a pothole is repaired within 9 days of discovery, based on Table 4, it should be fixed within a maximum of 3 days, resulting in a 6-day delay. Therefore, the value of *T* in the formula is 6.

Table 4 Response times for road performance indicators

Components	Conditions	Response Time
Road Pavement		
Potholes	Any pothole	< 3 days
Cracks	Width > 3 mm, area 5% per 100 m of length	< 7 days
Deflection/Depression	Depth > 3 cm, area 5% per 100 m of length	< 7 days
Uneven patching	Not in compliance	< 7 days
Pavement roughness	IRI > 4 mm	< 30 days
Rutting	Depth > 3 cm	< 14 days
Raveling	Any raveling	< 14 days
Road Shoulders		
Potholes	Any potholes	< 7 days
Elevation	Height difference > 5 cm from the road	< 14 days
Sinkhole	Depth >10 cm, area > 3% per 100 m of length	< 7 days
Ponding	Any ponding	< 7 days
Drainage		
Clogging	Clogging in drainage channels > 10%	< 7 days
Dirty	Dirty	< 7 days
Structural damage	Damage	< 14 days
Embankment slopes	Deformation and erosion, as well as poor functionality	< 14 days
Excavation slopes	Unstable, weak against erosion, and not functioning properly	< 14 days
Road Equipment		
Warning and traffic signs	Not correctly installed according to regulations, structurally weak, and some of the poles are bent	< 7 days
Temporary signage	Unrepaired road damage	≤ 24 days
Median/sidewalk	Not sturdy, not functioning correctly, or not visible at night	< 7 days
Guardrail	Not sturdy, not properly installed, and experiencing damage	< 14 days
Road markings	Unclear and faded	< 30 days
Complementary Structures		
Access road or driveway	Slope > 5 cm	< 7 days
Retaining wall	Damaged, cracked, or broken	< 14 days
Clearance		
Wild vegetation	Height > 10 cm	< 7 days
Cleanliness	Debris, trash, sand/dirt, rubble, or other obstructions	< 7 days
Illegal advertisement/banner	Illegal advertisement/banner	< 7 days

Source: Survey results.

4.1.3 Traffic volume factor (F_v)

The traffic volume factor (F_v) is determined based on secondary data on the average annual daily traffic (AADT) volume on the road section under review. Road damage on a section with high AADT has a greater impact on road users compared to a section with lower AADT [25]. Retallack and Ostendorf [26] stated that the frequency of accidents increases with higher traffic volumes. The accident rate gradually increases with the increase in traffic volume until around 11,000-13,000 vehicles/day on a two-lane road. At this limit, traffic flow instability conditions are prone to occur, such as lower driving speeds and limited maneuvering space, which leads to a higher risk of accidents [27,28].

The relationship between the number of traffic accidents and AADT is not entirely linear but shows an exponential relationship [29]. The pavement condition is one of the main factors contributing to accidents [30-32]. Li et al. [33] stated that poor pavement conditions are proportionally associated with more severe accidents, but very poor pavement conditions are associated with less severe accidents. Excellent pavement conditions may lead to high-speed driving behavior and result in more severe accidents. The severity of accidents can be reduced if the pavement condition is maintained in good condition [34].

Road classification based on AADT is shown in Table 5. As road classification varies and there is currently no road classification based on traffic volume in Indonesian regulations, guidelines, or literature, the traffic volume factor (F_v) based on road classification in the National Road Decision is used.

Table 5 Classification of roads based on average annual daily traffic (AADT)

Classification	AADT
Low	30,000-60,000
Moderate	60,000-100,000
Moderate-High	100,000-200,000
High	> 200,000

Source: [35]

The classification of roads is determined by their function, categorized as arterial, collector, and local. Additionally, roads are classified based on the road system into primary and secondary. Based on the Minister of Public Works and Housing Decree Number 430/KPTS/M/2022 regarding the Designation of Road Segments, in according to their function, roads can be categorized as Primary Arterial Roads (PAR) and Primary Collector Roads-1 (PCR-1). The differences between PAR and PCR-1 are shown in Table 6. The traffic volume factor (F_v) is determined based on Table 6 with the classification of PAR and PCR-1 roads. From the survey results, F_v for PAR is determined to be 1.0, while F_V for PCR-1 is 0.9.

Table 6 Comparison of Primary Arterial Roads (PAR) and Primary Collector Roads-1 (PCR-1)

Classification	PAR	PCR-1
Connectivity	Among NAC, NAC with RAC	NAC with LAC, among RAC, RAC with LAC
Distance	Long distance, should not be disrupted by bi-directional traffic, local traffic, and local activities	Medium distance
Planned Speed	Min. 60 km/hour	Min. 40 km/hour
Capacity	Greater than its average traffic volume	Greater than its average traffic volume
Road width	Min. 11 m	Min. 9 m

Notes: NAC = National Activity Center; RAC = Regional Activity Center; LAC = Local Activity Center.
Source: [5]

4.1.4 Penalty multiplier factor (N)

The penalty multiplier factor (N) is established as the basis for the proposed formula calculation. The analysis shows that the penalty multiplier factor (N) used is the value of the self-estimated cost for routine work. This value is chosen because each service provider/contractor can bid on low-scope routine work, resulting in a low contract value for routine work. The 2018 Revision 2 General Specification for Road Construction imposes penalties for delays in meeting the road service level based on the value of the contract's work scope. Based on the analysis results, the penalty multiplier factor in the formula resulting from this study is the value of the routine work scope in the contract, in accordance with this regulation.

4.1.5 Public complaints factor (F_A)

The public complaints factor (F_A) was also established as the basis for the proposed formula calculation. The research results show that the types of complaints considered in the penalty formula calculation are those that have been verified by the National Road Implementation Center. Reports or complaints are gathered through various channels, including social media platforms (*Instagram*, *Facebook*, and *Twitter*), letters or email, *www.lapor.go.id*, Command Center *Bina Marga*, direct visits, and other mediums such as *WhatsApp*, *LaporGub*, *Jalan Cantik*, and other channels. The survey results indicate that a penalty multiplier of 1.5 times should be applied in the case of a complaint regarding road performance, and a penalty

multiplier of 2 times should be applied in the event of an accident caused by road damage.

4.1.6 Substandard road length (J)

The formula developed in this study considers the factor of road length that does not meet the criteria (J). Based on the literature review and analysis results, the penalty multiplier value in the developed formula is determined by dividing the length of any segment of at least 100 m of defective road (not meeting performance indicators) by the total road length (m) specified in the contract based on the scope of work. This calculation adheres to the guidelines provided by the Directorate General of Highways.

4.2 Trial of penalties model

4.2.1 Model trial on roads with short routine scope

The Keprekan-Muntilan-Salam road preservation package is a long segment package with a total contract value of $4,127,381. This package's scope of work encompasses standard enlargement, preservation reconstruction, road rehabilitation, routine road preservation, routine condition maintenance, holding, bridge preservation, and routine bridge preservation. Routine road preservation, routine condition maintenance, and holding are included in the management scope of the road performance indicators. These domains are subject to monetary penalties for failure to meet road service levels on time, with the following data breakdown:

- Self-estimated cost of routine scope (N or Nlp): $6.340.
- Length of routine scope: 3,430 m.
- Function and road system: Primary Arterial Road (PAR).
- Road Segments: Keprekan-Muntilan City Border; Muntilan-Salam (Boundary of the Special Region of Yogyakarta).

Table 7 Determination of penalty values for the preservation package of Keprekan-Muntilan-Salam road using the formula from the research results

Component	Type of Damage	Road Segment	Response Time	Actual Response Time	Koef	T (days)	F_V	F_A	J	S ($)
Road Pavement	Pothole, diameter < 10 cm and depth < 4 cm	Keprekan-Muntilan City Border	3	10	0.027	7	1	1.0	0.029	34.93
	Uneven patching	Keprekan-Muntilan City Border	7	11	0.027	4	1	1.0	0.029	19.96
	Pothole, diameter > 10 cm and depth > 4 cm	Muntilan- Salam	3	11	0.027	8	1	1.5	0.029	59.88
Road Shoulder	Ponding	Muntilan-Salam	7	9	0.020	2	1	1.0	0.029	7.39
Total										122.17

Notes: Exchange rate $1 = Rp15,902; Response time used is from Table 4; T or late is calculated by subtracting actual response time with response time; F_V for PAR is 1; F_A is 1 since there was no public complaints regarding this damage; J is calculated by dividing 100 m (this is the least number of defective road) with the length of road in the contract (3,430 m); N = $6.340.

Table 8 Determination of penalty values for the preservation package of Keprekan-Muntilan-Salam road using the formula from the Directorate General of Highways

Component	Type of Damage	Road Segment	Response Time	Actual Response Time	Koef	H (days)	Pjc/Pjl	D ($)
Road Pavement	Pothole, diameter < 10 cm and depth < 4 cm	Keprekan-Muntilan City Border	NA	NA	NA	NA	NA	NA
	Uneven patching	Keprekan-Muntilan City Border	NA	NA	NA	NA	NA	NA
	Pothole, diameter > 10 cm and depth > 4 cm	Muntilan-Salam	7	11	0.010	4	0.029	7.39
Road Shoulder	Ponding	Muntilan-Salam	NA	NA	NA	NA	NA	NA
Total								7.39

Notes: Exchange rate $1 = Rp15,902; Response time used is adopted from the 2018 Revision 2 General Specification for Road Construction; Response time with NA (not applicable) means that the type of damage is not listed in the regulation, and therefore, the service providers are not obligated to perform any maintenance; H is calculated by subtracting actual response time with response time; Pjc/Pjl is calculated by dividing 100 m (this is the least number of defective road) with the length of road in the contract (3,430 m); Nlp = $6.340.

4.2.2 Model trial on roads with long routine scope

The preservation and rehabilitation package for the Sruwen-Kartosuro-Klaten-Prambanan road is a long-segment project with a total value of $6,554,918. This programme entails widening to standard width, road rehabilitation, routine road maintenance, periodic bridge maintenance, and routine bridge maintenance. Routine road maintenance is included in the road performance indicator's scope of management. This scope is subject to financial penalties for failing to satisfy the road service level on time, as outlined below:

- Self-estimated cost of routine scope: $1,026,486.389.
- Length of routine scope handling: 68,270 m.
- Road function and system: Primary Arterial Road (PAR).
- Road segments: a. Sruwen-Boyolali Terminal; b. Pandanaran II Boyolali; c. Pandanaran I Boyolali; d. Perintis Kemerdekaan/Southern Ring Road Boyolali; e. Boyolali City Border -Kartosuro; f. Kartosuro-Klaten City Border; g. Perintis Kemerdekaan Klaten; h. Diponegoro Klaten; i. Kartini Klaten; j. Suradji Klaten; k. Klaten City Border-Prambanan.

Table 9 Determination of penalty values in for preservation and rehabilitation package of Sruwen-Kartosuro-Klaten-Prambanan road using the formula from the research results

Component	Type of Damage	Road Segment	Response Time	Actual Response Time	Koef	T (days)	F_V	F_A	J	S ($)
Road Pavement	Pothole, diameter > 10 cm and depth > 4 cm	Klaten City Border-Prambanan	3	10	0.027	7	1	2.0	0.001	568.35
Road Shoulder	Pothole, diameter < 20 cm and depth < 10 cm	Sruwen-Boyolali Terminal	7	9	0.020	2	1	1.0	0.001	60.14
	Ponding	Kartosuro-Klaten City Border	7	9	0.020	2	1	1.0	0.001	60.14
Drainage	Clogging	Southern Ring Road Boyolali	7	9	0.011	2	1	1.0	0.003	66.16
	Structural damage	Boyolali City Border-Kartosuro	14	19	0.011	5	1	1.0	0.004	248.09
Road Equipment	Damaged median	Kartosuro-Klaten City Border	7	11	0.001	4	1	1.0	0.001	6.01
Clearance	Wild vegetation	Diponegoro Klaten	7	10	0.017	3	1	1.0	0.009	460.09
Total										1,468.99

Notes: Response time used is from Table 4; T is calculated by subtracting actual response time with response time; F_V for Primary Arterial Road is 1; F_A is 1 since there was no public complaints regarding this damage; J is calculated by dividing 100 m (which represents the minimum number of road defects) by the length of road specified in the contract (68,270 m). However, for drainage clogging and structural damage and clearance, J is calculated by dividing 200, 300, and 600 m, respectively, by the length of road in the contract; N = $1,026,486.389.

Table 10 Determination of penalty values in for preservation and rehabilitation package of Sruwen-Kartosuro-Klaten-Prambanan road using the formula from the Directorate General of Highways

Component	Type of Damage	Road Segment	Response Time	Actual Response Time	Koef	H (days)	Pjc/Pjl	D ($)
Road Pavement	Pothole, diameter > 10 cm and depth > 4 cm	Klaten City Border-Prambanan	7	10	0.010	3	0.001	45.11
Road Shoulder	Pothole, diameter < 20 cm and depth < 10 cm	Sruwen-Boyolali Terminal	NA	NA	NA	NA	NA	NA
	Ponding	Kartosuro-Klaten City Border	NA	NA	NA	NA	NA	NA
Drainage	Clogging	Southern Ring Road Boyolali	7	9	0.010	2	0.003	60.14
	Structural damage	Boyolali City Border-Kartosuro	21	19	0.010	In compliance	0.004	0
Road Equipment	Damaged median	Kartosuro-Klaten City Border	21	11	0.010	In compliance	0.001	0
Clearance	Wild vegetation	Diponegoro Klaten	7	10	0.010	3	0.009	270.64
Total								375.89

Notes: Response time used is adopted from the 2018 Revision 2 General Specification for Road Construction; Response time with NA (not applicable) means that the type of damage is not listed in the regulation, and therefore, the service providers are not obligated to perform any maintenance; H is calculated by subtracting actual response time with response time; Pjc/Pjl is calculated by dividing 100 m (this is the least number of defective road) with the length of road in the contract (68,270 m). However, for drainage clogging and structural damage and clearance, Pjc/Pjl is calculated by dividing 200, 300, and 600 m, respectively, by the length of road in the contract; Nlp = $1,026,486.389.

The penalty value for delays in meeting road service levels for the preservation package of Keprekan-Muntilan-Salam road (short routine scope) is 16 times higher when using the formula derived from this study (Table 7) compared to the formula from the Directorate General of Highways (Table 8). In the case of the preservation and rehabilitation package of Sruwen-Kartosuro-Klaten-Prambanan road (long routine scope), the formula derived from this research (Table 9) resulted in a penalty value that was nearly 4 times greater than the formula from the Directorate General of Highways (Table 10). The difference in results between the two formulas occurs because, in addition to the impact of variables included in the formula, the proposed formula introduces new indicators for penalty consideration. For instance, the trial includes factors such as potholes with a diameter less than 20 cm and depth less than 10 cm, uneven patching, and ponding. Additionally, the proposed formula also employs the suggested response time for enhancing road performance.

4.3 Implication and application

The newly developed penalty formula introduces a significant advancement in ensuring road quality. It surpasses conventional methods of penalty calculation, providing a more sophisticated system. This modification has the potential to substantially impact how penalties operate and enhance the understanding of how companies manage roads. In regions where companies oversee road maintenance, challenges arise. Companies sometimes neglect rules and delay road repairs. The existing fines for these delays are minimal, often overlooked by companies. The formula acts as a tool to incentivize companies to comply with rules and improve road maintenance. The formula is not just theoretical; it can be applied in practical situations. It integrates smoothly into existing decision-making systems for road service, offering various benefits such as ensuring fair fines and holding companies accountable for their responsibilities. Its adaptability makes it a valuable tool for enforcing rules in different scenarios. However, it is crucial to acknowledge that the formula is not flawless. Its effectiveness may be influenced by the availability and quality of data, especially in regions where data collection is challenging. Additionally, it may not perform optimally in all road situations, as unforeseen variables could impact its predictive accuracy. Continuous refinement is necessary to enhance its practical utility and reliability in real-world enforcement scenarios.

5 Conclusions

This research successfully developed a new penalty formula for non-compliance in meeting road service levels applied to road service providers. This formula includes additional indicators such as coefficients for each road component based on their significance, proposed improved response time, traffic volume factor, and community complaint factor. In addition to these factors, the financial flow of the penalty system plays a crucial role. The results of the formula trial on two road sections yielded values that were 16 and 4 times higher than the fines resulting from the formula used by the Directorate General of Highways. These relatively high penalties are in line with the Asian Development Bank recommendation that payment deductions (in this case, penalties) should be sufficiently high to provide adequate incentives for contractors to comply. If payment deductions are too low, contractors are likely to be less compliant, while if they are too high, contractors will apply risk premiums to their tender prices. In contracts that apply financial penalties for each failure to meet road service levels, contractors/service providers strive to continuously improve performance while reducing costs. However, experience has shown that payment deductions are often not strictly enforced by the Asian Development Bank, including in Indonesia, so strict enforcement of penalties for delayed delivery of road service levels is necessary.

It is recommended to conduct further research related to the value of reducing payment penalties in road maintenance contracts in Indonesia. Future investigations should delve into the impact of strict penalty enforcement on contractor behavior and overall project outcomes, assessing whether heightened penalties lead to sustained improvements in road infrastructure quality. In addition, a comparative analysis of penalty systems in road maintenance contracts across different countries could uncover best practices adaptable to the Indonesian context. Furthermore, researchers should examine the role of effective stakeholder collaboration and communication in ensuring the successful implementation of penalty systems. The research should culminate in specific policy recommendations for enforcement agencies, offering guidelines for the monitoring, evaluation, and adaptation of penalty structures to enhance their effectiveness and fairness over time. Finally, long-term monitoring of road conditions and an assessment of public perception and community impact would contribute to a comprehensive understanding of the ramifications of such penalty structures.

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Talent identification for revolutionizing human resource management in Saudi Arabia's logistics industry
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Talent identification for revolutionizing human resource management in Saudi Arabia's logistics industry

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Keywords: logistics industry, talent pool, skills, competencies.
Abstract: The logistics industry in Saudi Arabia has seen a significant change, with national companies now focusing on hiring local talent to decrease their dependence on expatriates. Despite the increased demand for Saudization, logistics firms face difficulties in matching available local talent with industry-specific job requirements. This gap highlights the importance of connecting human resource development (HRD) with talent identification and assessment (TIA) practices. Study uses the DEMATEL technique to analyse the important factors that impact the effectiveness of Human Resources (HR) Departments in logistics firms in Saudi Arabia. A total of nineteen HR professionals from the logistics sector in the country took part in the study, offering evaluations on a Likert scale that ranged from 0 to 4 for each criterion. The research shows that the level of education has a strong impact on the potential and future development of job candidates in Saudi Arabia's logistics companies. Academic qualification, along with skills and competencies, greatly influences the evaluation of candidates. The criteria have influence values of 0.30559487, 0.007953708, and 0.628534572, respectively. In addition, the criterion of "Potential and Future Development" stands out as a significant factor that influences all others, except for "Skills and Competencies," with values exceeding the threshold of 0.926061035. Results highlight the importance of HR professionals prioritising cause criteria when selecting candidates and managing HR processes. By understanding and tackling these important factors, logistics companies can improve their methods of identifying and evaluating talent, ultimately boosting their organisational effectiveness and competitiveness in Saudi Arabia's ever-changing logistics industry.

1 Introduction

The logistics sector is considered a crucial component in Saudi Arabia's efforts to diversify its economy away from oil-based revenues and towards a more service-oriented economy. Logistics plays a crucial role in driving economic development and adding significant value by enhancing the efficiency and effectiveness of storing, handling, and transporting goods. As a result, the methods of freight and transportation would be enhanced, leading to cost reductions. It has been established that administrative innovation stands as one of the primary logistical capabilities of Logistics Service Providers [1]. Human resources is one of the key aspect of any organization [2]. Effective management of human resources is vital for the success of logistics enterprises [3]. The Kingdom of Saudi Arabia (KSA) has faced numerous challenges in its efforts to meet the increasing demands in developing its human resources. Investing in human resource development (HRD) has been a priority to enhance the skills, knowledge, and attitude of the workforce. This investment is anticipated to improve the effectiveness and efficiency of services in both the public and private sectors. Choosing competent managers is crucial for successful human resources management in logistics companies [4]. Knowledge-based HRM practices have a significant impact on the performance of logistics firms, and this impact is further enhanced by the role of logistics capability as a mediator [5]. The evolution of human resources departments in international companies, such as Kuehne+Nagel, showcases the transition towards a more strategic and consultative approach in overseeing employee motivation and commitment [6]. Strategic organisational challenges greatly influence human resources planning in SME logistics companies, underscoring the need to tackle these challenges for efficient management [7]. In the logistics industry, it is crucial to have efficient human resources management in order to retain talent, improve organisational performance, and stay competitive.

The primary objective of the Ministry of Transport and Logistics Services in Saudi Arabia is to improve the Kingdom's transport infrastructure with the aim of establishing it as a pivotal logistics centre that connects three continents. This endeavour is in accordance with the overall objectives of supporting sustainable economic development and enhancing competitiveness in keeping with the Saudi Vision 2030 programme. Saudi Arabia's advantageous geographical location, connecting three continents, makes it a crucial hub for global trade, enhanced by its plentiful natural resources. The National Industrial Development and Logistics Programme (NIDLP) takes the lead in promoting the growth of important sectors like mining, energy, industry, and logistics [8]. The rapid development has led to an increase in benefit categorization and a high demand for skilled professionals due to a shortage in the workforce [9]. Effective ability management is crucial for a business as it provides a significant competitive advantage. Effective

management of talent is crucial for a company's success and can lead to significant profits. Identification and evaluation of skills play a crucial role in developing a talented workforce [10]. However, there is a lack of literature addressing the specific circumstances in the Saudi Arabia regarding talent management of Logistic industries. It is estimated that the market size for the Saudi Arabia Freight and Logistics sector will be roughly 25.33 billion US dollars in the year 2024, and it is anticipated that this market size will expand to 32.88 billion US dollars by the year 2029 [11].

This research established that among the crucial issue associated to "Talent Identification and Assessment" for revolutionizing human resource management in Logistics Industry of Saudi Arabia, lies with the Streamlining and improving talent identification processes, that is how can Saudi Arabia's logistics industry can meet the goals of the NIDLP by successfully identifying and recruiting individuals with the right set of skills to fuel the expansion and efficacy of logistics services in the Kingdom. Another important research question that arises from the current study is whether there is a shortage of skilled workers in Saudi Arabia's logistics sector, specifically in key areas such as warehousing and storage, freight forwarding, freight transportation, and courier, express, and package services [12]. Finally, this research also delves into the challenges concern associated with assessing the effectiveness of human resource management techniques in logistics enterprises based in Saudi Arabia. This requires comprehending how these organisations are successfully attracting, keeping, and cultivating people through the use of diverse human resource management strategies and practices. Essentially, the main focus is on improving these methods in line with the goals of Saudi Vision 2030, which aims to promote sustainable growth in the logistics sector. The main inquiry is: How can different approaches be improved to completely transform logistic industry human resource management, creating a work environment that promotes the retention of talented individuals, facilitates career advancement, and enhances overall employee contentment?

2 Literature review

Revolutionizing Human Resource Management in Saudi Arabia's logistics industry involves talent identification and assessment to enhance organizational performance. Talent management practices in Saudi Arabian oil and gas organizations have highlighted the need for formal approaches in identifying talent and providing development opportunities [13]. Implementing logistics hubs (LHs) strategically can significantly impact Saudi Arabia's Logistics Performance Index (LPI) ranking, demonstrating the positive correlation between investing in logistics infrastructure and LPI ranking improvement [14]. Human Resource Management (HRM) practices in the Saudi Arabian manufacturing sector influence employee behavioral outcomes during organizational change, emphasizing the importance of organizational commitment, job performance, and employee productivity [15]. Additionally, developing e-recruitment support systems can streamline candidate selection processes, ensuring the best-fit individuals are identified for roles in the logistics industry [16].

Samarin et al. [17] explores the Saudi National Human Resources Development (NHRD) and provides viable solutions to improve NHRD within the context of a knowledge-based economy. The paper thoroughly analyses the complex interconnections between the political, economic, and socio-cultural aspects of the NHRD context. The challenges faced by different parts of the developing workforce, such as unemployed, women, and students, are thoroughly examined.

Iqbal [18] evaluates the influence of enhancing logistics on the factors of service quality (SQ) for Small and Medium Enterprises (SMEs) in Saudi Arabia. The study employed a quantitative methodology to investigate multiple industries and cities in Saudi Arabia, including Jeddah, Khobar, Dammam, and Riyadh. The study revealed three critical challenges faced by Saudi SMEs in the field of logistics: the availability of skilled logistics staff, effective inventory management, and the high costs associated with adopting advanced technologies. These factors were found to have a substantial impact on the overall improvement of logistics in these dimensions.

Alruwaili et al. [19] examine the effects of incorporating Human Resources (HR) best practices in the recruiting process of Saudi nationals, particularly those who have graduated from prestigious US and British colleges, on the performance indicators of Ma'aden Company. The performance dimensions being examined consist of technological skill, fluency in the English language, and the ability to adapt to globalisation. The study specifically examines a group of highly educated individuals who have obtained their degrees from colleges in the United States or the United Kingdom and are currently employed at Ma'aden Company. The report highlights the importance of Saudi graduates from renowned international universities in shaping human resource practices at Ma'aden Company. Moreover, it sheds light on their contribution to improving the company's performance in technological control, English proficiency, and adaption to global dynamics.

It is worth noting that there is a significant lack of research on talent management in Saudi Arabia and the wider Arab world, especially in GCC countries. That is why the Jamjoom [20] utilises quantitative analysis of survey data collected from experts and professionals across various sectors in Jeddah, KSA. The study's findings indicate that talent management practices are indeed implemented by organisations in KSA. It is worth noting that the study reveals no clear connection between the size or type of organisation and employee engagement in talent management practices. In addition, it indicates that there is no notable difference in talent identification and recruitment, whether it is during times of crisis or not. However, there is a noticeable difference in talent

development and retention between these periods. According to Aleisa et al [21], recruiters use candidate data to create metrics that help them choose the right candidates, while job seekers develop their own metrics to assess job offers and find the best opportunities. This paper explores how AI techniques can improve the Saudi labour market by connecting recruiters and job seekers. Based on the study's findings, it is clear that the proposed approach and technology have the ability to greatly assist the Saudi government in making well-informed and timely decisions. By providing a thorough understanding of the labour market dynamics, these tools offer valuable insights that can be used strategically.

Bahamdain et al. [22] examined private and public logistics customer satisfaction in Saudi Arabia during the COVID-19 epidemic. It was revealed that logistics service efficiency and quality recommendations. HR and IT managers collaborated to complete surveys, offering insights on the current status of HR systems in Saudi Arabia [23]. The results highlighted the preparedness of the Saudi market to embrace and execute novel strategies. Nevertheless, the levels of satisfaction with the existing solutions were comparatively low, which called for rapid remedial measures. Significantly, advancing, especially in adopting the SaaS model, is crucial to enhance firms' competitive edge and move them towards a more successful future.

Alotaibi [24] examined the ways in which e-commerce stores modified their business strategy to accommodate the needs of e-fulfilment clients. Furthermore, the current logistics model and the environmental responsibility associated with it will be examined. In addition, Saudi Arabia has recognised the significance of the environment in accordance with their vision for 2030. Transport has been increasingly crucial in recent years due to the rapid growth of e-commerce in the Saudi market. This has led to the need for further exploration of green logistics. In their study, Darwish et al. [25] analysed data from 157 multinational enterprises (MNEs) operating in Saudi Arabia. They discovered a strong correlation between the localization of the human resource management (HRM) function and the indigenization of the workforce. The study identified key factors that contribute to workforce localization, such as recruitment and training practices that are tailored to the needs of local employees. In their study, Alshammari [26] examines the role of knowledge management in mediating the relationship between organisational performance (OP) and human resource management (HRM) practices. The study revealed a substantial impact of HRM practices on knowledge management capacities, organisational culture, organisational performance, and organisational learning in Saudi Arabia. Almatter [27] assesses the influence of human resource management (HRM) techniques on the performance of organisations in the Kingdom of Saudi Arabia. The study aims to elucidate the primary concepts of HRM strategies and organisational performance by integrating perspectives from experts and professionals through a comprehensive examination.

This study focuses on addressing the research gap related to the effective implementation of human resource management (HRM) methods in the logistics business in Saudi Arabia. While numerous studies have explored different aspects of HRM strategies and their impact on overall organisational success, there is a clear lack of research specifically focusing on the unique challenges and opportunities within the logistics industry.

3 Conceptual framework

This research was conducted with a focus on the resource-based view (RBV) of the firm. The Resource-Based View (RBV) is a theoretical framework that aims to clarify and forecast the reasons behind organisations' ability to attain competitive advantage and thus achieve higher profits [28]. This idea conceptualises a firm as a collection of resources that generate capabilities, which can potentially serve as a strong source of competitive advantage. It also posits that company success is primarily determined by resources that possess the qualities of value, rarity, and high imitation costs [29]. Understanding the RBV theory is crucial for recognising the significance of internal resources such as human capital, knowledge resources, and leadership. These factors play a vital role in shaping competitive strategies and ultimately achieving sustainable competitive advantages. Through the effective utilisation of internal resources, companies can strengthen their market position, performance, and long-term sustainability in ever-changing business landscapes [30]. Some of the key variables establish from the theory include: "Human Capital", "Knowledge Resources", "Leaderships", "Competitive Strategies", Competitive Advantages" (see Figure 1).

Figure 1 The RBV theoritical framework

The "Knowledge resources" include the valuable knowledge and assets that an organisation possesses, such as intellectual property, patents, proprietary technologies, and organisational know-how. The "Leadership" is a crucial internal resource that has a significant impact on shaping organisational culture, strategy formulation, and execution. The human capital is the variable that this research explores and contributes towards its application, which dwell on the people who work and their collective talents, expertise, knowledge, and experience. The "competitive strategies" is sometimes called "Strategic Alignment", and it highlights the importance of aligning internal resources and capabilities with market opportunities and competitive dynamics to gain a competitive advantage. Hence, according to RBV theory, competitive advantages arise from having resources and capabilities that are valuable, rare, inimitable, and non-substitutable [28]. Companies that effectively utilise their internal resources to meet customer demands, outperform rivals, and achieve strong financial results can gain long-lasting competitive advantages. RBV underscores the ever-changing nature of competitive advantages, stressing the importance of ongoing investment in resource development, innovation, and strategic adaptation to stay competitive in evolving markets.

RBV theory acknowledges the importance of human capital as a vital internal resource that enhances a firm's competitive advantage. Human capital encompasses the various skills, knowledge, experience, and capabilities that individuals bring to an organisation. RBV highlights the significance of investing in human capital through recruitment, training, and talent development initiatives. Understanding how to effectively utilise human capital can significantly boost a company's competitive edge by promoting innovation, creativity, and productivity within the workforce. From the RBV, this study conceptualized "Human Capital" to dwell on "High-performance human resources" which are an extremely valuable logistic industry asset and are extracted from the "talent pool" consists of a select group of "highly skilled and valuable employees" (see Figure 2). The main argument of the study is that by effectively identifying and placing talented individuals in positions that align with their skills, an organisation can establish itself as a formidable force in the market.

Figure 2 The RBV theoritical approach towards human capital framework

However, it is important to consider the effectiveness of talent identification practices being used in Saudi Arabia in locating the right people. Are they effectively evaluating their talent using appropriate methods? What are the noticeable differences in job performance between employees who undergo assessments and those who do not? These questions have not received much attention, so they were the primary focus of this research. As a result, this study aimed to analyse the talent identification and assessment practices in the logistics industry of Saudi Arabia.

The talent pool from the RBV theoretical approach towards human capital framework presented in Figure 2, has been conceptual in this study to be derived from "highly skilled and valuable employees", this is further conceptualized to be associate to the following: "Academic Qualification", "Skills and Competencies", "Experience and Track Records", "Cultural Fit" and "Potential and Future Development" (See Figure 3).

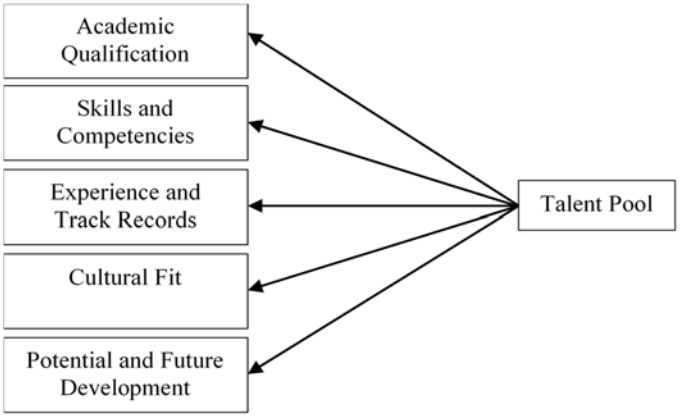

Figure 3 The proposed conceptual framework

3.1 Academic qualification

Academic qualification is operationally defined by this study to refers to the educational credentials obtained by an individual in the logistics industry, such as degrees, diplomas, certifications, and professional qualifications from accredited institutions. This criterion evaluates the extent of academic achievement and expertise in areas such as logistics management, supply chain management, transportation, and related fields. The justification of using this variable lies with the fact that, having a strong academic background is crucial for excelling in the field of logistics. It requires a diverse range of skills and competencies that are essential for achieving success in this profession. These skills encompass critical thinking, the ability to solve problems, strong interpersonal skills, creativity, the ability to work well in teams, effective management abilities, and a global mind-set. With the rise of technology and global collaboration, the logistics industry has experienced a significant change. This has resulted in a greater need for knowledge and expertise, affecting both manual and office-based roles. Modern teaching methods and information and communication technologies are now essential in educational programmes in logistics to adequately equip students for the industry.

3.2 Skills and competencies

Skills and competencies in this study pertain to the specific abilities, proficiencies, and technical knowledge required to thrive in the logistics industry. This criterion evaluates a candidate's practical skills in various areas such as inventory management, transportation planning, warehousing operations, freight forwarding, route optimisation, as well as their soft skills including communication, problem-solving, teamwork, adaptability, and attention to detail.

It is important to consider this variable because logistic companies need employees who possess a wide range of skills and competencies to effectively handle the complexities brought about by globalisation. In order to excel in the ever-changing field of logistics, it is crucial to possess a range of skills including interdisciplinary knowledge, problem-solving abilities, and effective coping skills. Human resources are essential for the success of service firms, as they have a significant impact on service quality and costs. This is particularly true in maritime logistics, where human factors continue to be crucial despite the capital-intensive nature of operations [32]. Effective logistics skills is crucial for maintaining a competitive edge. It requires a team of highly skilled employees who can navigate complex processes and possess strong social and decision-making skills. These factors have a direct impact on employee retention and overall performance. In general, there is a noticeable trend in the logistics sector towards valuing specialised critical skills rather than traditional hierarchical roles. This shift highlights the importance of being adaptable and proficient in uncertain environments.

3.3 Experience and track records

Experience and track records is operationally defined in this study as the reflection of professional background, work history, and demonstrated achievements of an individual within the logistics sector. This criterion evaluates the extent and variety of hands-on experience in positions related to logistics operations, including logistics coordination, warehouse supervision, transportation management, customs clearance expertise, and procurement responsibilities. It involves evaluating the length of employment, range of duties, noteworthy achievements, and performance reviews.

The reason for using this variable lies with the fact that, the success and efficiency of a logistic company are intricately linked to its level of expertise, past performance, and effective management strategies. Having a strong background in partnership management, collaboration, and building relationships is crucial for achieving success in logistic partnerships [33]. In addition, the development of logistic operators and their integration into the economic system is essential for optimising logistics processes for companies, resulting in higher profitability and stability in the global market. In addition, the evaluation of logistic management in various countries, based on indicators such as customs, infrastructure, and timeliness, emphasises the significance of expertise and effective management practices in the logistics industry. Implementing tracking systems in logistics and transportation operations can greatly improve fleet optimisation, cost reduction, and asset utilisation while also enhancing driver safety, because the importance of track records in logistic operations cannot be overstated.

3.4 Cultural fit refers

Cultural fit is operationally defined as the compatibility with the company culture, can be measure by the extent where the compatibility between an individual's values, work style, and behavioural traits with the organisational culture in the logistics industry in Saudi Arabia. This criterion assesses how well a candidate aligns with the company culture, including factors like work ethic, collaboration, respect for hierarchy, adaptability to cultural nuances, and dedication to organisational goals and vision.

The justification of adopting this variable lies with the fact that the compatibility of corporate culture within logistic companies is a key factor in determining their success and performance [34]. Research suggests that the culture within an organisation has a significant impact on various aspects such as knowledge sharing, communication, decision-making, and interpersonal relationships among employees. In addition, the culture of a company, specifically the adhocracy and market orientation culture, has a positive effect on the innovation of firms in the logistics sector. Implementing effective innovation management practices is crucial in cultivating an innovative organisational culture within logistics companies. This fosters a stronger commitment to

innovation and the development of core organisational values. Thus, it is crucial for logistic companies to prioritise compatibility with the company culture in order to improve knowledge sharing, decision-making, innovativeness, and overall performance.

3.5 Potential and future development

The potential and future development of an individual within the logistics industry in Saudi Arabia in this study can be determined by their inherent capabilities, aptitudes, and growth prospects, which are influenced by the changing landscape of the industry. This criterion evaluates not just the present skills and competencies, but also the ability to learn, adapt to change, demonstrate leadership potential, and be prepared for future roles and responsibilities within the organisation. It entails recognising individuals with great potential for growth and investing in their professional development through training, mentoring, and opportunities for career advancement.

The justification of selecting this variable lies with the fact that the growth and advancement of a logistics organisation encompass multiple factors, including sustainable development, the provision of value-added services, and the incorporation of innovative ways in the market. Sustainable development involves achieving internal stability through the use of management techniques and ensuring external stability at the global, regional, and national levels [35]. The production of value-added services in logistics is essential for efficiently meeting client demands and growing the range of services provided, so contributing to the overall success of the firm. The development of logistics potential is influenced by various factors, such as the implementation of new technologies, the extensive utilisation of information systems, and the incorporation of environmental considerations to ensure sustainable business practices. Moreover, the use of cutting-edge logistical strategies, such as fourth-party logistics, can prompt changes in the geographical distribution of global production networks and improve service offerings by forming partnerships with multinational corporations.

4 Methodology

This study employs the Multi-criteria decision making (MCDM) technique, which is a methodical strategy utilised to assess and rank alternatives or courses of action in situations where many, frequently competing, criteria must be simultaneously taken into account. MCDM approaches are designed to assist decision-makers in choosing the most appropriate option from a group of possibilities, considering multiple criteria or objectives that may vary in priority or preference. MCDM provides a methodical and organised approach to handling intricate decision-making situations, allowing decision-makers to take into account many viewpoints, goals, and limitations in a clear and logical way. MCDM approaches facilitate organisations in making well-informed and resilient decisions that are in line with their aims and objectives by considering a wide range of criteria and preferences.

The justification of using this method for this study lies with the fact that "Experts" who have a deep understanding of the Saudi Arabian logistics industry can offer valuable insights into the specific skills, competencies, and attributes required for success. MCDM requires expert evalaution, with a deep understanding of the industry's changing dynamics. Similarly, professionals who possess a strong understanding of different cultures and are well-versed in the business practices of Saudi Arabia can skillfully evaluate compatibility of local culture and HRM operations. This is also associted to having a strong grasp of the intricacies of the logistics industry. The final justification lies wth the fact that Karahan et al. [4] established that "Multi-criteria decision-making methods" are commonly used for the manager selection problem, and that it why the study identified ten criteria for selecting a human resources manager in logistics companies and applied the intuitionistic fuzzy weighted averaging (IFWA) method for weighting criteria in order to determine the most important key criteria among them. The finding of the analysis revealed that the "experience criterion" was determined as the most important for selecting a logistics human resources manager. Furthermore, Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique which belong to the MCDM is used to understand the influential characteristics of the challenges to Human Resource (HR) Practices in start-up companie.

4.1 DEMATEL process

The DEMATEL approach is a sophisticated analytical tool that is utilised in the process of decision-making to gain an understanding of the intricate correlations that exist between the many components. The ability to visualise the cause-and-effect linkages between various criteria or elements is beneficial to decision-makers because it enables them to discover significant drivers and dependencies within a system. DEMATEL is especially helpful in circumstances in which numerous criteria or variables interact with one another, making it difficult to establish the relative relevance or influence of each of these factors.

The purpose of the activity was to have experts evaluate the criteria by considering the different components of each criterion. These components were designed to empower the expatriate and give them more control over their personal experience. Experts assign a value to $\boldsymbol{x_{ij}}$to indicate the significance of each criterion's impact. The values are determined based on the cause and effect criteria, denoted by *i* and *j*. Therefore, an expert's response is obtained for each value of $n = 1,2,3\ldots, n$. This results in a non-negative $n \times n$ direct relation matrix, formed by equation (1):

$$\boldsymbol{x^y} = \left[\boldsymbol{x_{ij}^y}\right]_{n \times n} \quad (1)$$

The variable y denotes the number of representations for each expert, with a range of $\mathbf{1} \leq \boldsymbol{y} \leq q$. The equation generates a matrix q for x^1, x^2,… x^q where q is the total number of experts. Equation 2 presents the average aggregated decision matrix for all the expert $Z=,\left[\boldsymbol{z_{ij}}\right]$ (2).

$$\boldsymbol{Z_{ij}} = \frac{\mathbf{1}}{\boldsymbol{q}}\sum_{\boldsymbol{i=1}}^{\boldsymbol{q}} \boldsymbol{x_{ij}^{y}} \quad (2)$$

Step 2: Generating the normalised direct relation matrix: The matrix *D*, which represents the direct relations, is created using equation (3).

$$D = max\left(\max_{1\leq i\leq n}\sum_{j=1}^{n} z_{ij}, \max_{1\leq j\leq n}\sum_{i=1}^{n} z_{ij},\right) \quad (3)$$

Consequently, every individual cell within matrix Z will possess a value that lies within the numerical interval of 0 to 1.

Step 3: Generating the total relation matrix involves exponentiating the normalised initial direct-relation matrix D to the power of m, where m indicates the indirect impact D^m. The resulting matrix, denoted as *T*, shows the cumulative influence generated by the participant's response. The total relation matrix T may be obtained by summing up the direct-relation matrices $D+D^2+...+D^m$. As D^m converges to zero, we can conclude that T is identical to the initial direct-relation matrix D. Therefore, the total relation matrix T can be expressed as $T = D + D^2 + ... + D^\infty$, which can be further simplified as $T= D+D^2+\ldots+D^\infty$ *is* $T=\lim_{m\to\infty}(\boldsymbol{D + D^2 + D^3 ... + D^m}) = \boldsymbol{D(I - D)^{-1}}$. Therefore (4):

$$\boldsymbol{T = D(I - D)^{-1}} \quad (4)$$

where *I* represents an identity matrix with dimensions $n \times n$.

Developing the rows and columns of the matrix is the fourth step. The vectors that are used to represent the rows and columns that are included in the total relation matrix. If the vectors *r* and *c*, respectively, are used to represent the total of the rows of matrix *T* and the total of the columns of matrix *T*, then the following is true if the following is true (5):

$$\boldsymbol{r} = [\boldsymbol{r_i}]_{n\times 1}=\left[\sum_{j=1}^{n} \boldsymbol{t_{ij}}\right]_{n}\times_1 \text{ and } \boldsymbol{c} = \left[\boldsymbol{c_j}\right]_{1\times n}=\left[\sum_{j=1}^{n} \boldsymbol{t_{ij}}\right]_{1}\times_n \quad (5)$$

If *j* is equal to *i*, then the sum of r_i and c_j will represent the influence that criterion *i* has on *j*. If *j* is not equal to *i*, the sum will reveal the overall effects experienced by criterion *i*, while the difference will show the net impact that criterion *i* contributes to the system. Conversely, if the value is positive, criteria *i* functions as a primary cause, and if it is negative, it functions as a primary effect. If the difference between $\boldsymbol{r_j - c_j}$ is positive, then the criteria have a significant influence on the other criteria, and they can be classified as part of the cause group. Conversely, if the difference between $\boldsymbol{r_j - c_j}$ is negative, it indicates that the criteria in question are being influenced by the other criteria collectively and should be classified as the "effect." Hence, the sum of *r* and *c* is referred to as the "Prominence," whilst the difference between *r* and *c* is referred to as the "Relation."

Step 5: Establishing a threshold value (α) for the purpose of generating an interaction diagram. Equation 7 is derived to determine the threshold value for the impact connection (6).

$$\boldsymbol{\alpha} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{n}}\sum_{\boldsymbol{j=1}}^{\boldsymbol{n}} \boldsymbol{t_{ij}/N} \quad (6)$$

The variable *N* represents the total number of matrix elements that will be obtained by calculating the average of the members of the matrix *T*. This calculation is done to identify and remove any impacts that are judged to be minor. This implies that the impact connections will not encompass any impacts that are less severe than the threshold value, as there will be none.

Step 6: Generating the relational diagram illustrating the causal relationship between factors and their effects: The results obtained from the calculations carried out in the previous steps will be used as the foundation for the relationship diagram. Therefore, the correlation between the cause and effect has been assigned to each of the coordinate sets that make up the full array of rows and columns. The rows and columns in this illustration depict the interactions between the criteria and provide valuable information for determining the relative importance of each criterion and how they interact with one another.

5 Analysis and presentation of the result

The DEMATEL technique was employed to investigate the key parameters influencing the effectiveness of competitive intelligence. To obtain the outcome of the analysis, the initial step is to code the criteria and input the data into an MS Excel sheet labelled "Academic Qualification" (AQ), "Skills and Competencies" (SC), "Experience and Track Records" (ET), "Cultural Fit" (CF), and "Potential and Future Development" (PF). Once the data collection process is over, this step marks the initial stage of collecting the analysis results. Hence, the viewpoints of the 19 specialists who took part in this study and shared their feedback on a Likert scale with whole number values ranging from 0 to 4, have been gathered and incorporated into an initial individual matrix. This matrix is presented in the form of an n×n non-negative direct relation matrix, as per equation 1. The presented matrix displays the mean total of decision matrices (Z) derived from the input of 19 experts from the Human Resources Department of logistics organisations in Saudi Arabia.

$$Z = \begin{bmatrix} 0 & 2 & 3 & 2 & 4 \\ 1 & 0 & 4 & 3 & 1 \\ 4 & 1 & 0 & 2 & 4 \\ 1 & 4 & 2 & 0 & 2 \\ 4 & 2 & 4 & 3 & 0 \end{bmatrix}$$

These experts have more than 10 years' record of evaluating logistic companies job-seeking candidates based on five criteria: (AQ, SC, ET, CF, and PF). The descriptive analysis of this total decision matrices suggest that the experts assessed the impact of "Academic Qualification" on itself as 0, indicating no direct influence., whereas, it has the greatest impact on "Potential and Future Development", as indicated by an average score of 4. This implies that experts firmly believe that a candidate's academic qualifications significantly contribute to their potential and future growth. It was also revealed that the greatest impact on "Experience and Track Records" comes from "Skills and Competencies" (with a score of 4), indicating that experts consider a candidate's skills and competencies to be highly indicative of their previous experiences and performance.

Experts assign equal weightage (score of 4) to "Academic Qualification" and "Potential and Future Development" when considering "Experience and Track Records". This suggests that a candidate's experience and track record are deemed equally significant in evaluating their academic qualifications and future potential. However, the most significant impact of "Cultural Fit" is on "Skills and Competencies", as indicated by a score of 4. This implies that experts prioritise a candidate's alignment with the "organization's culture" when assessing their abilities and qualifications. On the other aspect of the greatest impact from "Potential and Future Development", it was revealed that it is evenly divided between "Academic Qualification" and "Experience and Track Records" (both with a score of 4), suggesting that experts view a candidate's potential and future growth as being equally affected by their educational background and previous accomplishments.

These scores represent the combined viewpoint of the 19 HR experts on the importance of each criterion when assessing candidates for positions in logistics companies in Saudi Arabia. However, the interactions as well as the causes and effect of these outcome are not yet revealed at this point.

Following the descriptive analysis of the total decision matrices, a normalized direct influence matrix was derived by utilizing equation 3, and the result is the normalized matrix *D* displayed below:

$$D = \begin{bmatrix} 0 & 0.153846154 & 0.230769231 & 0.153846154 & 0.307692308 \\ 0.076923077 & 0 & 0.307692308 & 0.230769231 & 0.076923077 \\ 0.307692308 & 0.076923077 & 0 & 0.153846154 & 0.307692308 \\ 0.076923077 & 0.307692308 & 0.153846154 & 0 & 0.153846154 \\ 0.307692308 & 0.153846154 & 0.307692308 & 0.230769231 & 0 \end{bmatrix}$$

The expert's response is used to get the normalised initial direct-relation matrix, and equation 4 is used to determine the total relation matrix, which refers to the total influence generated by the expert's response. This matrix is valuable for decision-making processes.

$$T = \begin{bmatrix} 0.841906236 & 0.829006339 & 1.169003391 & 0.915538847 & 1.13105558 \\ 0.736819991 & 0.561897391 & 1.016828837 & 0.811278195 & 0.784542238 \\ 1.098474126 & 0.783200649 & 0.9910143 & 0.922055138 & 1.152712664 \\ 0.719570986 & 0.806774289 & 0.915251364 & 0.625814536 & 0.815207135 \\ 1.184144184 & 0.922534277 & 1.339960195 & 1.065413534 & 1.011521451 \end{bmatrix}$$

By computing the sums of the rows and columns of the matrix that generates the total relation matrix, also known as the rows matrix vectors and columns matrix vectors of the total relation matrix, one can establish the causes and effects based on the study. The solution of equations 5 yields these outcomes. In other words, "cause" and "effect" can be determined if the vectors *r* and *c* represent the sum of the rows and the sum of the columns of the entire relation matrix. This enables the identification of "cause" and "effect." As a result, the result of the computation is displayed in the matrix Table 1.

Table 1 Direct influenced of the criteria among themselves

Criteria	r_i	c_i	r_i+c_i	r_i-c_i	***identity***
AQ	4.886510394	4.580915524	9.467425918	0.30559487	*cause*
SC	3.911366652	3.903412944	7.814779596	0.007953708	*cause*
ET	4.947456877	5.432058086	10.37951496	-0.484601209	*effect*
CF	3.88261831	4.340100251	8.222718561	-0.45748194	*effect*
PF	5.52357364	4.895039068	10.41861271	0.628534572	*cause*

Criteria such as "Academic Qualification", "Skills and Competencies", and "Potential and Future Development" are recognized as determinants that significantly influence the assessment of candidates in several aspects. The HR department may prioritize cause criteria when evaluating recruits or creating training and development programs. These factors are essential for success in employment within the logistics business and therefore attract significant consideration during the selection process. Criteria categorized as "effect" are those that are impacted by other criteria. Secondary factors are influenced by the major drivers that have been recognized as the causes. Within the HR department of logistics firms in Saudi Arabia, the term "effect" criteria refers to traits or qualifications that are the result of other elements. For instance, Experience, Track Records, and Cultural Fit are categorized as effects, implying that they are influenced by other factors such as Academic Qualification and Skills and Competencies.

The next essential step is constructing an interaction diagram, this is established by a threshold value, obtained from the full relation matrix using Equation 7. As a result, the threshold value is estimated to be 0.926061035. This value signifies that any value in the total relation matrix that above the threshold has an impact on the relationships diagram, whereas any value in the total relation matrix that is below the threshold value does not impact the relationships diagram. Consequently, the values that are being scrutinised have been emphasised in bold inside the matrix provided in Table 2.

Table 2 The values that determine the relationships impact

	AQ	SC	ET	CF	PF
AQ	0.841906	0.829006	**1.169003**	0.915539	**1.131056**
SC	0.73682	0.561897	**1.016829**	0.811278	0.784542
ET	**1.098474**	0.783201	**0.991014**	0.922055	**1.152713**
CF	0.719571	0.806774	0.915251	0.625815	0.815207
PF	**1.184144**	0.922534	**1.33996**	**1.065414**	**1.011521**

Table 2 displays the values that define the impact of relationships between various criteria. The values are utilised to depict arrows in a diagram (See Diagraph in Figure 4) in order to graphically illustrate the connections between the criteria. AQ has a direct influence on ET as well as PF. This implies that when evaluating AQ, HRM should also take into account ET as well as PF. Two arrows are depicted in the diagraph, originating from AQ and pointing towards ET and PF, respectively. SC solely influence ET. When assessing SC, it is important to thoroughly examine ET. A directional arrow is depicted, originating from the source node SC and pointing towards the target node ET in the diagraph. ET have a direct influence on both AQ and PF. ET significantly influence both AQ and PF. The diagraph includes two arrows originating from ET and pointing towards AQ and PF, respectively. Additionally, there is a looping arrow that represents the impact of ET on itself. CF appears to have no influence on any other criteria. Consequently, there are no arrows originating from CF in the diagraph.

PF is the sole determinant that influences all other criteria, with the exception of SC. This indicates that PF has a pivotal role in exerting influence on other criteria. The diagraph illustrates the influence of PF on three criteria: ET, CF, and PF itself. This is shown by three arrows drawn from PF to each of these criteria. The diagraph interconnects mutual influence of the variables in the decision-making process of HRM in logistics organisations in Saudi Arabia. This research serves to illuminate the correlations between criteria and underscores the need of taking into account several elements when assessing applicants or making HR-related choices (Figure 4).

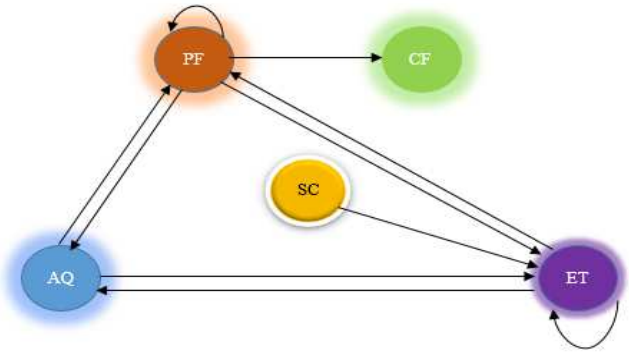

Figure 4 The interrelationship diagraph

6 Discussion and implication of the study

The study utilises the DEMATEL technique to examine the crucial factors that impact the efficiency of competitive intelligence in the Human Resources Department of logistics companies in Saudi Arabia. By employing this method, the study seeks to reveal the cause-and-effect connections among various criteria. Within logistics companies, the assessment of Saudi Arabia logistic companies job-seeking candidates is significantly influenced by parameters such as Academic Qualification, Skills and Competencies, and Potential and Future Development, according to the study. These parameters are considered significant factors and are given high priority in

the evaluation process, highlighting their crucial role in candidate selection and HR decision-making.

Through a thorough examination of the connections between various factors, this study uncovers the intricate web of cause and effect relationships. Identifying primary drivers that influence other criteria includes factors such as academic qualifications and skills and competencies. However, the outcomes of effect criteria, such as Experience and Track Records and Cultural Fit, are influenced by the cause criteria. Having a clear understanding of these relationships is essential in order to develop recruitment strategies and training programmes that are specifically tailored to meet the organization's needs. The study underscores the importance of Potential and Future Development in candidate assessment, highlighting its significant impact on other criteria. It is crucial to take into account a candidate's potential for growth and development when making HR decisions in logistics companies. The study's findings provide valuable insights for HR management in logistics companies in Saudi Arabia. Through a deep understanding of the connections between various factors, HR professionals can create evaluation methods that are more comprehensive and impactful when it comes to selecting, training, and developing candidates. By focusing on key factors like Academic Qualification and Skills and Competencies, you can easily identify top talent. Additionally, considering factors like Experience and Cultural Fit can greatly contribute to building a strong and high-performing workforce.

This study makes a valuable contribution by utilising the DEMATEL technique to analyse the intricate relationships between various criteria. This approach offers a well-organized framework for comprehending cause-and-effect relationships and their impact on HR decision-making processes. Utilising quantitative data analysis and visualisation techniques can greatly improve the understandability of the results and support well-informed decision-making. Although the study has made valuable contributions, it does have some limitations. For example, the sample size of 19 HR experts may not provide a comprehensive representation of the various perspectives within logistics companies in Saudi Arabia. Future research may consider addressing this limitation by increasing the sample size and conducting comparisons across different industries.

Similarly, studies should focus on the relevance of the results in various sectors and areas within Saudi Arabia in order to provide a comprehensive explanation of "Saudization" since they may not be universally comprehended. In addition, it would be beneficial to conduct a more in-depth analysis to examine how various factors impact employee performance and the overall success of the organisation in the long run. The study offers valuable insights into the factors that impact the effectiveness of competitive intelligence in the HR department of logistics companies in Saudi Arabia. Through a deep understanding of the cause-and-effect connections between various factors, HR professionals can create customised recruitment and HR management strategies that meet the specific needs of the organisation. This, in turn, leads to improved performance and competitiveness within the logistics industry.

7 Conclusion

Ultimately, this study employs the DEMATEL technique to examine the crucial criteria that impact the Talent pool of HR of logistics companies in Saudi Arabia. By thoroughly examining the criteria, this study provides valuable insights into the connections between these criteria and their impact on HR decision-making processes. The study's findings emphasise the crucial significance of specific factors, including Academic Qualification, Skills and Competencies, and Potential and Future Development, when evaluating job applicants in the logistics industry. These criteria are crucial factors that are carefully considered during the evaluation process, highlighting their significant role in candidate selection and HR management. In addition, the study explores the relationships between different criteria, shedding light on both the causes and effects and offering a holistic understanding of their interconnections. Having a deep understanding of these relationships is crucial in order to develop recruitment strategies, training programmes, and HR management practices that are customised to meet the unique needs of logistics companies in Saudi Arabia. The study's findings have practical implications for HR professionals, providing valuable insights to improve candidate selection, training, and development processes. By focusing on cause criteria and effectively addressing effect criteria, HR departments can enhance their recruitment efforts and cultivate a unified and high-performing workforce. The study makes a valuable contribution by utilising the DEMATEL technique to analyse intricate relationships between criteria in a systematic manner.

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Optimizing scholarship distribution: a management information system approach
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Optimizing scholarship distribution: a management information system approach

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Keywords: scholarship, distributions, management information system, rapid application development.
Abstract: Baitul Mal Unisba (BMU), a zakat-based philanthropic institution, offers scholarships to its students, aiming not only to support their tuition but also to foster exceptional character development. This research addresses a significant challenge at BMU: the inefficiency in its administrative processes due to the absence of a robust information system. The study proposes developing a management information system to optimize scholarship distribution, precision, and accuracy of managing scholarship data - from collection and recording to processing and reporting. This improvement is anticipated to support more informed decision-making in scholarship distribution. The system was built using the Rapid Application Development process, which consists of three stages: requirements planning, workshop design, and implementation. The emphasis is on the optimal use of scholarship funds, time, and manpower. This research made an important contribution by developing a prototype of a web-based scholarship information system aimed at improving the effectiveness of distribution. The newly created scholarship management information system improves these processes by removing duplicate tasks and streamlining the overall workflow. It provides comprehensive data for the decision-making panel, including academic performance, activity reports, and scholarship quotas. Initial testing of the prototype shows that it meets all functional requirements, suggesting its potential effectiveness in resolving the current challenges in BMU's scholarship selection and distribution process.

1 Introduction

The rapid evolution of information technology (IT) has significantly enhanced the efficiency and effectiveness of various sectors. This technological progress draws increasing interest from diverse organizations, including those in the philanthropic domain, to upgrade their IT performance [1]. In the field of philanthropy, IT plays a crucial role, especially for organizations involved in collecting and distributing donations [2]. The implementation of IT in zakat management systems notably impacts the quality of management reporting, both financially and non-financially [3]. Baitul Mal Unisba (BMU) as a zakat philanthropic institution should also look for the possibility of using information technology to improve its services. BMU, operating under the Universitas Islam Bandung, focuses on zakat, infaq, and alms funds management and distribution. Its primary program is a scholarship initiative for Unisba students. These scholarships, awarded based on merit, Quran memorization, and financial need, are pivotal for fostering competent and competitive resources [4]. Ensuring objectivity in their distribution is essential for aiding students in their academic pursuits [5].

BMU utilizes various communication channels to promote the scholarship program, including its website, Instagram, WhatsApp, and email. The rapid spread of information via these platforms necessitates careful content management to prevent misinformation [6]. The program provides financial assistance and focuses on character-building through various coaching activities. Participation in these activities, along with academic performance, is crucial for the annual scholarship renewal assessment. However, BMU faces challenges due to non-integrated computer systems for tracking scholarship recipients' activities, leading to inefficiencies and reduced organizational effectiveness. This situation delays decision-making and impacts the optimal distribution of scholarships.

Optimizing scholarship distribution aims to ensure the efficient and effective use of educational financial aid in meeting its designated objectives. To enhance scholarship distribution, various factors need consideration, including the criteria for awarding scholarships, the quantity of aid

provided, and the equity of the selection process. Numerous studies focus on augmenting scholarship allocations, incorporating technological advancements. The integration of information technology streamlines the submission, processing, and monitoring of scholarship applications. The utilization of machine learning for enrollment estimation has seen limited exploration in scholarship disbursement strategies [7]. Employing neural networks and genetic algorithms to fine-tune financial aid allocation [8] and leveraging student application data in higher education for scholarship optimization through machine learning and numerical methods are emerging approaches [9].

The research question is how the design of BMU's information system can minimize inefficiencies, eliminate redundant activities, simplify the overall workflow, and enhance organizational efficacy, thereby expediting decision-making processes to refine scholarship distribution. This study aims at designing a scholarship information system based on user needs. The users, in this case, are students who apply for the scholarships BMU Administration processes the applications. BMU scholarship information system can be used to manage academic information and student activities for scholarship recipients. Thus, academic progress and other coaching activities can be stored and retrieved to assess scholarship applications.

This study presents a distinctive approach to the development of information systems that are tailored to effectively facilitate the process of distributing scholarships. These systems are meant to cater to the distinct requirements and intricate nature of scholarship distribution. The present method incorporates multiple criteria for scholarship selection, including academic records, student involvement in extracurricular activities, and the availability of quotas. This integration aims to enhance the precision and reliability of the scholarship recipient selection process.

Rapid Application Development (RAD) is a prototyping-focused iterative application development approach that may be completed in a short period with a team of two to six people [10]. The RAD method is frequently employed in the domain of business software development. Its application in the realm of scholarship management can yield significant contributions. The outcome of this study yielded a prototype of a web-based system for disseminating scholarship material, to enhance accessibility and expand the user base. The utilization of the system can enhance the efficacy and accuracy of the decision-making process about scholarships, hence offering substantial advantages to the awarding organization.

2 Literature review

The literature review presents concepts and techniques in Rapid application development (RAD), Business process management notation (BPMN), Entity relationship diagram (ERD), and Use Case Diagram (UCD).

2.1 Rapid application development

The waterfall model and its variations are examples of traditional system development methodologies. RAD is a collection of methodologies intended to address the flaws of traditional methodologies [11]. Rapid Application Development can help in producing high-quality systems, while at the same time lowering the development cost and time [12]. This paradigm stresses a quick planning process and focuses on the software development process, testing, and feedback in its use [13].

There are three methods for implementing it: (i) iterative development, (ii) system prototyping, and (iii) single-use prototypes. A project is divided into series/versions that will be progressively produced through iterative development. The most crucial aspect of this strategy is creating the initial version of the system. A simplified waterfall approach was used to create this version quickly. Once implemented, users can provide feedback for the improvement of the next version of the system. Figure 1 depicts the phases of development.

2.2 Business process model notation

Business Process Model Notation (BPMN) is an essential modeling method. BPMN's core function is to visually represent business processes, aiming to enhance and refine aspects such as quality, time, and cost efficiencies. BPMN's major purpose is to offer a universally understandable notation that is accessible to a diverse range of stakeholders involved in business operations. This includes business analysts, who create initial process designs, technical specialists responsible for implementing the technology necessary to execute these processes, and managers overseeing their execution [14]. BPMN modeling aims to give notes that are simple to comprehend and comprehend by businesspeople. The purpose of BPMN is to serve as a link between the design and implementation processes. BPMN 2.0 offers a unified specification encompassing the notation, metamodel, and interchange format of the novel business process model. However, it does so with an altered vocabulary that maintains the BPMN label. Aligning BPMN, facilitating the interchange of business process models, and diagram layouts, and expanding BPMN to allow symphonic models and choreography are all features accessible in BPMN 2.0 [15].

2.3 Entity relationship diagram

The Entity-Relationship Diagram (ERD) is a model defined as a graphical representation of a data set's logic that includes a complete description of all entities, relationships, and restrictions [16]. ERD is also known as a technique for modeling data needs, and it is commonly used in system analysis and process requirements analysis of systems development projects. Based on the preceding

description, it can be stated that an ERD is a graphical representation of a data model that offers a complete image of all entities, and connections, and solves problems using analytical methods [17]. This ERD connects the contents to create conceptual data models, data structure and relationship modeling, and logical and physical DBMS implementations. This data modeling is viewed entity-relationship diagram by considering the required or not required provisions. Then, entity relationships can assist in answering the questions that need to be answered and how to apply the answers to the data.

2.4 Use case diagram

A use case diagram (UCD) visualizes a system's behavior and the actors who interact with it. When the system reacts to requests from actors, use cases define what happens in all circumstances. The principal actor initiates a system request based on the aim, and the system responds to the proposal [18]. In systems analysis, a use case is a method for identifying, clarifying, and managing system requirements. UML (Unified Modeling Language) serves as the preeminent modeling language for tangible systems and objects [19], use case diagrams are utilized Use case diagrams are a subclass of the Unified Modeling Language (UML) behavior diagrams [20].

3 Methodology

This research describes the system using the Rapid Application Development (RAD) development approach as a step method and focuses more on development [21]. The phases of this process resulted in the creation of a prototype that may be utilized as a foundation before being implemented on a real natural them. The three steps are the requirements planning stage, workshop design, and implementation. A system request and feasibility study are used to determine the planning stage. Before identifying, the study first collected information through direct interviews with several stakeholders, including directors, heads of programs and services, collection and marketing staff, and financial administration staff of BMU. Interviews were also conducted with representatives of students who will apply for scholarships and students who have received scholarships for 3 years. Other information was also obtained from documents and files of BMU.

Modeling business processes, identifying functional and non-functional system requirements, logical modeling using BPMN 2.0 for business process modeling [22], activity interaction modeling Use case Diagrams, and data modeling Entity-Relationship Diagram (ERD), which is one of the techniques used to model an organization needs, are all stages of the analysis. Analysts often use ERD to create systems, engineering diagrams, or visual aids. It is the foundation for constructing the relational database that underpins the information system [23].

The next step is to create a prototype design consisting of designs carried out in the system, such as physical business process modeling, physical data modeling, and prototype interface design using Figma. The system will be built utilizing an app server with a code igniter (CI) framework. As well as using Visual Studio Coding as a code editor. Figure 1 depicts the stages of the Rapid Application Development (RAD) stage technique. Rapid Application Development (RAD) steps are requirements planning, RAD design workshop, and implementation [24], as shown in Figure 1.

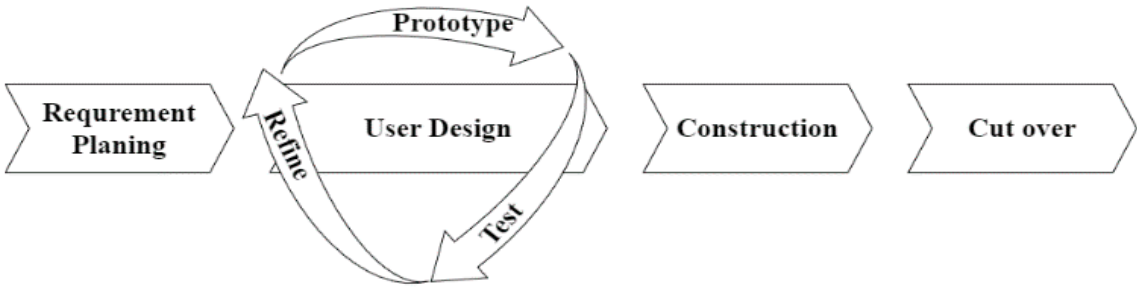

Figure 1 Method of Rapid Application Development (RAD) (Wixom, Roth, and Dennis, 2014)

3.1.1 Requirements planning

Users and analysts get together to start the first step of requirements planning by determining the application or system's goals. Then it's on to problem-solving.

3.1.2 Design Workshop

This step entails creating and perfecting a previously designed development. System decision support to encourage users to agree with an existing user. The role of programmers and analysts is to create and offer a visual representation of methods and procedures. The user will next give feedback on the actual working prototype. The analyst then refines the designed module in response to user feedback.

3.1.3 Implementation

The last stage is implementing the newly developed or partially built system, testing it, and introducing it to the company. There's no need to operate the old system parallel after making a new one.

4 Result and discussion

4.1 Requirements planning

The flow of scholarship activities at BMU is now specified using use case diagrams and BPMN 2.0 business processes to identify the parties involved and the phases of actions that must be completed. After discovering the flow of scholarship activities at BMU, system modeling using ERD was used to determine the data flow that happened in each step. The information system planning step is based on the use case, business processes, and ERD.

Table 1 System request baitul mal scholarship application Unisba

System Request - Baitul Maal Unisba Scholarship Application
Project Sponsor: Baitul Mal Unisba (Scholarship)
Business requirements: Potential scholarship applicants can register and upload registration files directly through the system, with the required data being recorded in a database.
Business Criteria: The system must meet the following needs: - It must be able to preserve data. - It must be able to show essential announcement information. - It must be able to upload file requirements. - The system may display user-created logins and registrations.
Business Value: BMU can improve services, such as scholarships, by allowing users to register and upload material directly to a database. Prospective scholarship winners can also view the availability of scholarship quotas and the notification of acceptance. The business value that may be produced is that the administration will be able to handle existing data easily and will be able to reduce the time it takes to verify registration requirements and inform the timetable for the implementation of acceptance operations.
Special Issues and Limitations: Shortly, a system is required.

At this stage, identification is carried out on the old system, and changes are discovered via a system request, as shown in Table 1. The following step is development, by assessing the information system on the scholarship process at BMU to determine the present system's requirements.

During the system analysis, two needs were identified: functional and non-functional requirements and logical design modeling study analytic practical conditions consisting of admin and user requirements, whereas non-functional requirements analysis consists of a system behavior or system operational requirements.

4.2 Design workshop

The following step is to create a logical system. A Use-case Diagram is used to model logical system interactions. Business Process Modeling and Notation 2.0 by logis menggambarkan pemodelan desain proses bisnis. The scholarship business process model follows a logical path from registration to comprehensive personal data. When applying for a scholarship, the prospective beneficiary enters the submission data and uploads the required documents right away. BMU administrator will next review the scholarship application data and deliver information about the activities of the admissions schedule to potential scholarship winners. Following that, potential scholarship applicants will be given information on the admissions timetable and will be required to participate in a series of activities according to the schedule, evaluate the written test surah memory test, and conduct interviews with potential scholarship applicants. BMU administration will disseminate information on the scholarship acceptance results via the website.

Figures 2 and Figure 3 illustrate user actions before and after, whereas Figures 4 and Figure 5 show the exchange of business processes before and after.

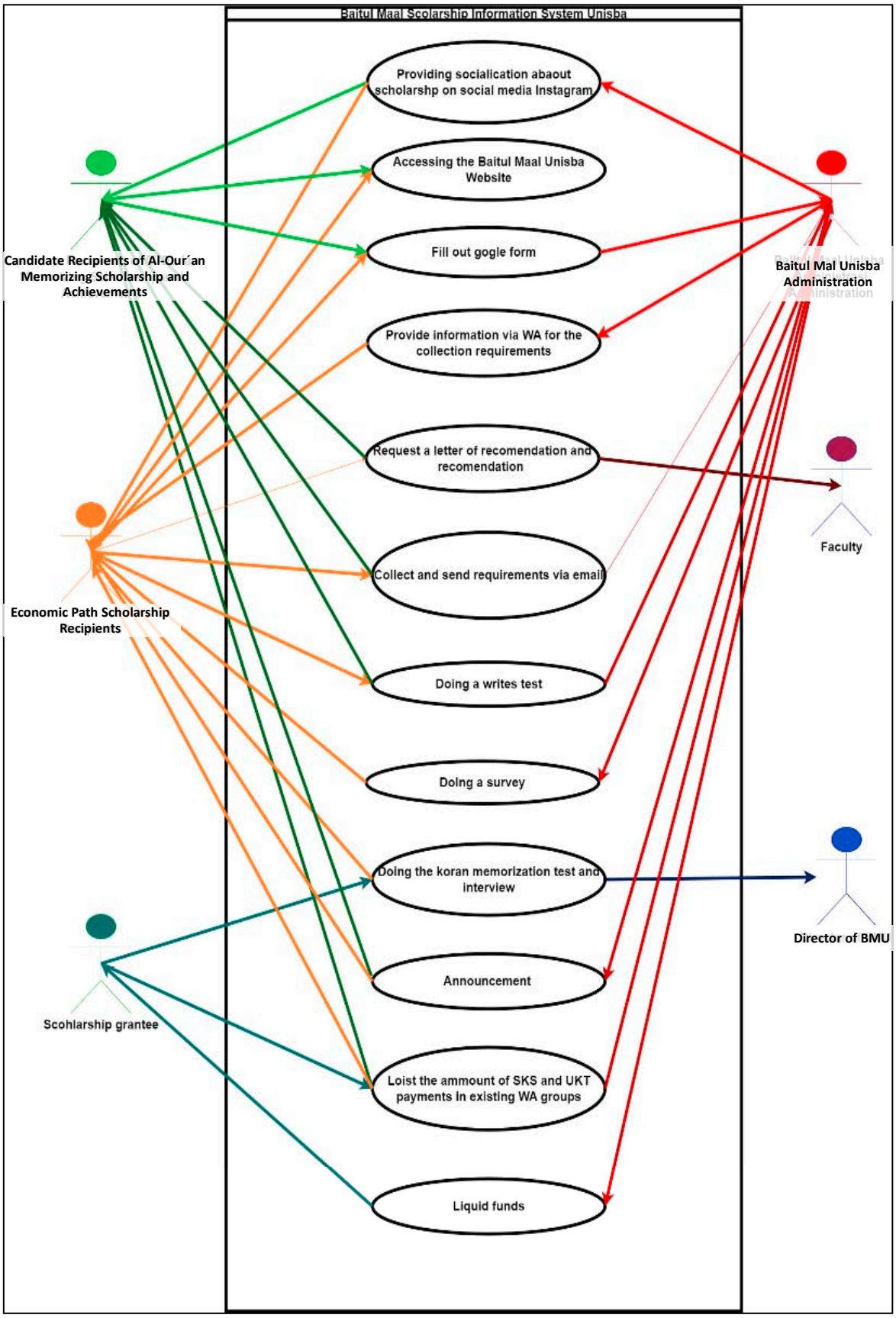

Figure 2 Use-Case Diagram with current use r activity

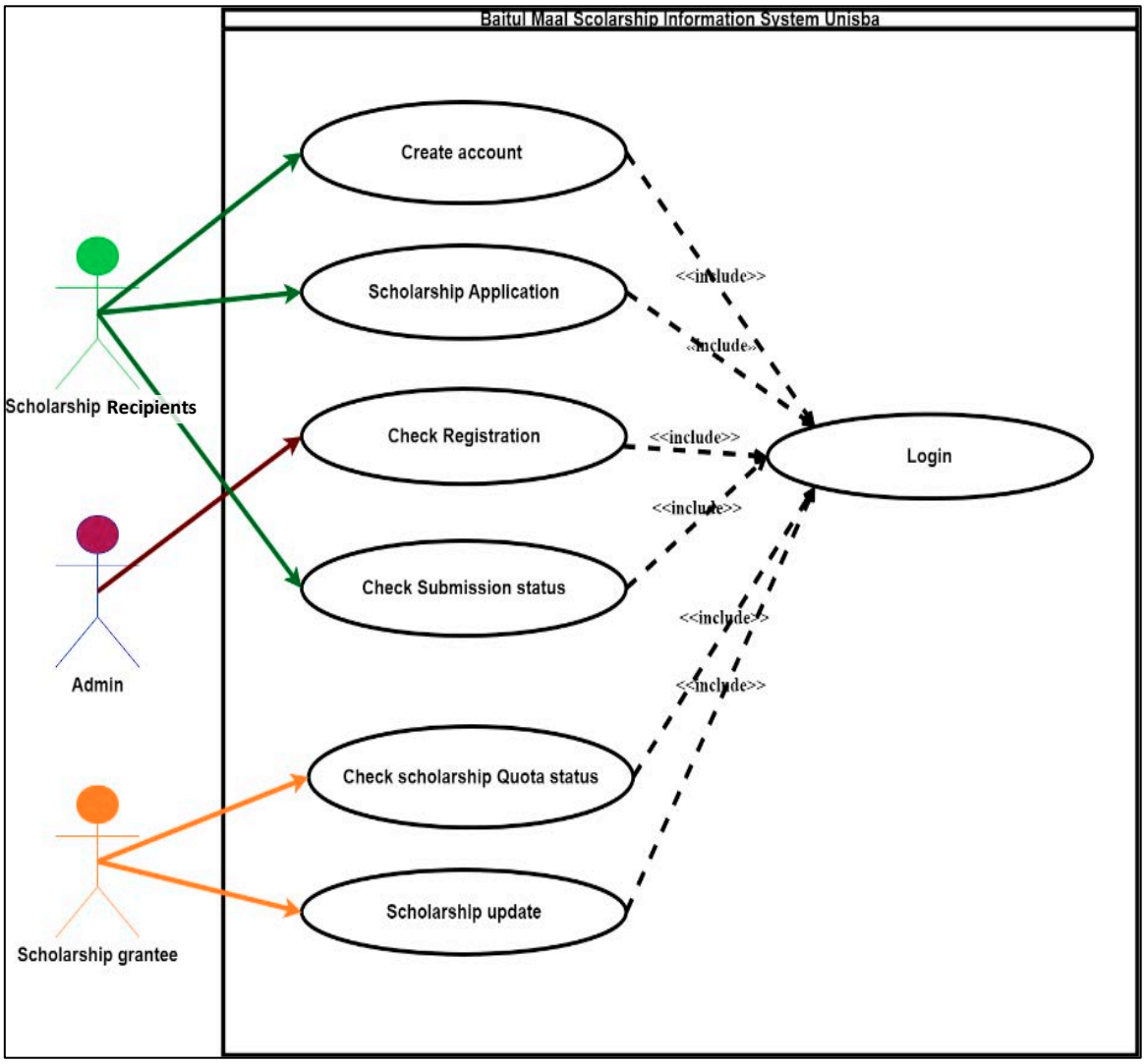

Figure 3 Use-Case Diagram with logical user activity

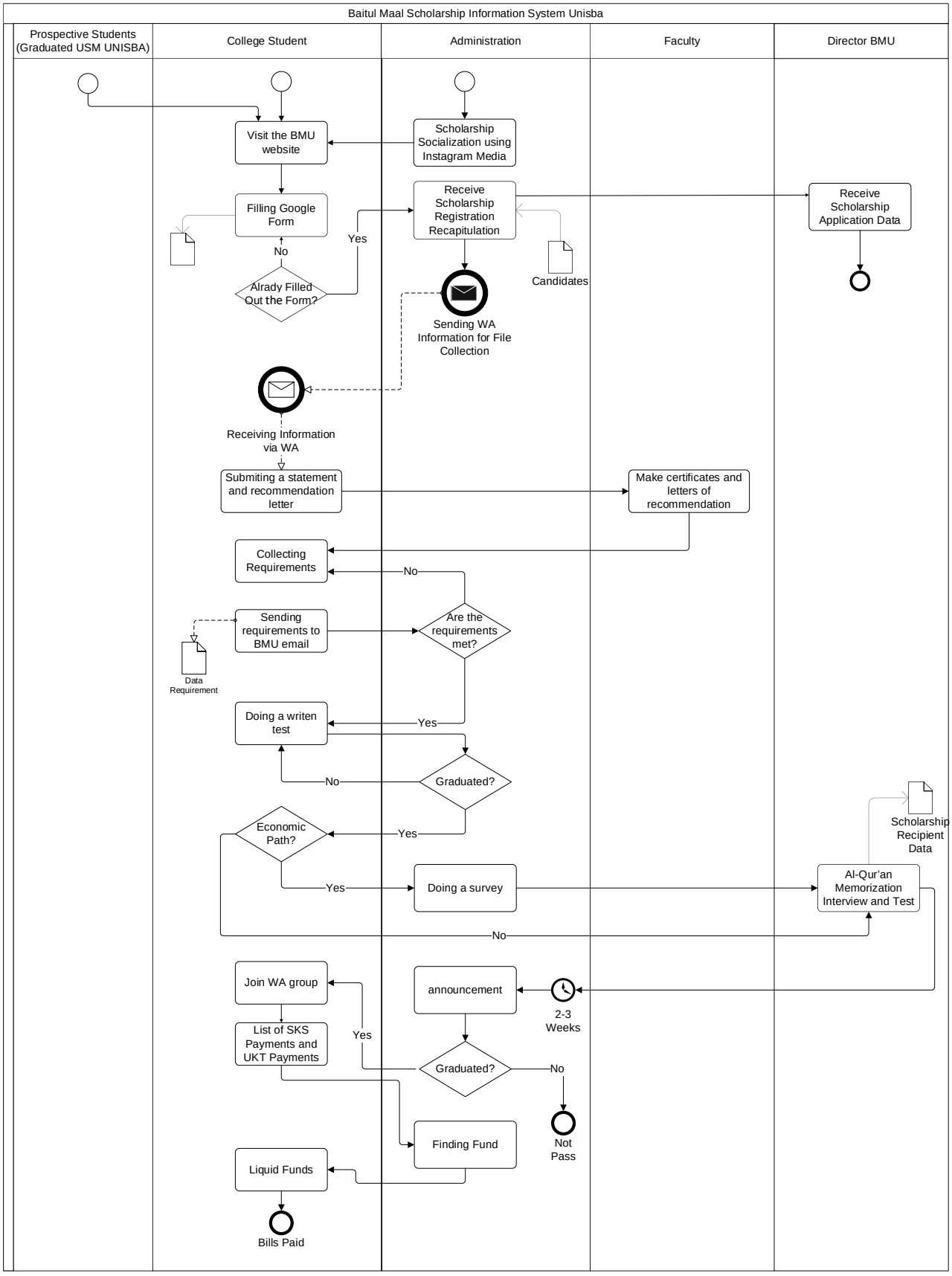

Figure 4 Business process in use

Optimizing scholarship distribution: a management information system approach
Yan Orgianus, Fijrina R.I. Lapalanti, Halbana Tarmizi, Hirawati Oemar

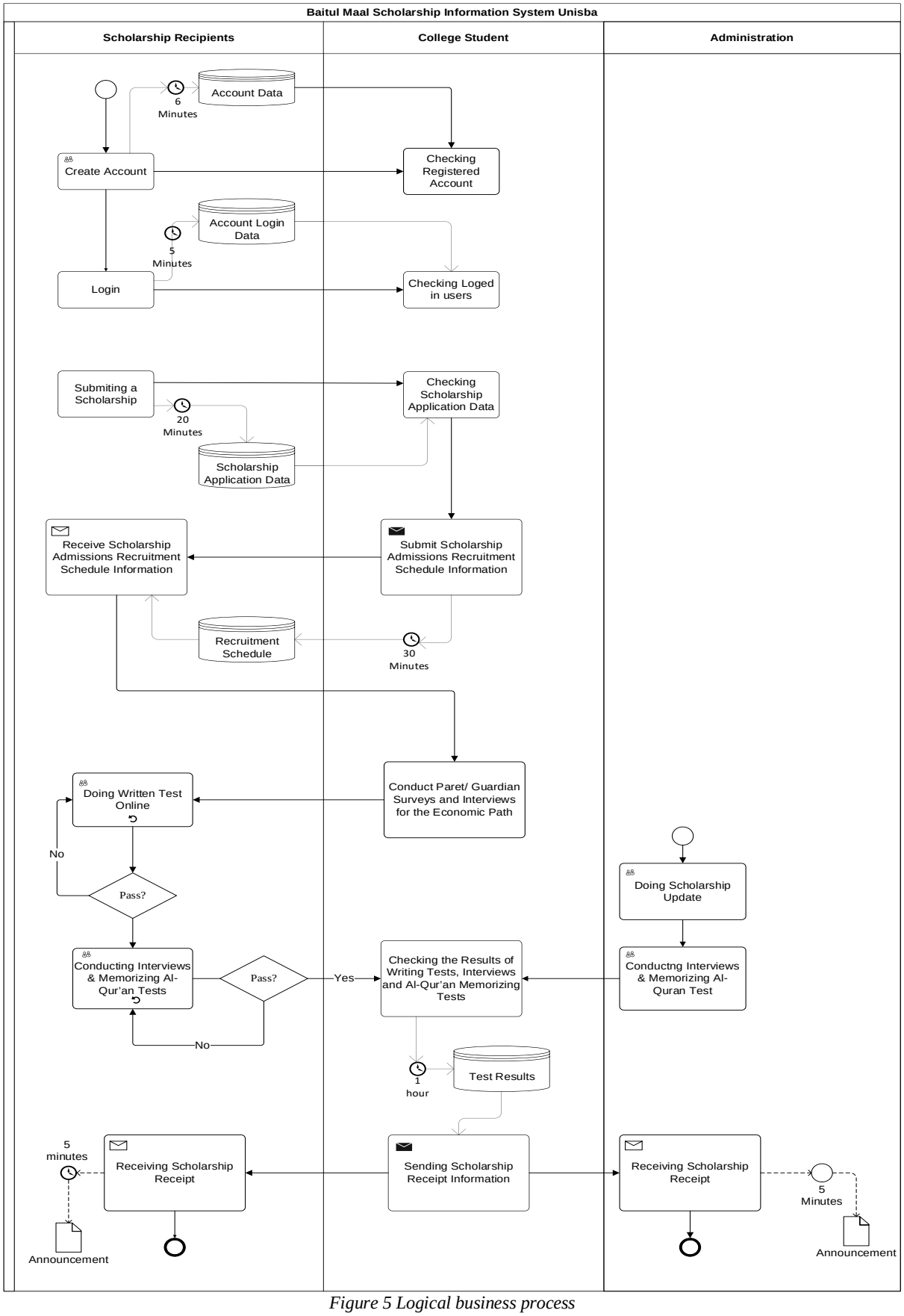

Figure 5 Logical business process

4.3 Implementation

4.3.1 Database design

Business processes and logical relationships between actors are used to create database designs. The database was created to make it easier to search for data and speed up the information delivery process—the existence of a database architecture that allows data to be appropriately structured and saved in one location. Normalization is one of the things that must be addressed while designing a database. Normalization aims to create a database structure that minimizes data duplication. This study of Baitul Mal Unisba's scholarship program employs normalization to the third stage, yielding 13 tables.

Proceed to the following step: create a data dictionary with data types, sizes, table components, and sample data based on the 13 tables. Then go on to make connections between tables that are connected. The visual representation of the relationship between tables in a database utilized in the application is called a relationship. The Entity-Relationship Diagram (ERD), as seen in Figure 6, depicts connections or relationships between tables.

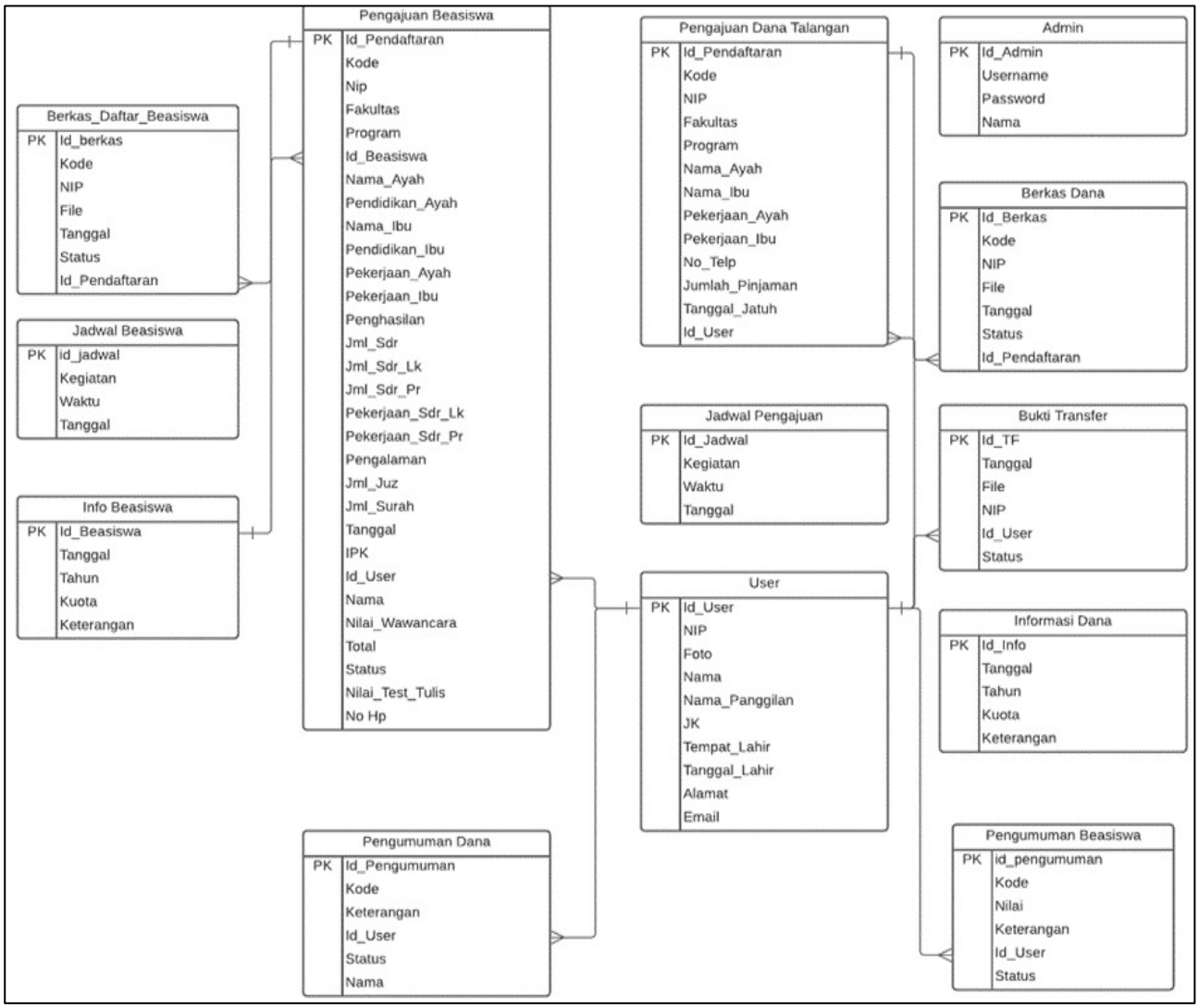

Figure 6 Table-to-Table Relationship

4.3.2 User interface design

The next step is to create a user interface that would make accessing the database easier for users. The Figma platform was used to create the user interface. In this study, the interface needs to amount to 43 forms with two access levels, admin and student, as follows:

- All users: form welcome;
- All users: form login;
- College student: shape create account;
- College student: form choose service;
- College student: form input scholarship application;
- College student: form scholarship information;
- College student: form scholarship announcement;
- Admin: Dashboard;
- Admin: Database scholarship information.

4.3.3 Application design

The next stage is to create the program after completing the user interface. The software code is made in line with the database and user interface utilizing the Visual Studio code application at this stage. The xampp server, MySQL database, and code igniter (CI) framework are used to create the application. Figure 7 and Figure 8, depict the application development design.

Table	Action	Rows	Type	Collation	Size	Overhead
admin	Browse Structure Search Insert Empty Drop	1	InnoDB	utf8mb4_general_ci	16.0 KiB	-
berkas_beasiswa	Browse Structure Search Insert Empty Drop	3	InnoDB	utf8mb4_general_ci	32.0 KiB	-
berkas_dana	Browse Structure Search Insert Empty Drop	1	InnoDB	utf8mb4_general_ci	32.0 KiB	-
bukti_tf	Browse Structure Search Insert Empty Drop	2	InnoDB	utf8mb4_general_ci	16.0 KiB	-
foto	Browse Structure Search Insert Empty Drop	0	InnoDB	utf8mb4_general_ci	16.0 KiB	-
foto_user	Browse Structure Search Insert Empty Drop	0	InnoDB	utf8mb4_general_ci	16.0 KiB	-
info_beasiswa	Browse Structure Search Insert Empty Drop	1	InnoDB	utf8mb4_general_ci	16.0 KiB	-
info_dana	Browse Structure Search Insert Empty Drop	1	InnoDB	utf8mb4_general_ci	16.0 KiB	-
jadwal	Browse Structure Search Insert Empty Drop	1	InnoDB	utf8mb4_general_ci	16.0 KiB	-
jadwal_dana	Browse Structure Search Insert Empty Drop	1	InnoDB	utf8mb4_general_ci	16.0 KiB	-
pengajuan	Browse Structure Search Insert Empty Drop	3	InnoDB	utf8mb4_general_ci	16.0 KiB	-
pengajuan_dana	Browse Structure Search Insert Empty Drop	1	InnoDB	utf8mb4_general_ci	32.0 KiB	-
pengumuman_beasiswa	Browse Structure Search Insert Empty Drop	3	InnoDB	utf8mb4_general_ci	32.0 KiB	-
pengumuman_dana	Browse Structure Search Insert Empty Drop	1	InnoDB	utf8mb4_general_ci	32.0 KiB	-
pengumuman_nilai	Browse Structure Search Insert Empty Drop	0	InnoDB	latin1_swedish_ci	16.0 KiB	-
user	Browse Structure Search Insert Empty Drop	3	InnoDB	utf8mb4_general_ci	16.0 KiB	-
16 tables	Sum	22	InnoDB	utf8mb4_general_ci	336.0 KiB	0 B

Figure 7 MySQL's database view

Figure 8 Database administrator view

4.3.4 Result analysis

This study develops a scholarship information system design in the form of a prototype that may be used to solve difficulties at BMU linked to scholarships. Some process tasks become fewer, and data is kept in a single database due to the availability of an application prototype. Furthermore, because diverse access privileges exist, the stored data has adequate storage security. The system's functional needs state is "Fulfilled," which means that the system can fulfill all applicable criteria and is available on the created system. The processes that happened earlier in each area have been recognized, and the new system may encounter different methods, process reductions, and process transfers during the information system development process. The following are the process modifications that occur:

College student:

1. The sort of scholarship that will be applied for may be viewed and used by prospective scholarship winners.
2. Applicants for scholarships can upload a file containing the conditions that must be satisfied as part of the scholarship application process.

3. The timetable of award acceptance events can be viewed in real-time by prospective scholarship winners.
4. The amount of available scholarship quotas is visible to scholarship awardees.
5. Scholarship winners get full access to comprehensive admission results.
6. Scholarship recipients can make changes to their profiles.

Administrator:
1. The administrator can process the database of scholarship receipts.
2. The administrator can update the timetable of scholarship acceptance activities.
3. The administrator can update scholarship quota information.
4. The administrator can enter the scholarship admission written test results.
5. The administrator can enter the scholarship acceptance announcement.

At the system planning stage, the system request presents the results of identifying the existing system and the system that the user expects. Table 2 shows the state of the system request following the construction of the information system. It can be observed from the table that all of the system request's expected indicators have been satisfied. The RAD (Rapid Application Development) approach is used to develop systems in phases, and the prototype created in this research will not be used (discarded). The new system will be constructed by revamping the database (physical data design), developing biological processes, and creating a more user-friendly interface than the previous one (prototype). In addition, the design of the system architecture began to be specified. Furthermore, the architectural system design began to be explained in greater depth. The database and system interfaces will be rebuilt and implemented on the live system.

Compared to previous studies, apart from differences in the methods used, in this study, the design of the information system is equipped with an academic information system and scholarship recipients' activities. The information system is made from the registration phase, assessment, announcement of results, academic progress, activities, and involvement in the coaching program that is followed, which will be used as an assessment of scholarship applications in the following semester.

Table 2 System request after system development

Main Reason	***Current System***	***System Request***	***Status***
Better Performances	Prospective scholarship applicants' data is still handled manually, and duplicate information is standard when the data is processed.	Data about prospective scholarship participants, such as scholarship registration data, data collection requirements files, and scholarship recipient data, is easy to find.	Data about prospective scholarship participants, such as scholarship registration data, file collecting data requirements, and the number of scholarship beneficiaries, is easily searchable.
More Information	Scholarship registration information is still kept in an Excel file, registration criteria are gathered by email, and scholarship participant acceptance information is sent via WhatsApp group.	Registration information and scholarship requirements files are maintained on a single server and may be accessed and displayed at any time and from any location. The receipt data can then be shown in detail.	Registration data and scholarship requirements files are all stored on one server and may be accessed and shown at any time and from any location. The receipt data can then be displayed in detail.
Stronger Control	Anyone has access to data.	Only authorized parties have access to data (administrator and scholarship recipients)	Data can only be accessible by authorized people when it has been fulfilled (admin and scholarship recipients)
Improved Services	Finding out the number of scholarship awardees and the scholarship quota available requires a significant amount of effort.	Admins and other interested parties can have immediate access to information on the number of admissions and the availability of scholarship quotas.	When this requirement is met, information on the number of admissions and scholarship quotas can be immediately available to administrators and other interested parties.

5 Conclusions

This research highlights significant differences between current and ideal business processes at Baitul Mal Unisba (BMU), particularly in the context of scholarship management. There are differences in current business processes compared to logical and physical business processes constructed when constructing the scholarship information system at BMU. Some activities may be removed by creating an information system, making the scholarship business process more straightforward. According to a status analysis of system requirements, the demands of each user are addressed by the information system that has been constructed. The newly developed scholarship management information system streamlines these processes by eliminating redundant activities, thereby simplifying the overall workflow. This scholarship information system will fulfill user demands and make it simpler for candidates, scholarship recipients, administrators, and other stakeholders who want information about BMU scholarships. Existing data may be adequately recorded and presented faster, more accurately, and more precisely, allowing it to be used to make the best decisions possible.

Looking ahead, the study opens avenues for future research aimed at enhancing the efficiency and impact of scholarship distribution. The integration of advanced technologies like Artificial Intelligence (AI) and Data Analytics presents an exciting frontier. These technologies could be employed to refine recipient selection, optimize decision-making, and forecast scholarship distribution trends. Such advancements promise to improve resource allocation efficiency within educational institutions. Furthermore, the development of sophisticated, secure data management methods will be pivotal in adapting to technological progress. The findings from this study lay a foundation for frameworks that can be adopted by various educational institutions, potentially revolutionizing scholarship allocation strategies for broader societal benefit.

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Value chain model of the smoked fish industry in small island
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Value chain model of the smoked fish industry in small island

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Keywords: value chain, smoked fish industry.
Abstract: A fishing industry value chain model identifies production, distribution, and marketing stages that enhance the value of fishery products. It aids in cost breakdown, process optimization, and gaining a competitive advantage. The study links activities from fresh fish to smoked fish, tracking the entire process to the final consumer and identifying all involved actors. Quantitative and qualitative methods analyze data, determining production costs, selling prices, added value, and ratios in each distribution channel. Findings reveal six key players in the smoked fish value chain: fishermen, wholesalers, traders, processors/IKM, retailers, and consumers. Fishermen, wholesalers, and traders supply raw materials to processors/SMEs, which act as both producers and distributors. Retailers sell directly to consumers. Significant added value, exceeding 40%, suggests ample potential for growth in the smoked fish industry. The value chain model holds implications for fisheries in small islands with abundant natural resources, promoting increased efficiency, business sustainability, improved quality, social sustainability, enhanced added value, market development, monitoring, supervision, and strategic planning. Some policy recommendations from this study are expected to create a conducive environment for business sustainability, improved product quality, and added value in the smoked fish industry, as well as provide positive benefits to local communities and maintain market order.

1 Introduction

The value chain is a practical strategy that aids businesses in identifying and connecting with different activities to convert inputs into valuable outputs for consumers. The concept of value chain as presented by [1] demonstrates a comprehensive plan necessary to provide products or services that align with this idea. This involves various manufacturing or operational procedures, distributing products to end-users and managing their disposal after use. By conducting value chain analysis, companies can enhance their understanding of the product value chain, ultimately increasing their competitiveness. This entails a sequential progression of products through all chain activities, earning value at each stage. This concept is consistent with the perspective [2] that the products accumulate value as they transition between participants within the chain. In addition, the value chain provides greater value than the sum total of its activities. As such, a value stream represents a fresh method for creating business models that optimize business potential, reduce expenses, and equip the enterprise with sustained high-level competitiveness over the long run [3].

The Moluccas region comprises numerous islands and a larger expanse of oceanic territory than the adjacent continent, making it endowed with abundant marine resources and fisheries [4]. According to [5], Moluccas Province is spread over an area of 46,914.03 square kilometers, accounting for 92.4 percent of the ocean's total surface and 7.6 percent of the continental area. It includes 1,388 islands with a potential reaching 536,112.6 tons, resulting in a production value of approximately IDR 13,820,522,191,000.

In 2019, Ambon City had 30 operating within the marine and fisheries industry. The companies included fresh, frozen, and processed products. Information pertaining to processed fish products in Ambon was compiled through the smoking and freezing method. The volume of smoked fish production totalled 3,828.32 tons, while frozen fish production amounted to 4,461.69 tons. Data from [6] indicates that the current capacity of fresh fish production in Moluccas is 29,010.53 tons with a production value of IDR 602,855,500,000. This situation suggests that there are business development opportunities in the fisheries sector. However, the fisheries industry that has developed is only a small and medium-scale industry.

Smoked fish SME is one of the most developed fisheries industries in Moluccas. Most Moluccans live in coastal areas and earn a livelihood as fishermen, enabling

them to process a substantial portion of their catches as smoked fish. According to data from [6], the Ambon City area which serves as the capital of the province, is home to 3,820 fishing households in 2021. Research [7,8] has revealed that in the Ambon Island region, there are 99 small and medium-sized enterprises (SMEs) that engage in smoking fish. The long-term sustainability of this smoked fish industry depends on the consistent availability of fish as the main raw material. Therefore, cooperation among stakeholders involved in the fish processing industry, including business entities and government entities, is crucial to maintain fish production for smoked fish processors and consumers.

The value chain concept provides an effective strategic tool for analyzing and organizing organizational operations [9]. This idea is supported by [10], which suggests that value chains are an essential tool for collaborating with stakeholders, expanding market access, and producing foreign currency. and increasing production in most developing countries. Several additional authors, including [11,12], and [13], have also written about the value chain notion. Diagnosing a business entity's potential requires knowing if it can provide added value in the future and whether it can capitalize on this now [14]. In the field of strategic management, Value Chain Analysis is seen as a fundamental analytical tool. Consequently, its significance should not be underestimated; rather, it needs to be continuously enhanced and applied [15].

According to [16], examining the value chain proves beneficial for a firm in pinpointing bottlenecks. To thrive effortlessly in the market, companies must establish a competitive edge over their counterparts. This analysis aims to overcome inefficiency constraints, including unpredictability, reduce vulnerability, and enhance adaptability to any changes that may occur. The objective of this study is to assess the effectiveness of the value chain in the production of smoked fish. Each distribution point and marketing channel will be evaluated for added value. The policy recommendations resulting from this analysis will contribute to efforts aimed at boosting fisheries processing and marketing on Ambon and other small islands.

2 Methodology

To elucidate the efficiency at each value-added node in the marketing channel, the author employs both quantitative and qualitative methods. The quantitative method, using a descriptive approach, is utilized to illustrate the correlation between inputs and outputs in the value chain and to comprehend the impact of changes in price variables within the value chain. Meanwhile, the qualitative method is employed to capture the perceptions and views of various stakeholders regarding the processes and interactions within the value chain. It is also used to visualize how each stage in the value chain is interconnected. This research is conducted on Ambon Island at the six clustered locations of smoked fish industries, including the Nusaniwe Subdistrict, Sirimau Subdistrict, Baguala Subdistrict, Teluk Ambon Subdistrict, Leihitu Subdistrict, and Tulehu Village, as well as Salahutu Subdistrict. The selection of these locations is based on the abundant availability of fishery resources, with a significant portion of the population residing in coastal areas and relying on the fishing sector for household income, engaging primarily as small-scale fishermen.

The data in this research is derived from a field survey conducted from January to June 2023. Respondents in this study included all parties involved in the smoked fish value chain, namely fishermen, SMEs (Small and Medium Enterprises) processing smoked fish, large-scale traders, collector traders, and retail traders located in the six regions of the clustered points. To gain a more in-depth understanding of the nodes in the value chain, the survey also covers fish landing ports, smoked fish processing facilities, and several markets on Ambon Island. In-depth interviews were also conducted with stakeholders to comprehend the production and distribution processes and factors affecting the smoked fish value chain, such as fishing boat owners, smoked fish SME owners, management of wholesalers and intermediary traders, and relevant government or agencies. Fresh fish production data from fishermen and smoked fish production data from smoked fish processors are collected to identify production volumes and types of fish produced.

The collected data is then analyzed to identify added value at each stage of the value chain. The difference between the product value and input costs, excluding labor costs is known as value added. The following are the components of the total value generated by the value chain (1), (2):

$$\text{Value added} = \text{Total of Revenue} - \text{The value of Intermediate\Level goods} \quad (1)$$

$$\text{Value Added Ratio} = (\text{Total Value Added} / \text{Product Selling Price}) \times 100\% \quad (2)$$

The results of this study are in the form of several policy recommendations that can be carried out by the government and business actors in the smoked fish chain to create an environment conducive to business sustainability, improved product quality, and added value in the smoked fish industry, and can provide positive benefits to local communities and maintain market order.

3 Result and discussion

3.1 Potential main raw material sources of smoked fish

The geographical location of Ambon Island, which is surrounded by sea waters, makes it easy for coastal communities living in the area to carry out fishing activities, taking into account seasonal and weather conditions. In addition, Ambon Island is supported by three

Fisheries Management Areas (WPP), namely 714 (Banda Sea), 715 (Maluku Sea and Seram Island), and 718 (Arafura Sea). This condition provides an advantage for small-scale fishers in Ambon Island, as it opens up opportunities for the development of the capture fisheries processing industry [17-20].

Important information that must be done before analyzing value chain of smoked fish is to know in advance the source of raw materials that supply fish to smoked fish producers. Field research indicates that the source of raw materials for smoked fish is mostly obtained from local fishermen located at several points in Maluku area, such as Latuhalat, Laha, Tulehu, Waai, Seram and Masohi. The percentage of fresh fish supply can be seen in Figure 1.

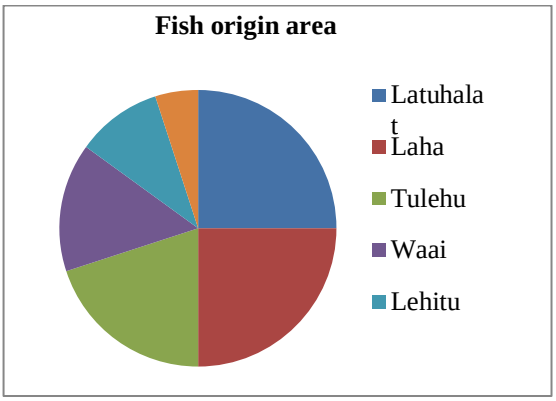

Figure 1 Source of fresh fish suppliers

The areas mentioned above are located in several regencies and cities, including Ambon City, Central Maluku Regency, and West Seram Regency. This is very possible due to the amount of capture fisheries production capacity for each district/city is quite large. Data on capture fisheries production capacity according to [6] are as follows: Ambon City with 25,343.00 tons, Central Maluku Regency with 174,875.50 tons and West Seram Regency with 67,582.80 tons.

3.2 Smoked fish value chain analysis

A value chain consists of a series of organizational tasks and processes that aim to increase value for customers. These activities include design, production, marketing, delivery of products and supporting endeavors.The objective key in establishing a value chain is to maximize firm's revenue while minimizing production costs. Additionaly, the value chain can raise the value or use of the product to be manufactured.

Analyzing the value chain involves examining the activities that contribute to creating value, which can come from both internal and external sources within the organization. The concept of value chain offers a viewpoint of the company's position in the industry value chain. In addition, value chain analysis further aids businesses to better understand the constituent elements of a product within the value chain. The particular value under consideration is the value that begins with the initial raw materials and extends to product management after consumers make a purchase. The company must identify their position within the value chain of the product. This is very important to identify opportunities from the competition. After identifying its position, the company recognizes the activities that make up the value. These activities are studied to identify whether they provide value to the product or not. If the activity provides value, it will continue to be used and improved to maximize value. Conversely, if the activity does not provide added value, it must be elimintaed [21].

Activities involved in producing smoked fish are categorized into primary activities and secondary activities in this study. According to [22], primary activities are concerned with the physical production of goods and final sales. These activities are grouped into important categories that are critical to increasing the industry's value, such as inputs, operations, outputs, marketing and sales of products, and services. On the other hand, secondary activities are those that provide support to primary activities and reinforce each other. They are classified into four groups: enterprise infrastructure, human resource management, technology development, and procurement. The smoked fish industry on Ambon Island exhibits these primary and secondary activities in its operations as illustarated in Table 1 and Table 2.

Table 1 Primary activities of the value chain system for smoked fish

Primary Activities	Value Chain Actors					
	Fishermen	Wholesale Traders	Collecting Traders	Industries/SMEs	Retailers	Customers
Arrest	√	-	-	-	-	-
Storage	√	√	-	-	-	-
Processing	-	-	-	√	-	-
Distribution	√	-	√	-	√	-
Purchasing	-	√	√	√	√	√
Sales	√	√	√	√	√	-
Standardization	√	√	√	√	√	-

Table 2 Secondary activities of the value chain system for smoked fish

Secondary Activities	
Infrastructure	Standardization of raw and supporting materials and final products
Human resources management	The existence of trainings from related agencies and universities
Technology development	Utilize production equipment assistance from the government and from universities
Procurement	Purchase of raw materials and supporting materials

In general, the chain of smoked fish production on Ambon Island from procurement of raw to marketing of final product, involves several processes:

1. Fishermen engage in the fishing process.
2. Fishermen themselves store their catch, while some of it is transferred to larger traders equipped with cold storage facilities to prevent spoilage.
3. The fishermen's catches are directly sold to major traders, intermediary traders, and small and medium enterprises that process smoked fish.
4. The smoked fish products processed by SMEs are sold to both retailers and consumers.

3.3 Value chain mapping of the smoked fish industry

Mapping the value chain is a critical aspect of conducting value chain analysis, with the aim of identifying the value chain actors who provide the most value. This aligns with the notion presented in [23] which suggests that the primary goal of value chain mapping is to recognize product flows and value chain actors.

When conducting value chain mapping, it is important to follow five fundamental principles:

1) mapping the actors or charting the participants within the value chain,

2) mapping the volume or charting the sales quantities of each participant throughout the value chain,

3) mapping the value or charting the product values at various stages of the value chain,

4) mapping the relative cost of processing or charting rhe precentage of expenses accured by each participant within the value chain,

5) mapping information and knowledge transfer or charting the flow of information and technology transfer.

Mapping the smoked fish value chain on Ambon Island is as follows:

1. Actors mapping

The process of mapping actors (Figure 2) aims to determine the different entities involved in a value chain. A value chain's actors typically begin with producers and progress through middlemen to end customers. However, the actors can be expanded to include companies that supply inputs to producers as well as producers themselves.

Participants in the smoked fish value chain comprise of fishermen, wholesale traders, collecting traders, small to medium-sized industries, retailers, and consumers. Refer to the figure below for a visualization of these actors.

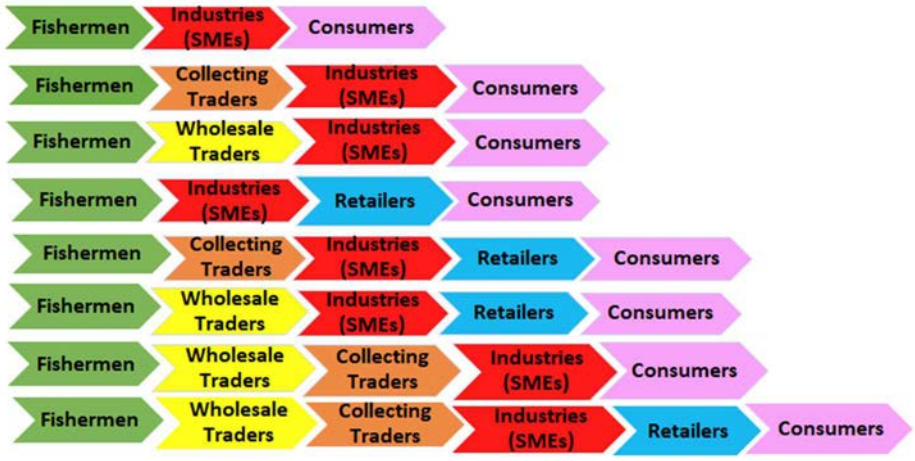

Figure 2 Mapping the actors in the value chain for smoked fish

2. Volume mapping

Volume mapping is utilized to map each actor's sales volume along the value chain. Volume mapping is extremely important for determining commodity flows and sales share along the value chain.

The sales volume mapping for smoked fish on Ambon Island is depicted in the following figure (Figure 3).

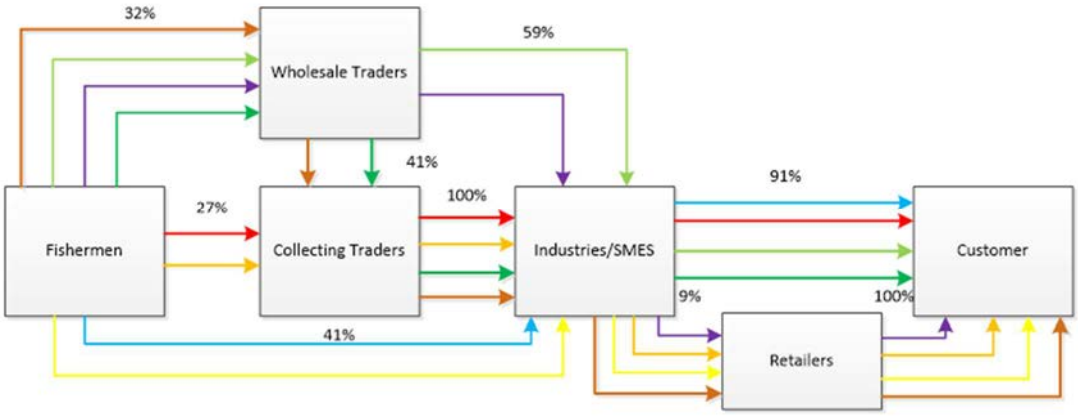

Figure 3 Sales volume mapping within the value chain for smoked fish

The volume of fish in each chain shows the average percentage of fish volume from each actor to the intended actor. Data from fishermen in six areas on Ambon Island revealed that on average 41% of their catch was sold directly to SMEs, 32% to large traders, and the remaining 27% to intermediary traders. SMEs that directly buy fresh fish from fishermen are located in coastal areas or near the beach or close to fish landing ports, such as in Latuhalat, Nusaniwe, Laha, Teluk Ambon, Leihitu, and Tulehu villages. Meanwhile, SME groups in the other two regions obtained fresh fish raw materials through intermediary traders and wholesalers. SMEs that chose to purchase raw materials from collecting traders did so because they were unable to purchase directly from fishermen, while SMEs that purchased raw materials from wholesalers faced difficulties in obtaining fresh fish at the fishermen or collecting traders level during extreme weather conditions. Under such conditions, fishermen's catches are minimal and limited, making it difficult for SMEs to obtain fresh fish, leading to higher fish prices. This scarcity usually occurs during the lean season from June to September.

3. Value mapping

Value mapping detemines the expenses of each player in a value chain. Value mapping is used to see the price received by every actor along the value chain and also to know the total cost.

In the value chain for smoked fish on Ambon Island, the costs incurred by each actor tend to be constant, but the price received by each actor is different for each marketing channel. Figure 4 shows the costs incurred and prices received by each participant per kilogram within the value chain specific for smoked fish.

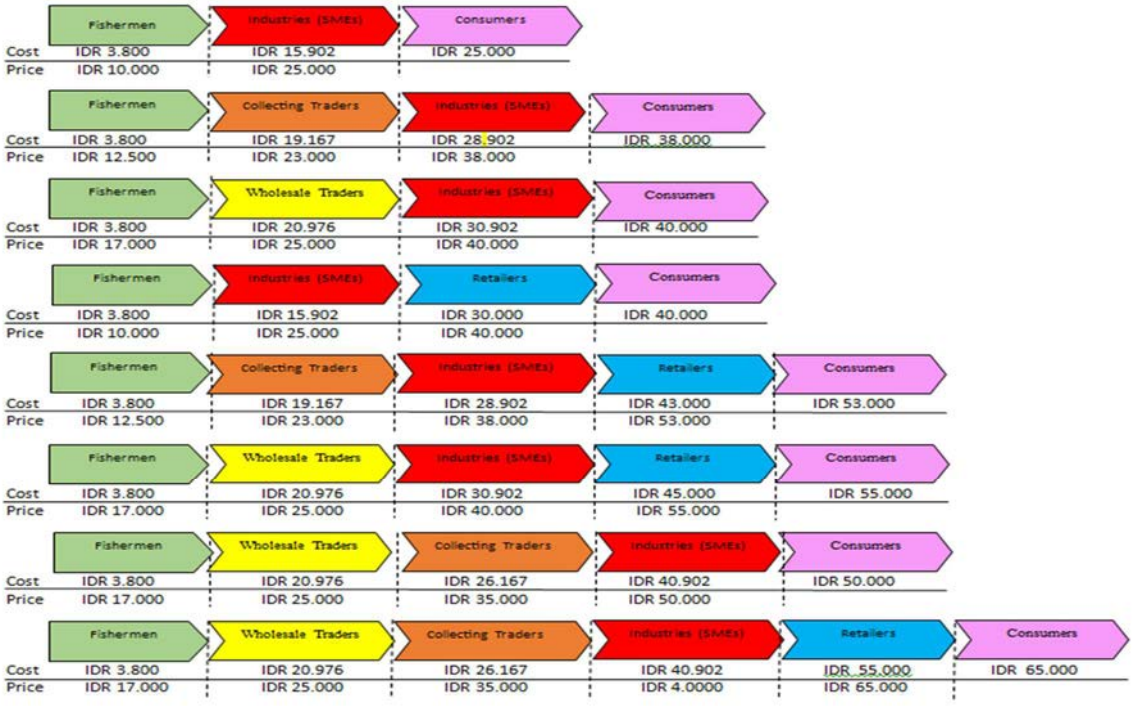

Figure 4 Value mapping in the value chain for smoked fish

In the figure above, the cost components incurred by each actor per kg of product can be explained as follows:

- Costs for Fishermen include the average sum of the costs of fuel, fishing gear, transportation, preservation of catches, and fishermen's supplies while at sea.
- Costs for Wholesalers include the average summation of the cost of block ice, other production costs, and the purchase price of fresh fish from fishermen.
- Costs for Collecting Traders include the average sum of block ice costs, transportation costs, other costs such as retribution fees, security fees, etc., and the purchase price of fresh fish.
- Costs to SMEs include the sum of average production costs and the purchase price of fresh fish.
- Costs to Retailers include the average sum of operational costs and the purchase price of smoked fish products from SMEs.

4. Mapping the relative cost of processing

Mapping relative cost of processing is used to examine the costs that are incurred as a result of improving the efficiency of each participant within the value chain.

Mapping the relative cost of processing on the smoked fish value chain can be seen in the image below.

Figure 5. Relative cost of processing mapping in the value chain for smoked fish

The figure 5 illustrates the average percentage of cost components incurred by each respondent, namely fishermen, wholesalers, collectors, SMEs, and retailers in the six regions selected as research sites. The total cost for each actor is 100%.

5. Mapping information and knowledge transfer

Mapping information and knowledge transfer is valuable for understanding the information and knowledge held by each actor possesses in relation to the commodities in the value chain.

In this value chain for smoked fish, each actor's knowledge is limited primarily to the weather, the price of fish and the type of fish available, which are heavily affected by natural conditions or weather, as illustrated in the table below.

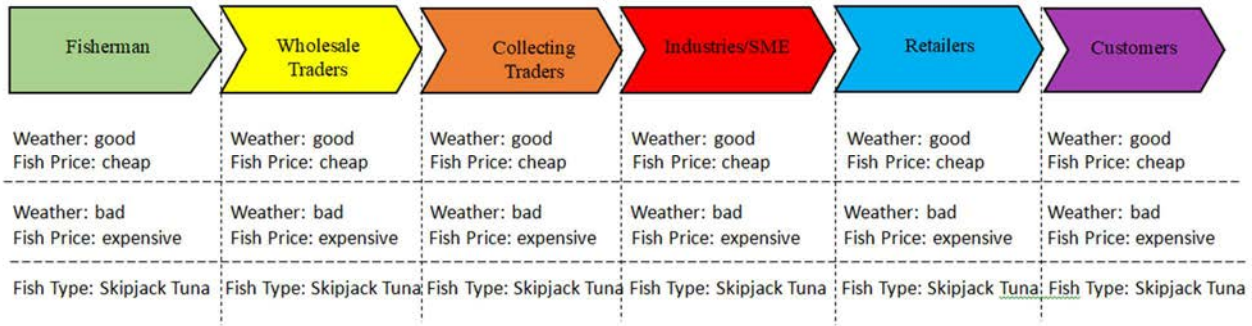

Figure 6 Information and knowledge transfer mapping in the value chain for smoked fish

In the figure above (Figure 6), information on weather conditions and fish prices is critical for business stakeholders. For SMEs, good weather conditions generally result in stable prices for fresh fish raw materials. However, poor weather conditions can have a significant impact on the difficulty and high price of fresh fish in the market. Therefore, SMEs can strategize accordingly in their production process. Regarding the type of fish, this paper is limited to one type, namely skipjack. On the other hand, if fishers communicate that their catch is skipjack, then all stakeholders in the value chain, including consumers, can anticipate the costs they will incur, given that skipjack is generally more expensive than other types of fish.

3.4 Value added analysis

The value-added concept is value-added analysis which begins from the procurement of raw materials through to the completion of the final product. This concept emphasizes the addition of product value during the process within the company. This also means that value-added analysis is a process to identify the percentage increase in the value of a product that has gone through post-harvest handling (processing) or transformation into a new product at each stage of the marketing channel.

The meaning of value added is the difference between the total revenue received by a company or industry from the sale of its output and the costs incurred for raw materials, components, or services purchased to produce those components. Value added can be identified by observing the disparity between the overall output value and the input value of an industry. Thus, value added is the gap between the sales costs and the expenses incurred for raw materials and the purchase of supporting materials. By eliminating non-value-added costs, a company can focus its attention on aspects that truly contribute value to the product.

Based on cost data and fish prices in the value chain of smoked fish, value added by calculating the selling price of products in each chain and the expenditure on raw materials, indirect costs and overhead costs included in the total cost of goods produced. Meanwhile, the value-added ratio is calculated by taking the value added per product output value and multiplying it by 100% as shown in the tables below.

Table 3 Value-added marketing channel

Marketing Channel	Number of Actors	Production Cost (IDR)	Product Selling Price (IDR)	Total Value-Added (IDR)	Value-Added Ratio (%)
1	3	9.702	25.000	15.298	61,19
2	4	16.363	38.000	21.631	56,92
3	4	13.678	40.000	26.322	65,81
4	4	14.702	40.000	25.298	63,25
5	5	21.363	53.000	31.631	59,68
6	5	18.678	55.000	36.322	66,04
7	5	14.845	50.000	35.155	70,31
8	6	19.845	65.000	45.155	69,47

The table above (Table 3) indicates that the longer the marketing chain, the more smoked fish product's added value. However, after further analysis, it turns out that the added value does not affect the quality of the product but occurs because of the additional costs incurred by the actors involved in the marketing channel. A significant increase in added value with an increase in the selling price of smoked fish. However, the largest marketing margin is found in marketing channel 7 at 70.31% with an added value of IDR 35,155. This added value is said to be efficient because all costs incurred are fully utilized to provide added value to the fish product from fresh fish to smoked fish. This has an impact on the selling price, which is quite high at the end consumer level. On the other hand, the value-added ratio shows a high value because the average is above 40%. This aligns with [24] opinion on value-added ratio indicators, that if the value-added ratio falls below 15%, it is categorized as low. If the proportion of added value falls between 15% and 40%, it is considered moderate. When the ratio of added value surpasses 40%, it is categorized as high.

3.5 Implications of utilizing the value chain model for fisheries industry in small islands

Porter's value chain model comprises tasks that a company must execute to take a product or service from its initial development stage all the way to its final consumption or utilization., recycling, or reuse [25]. Primary activities and secondary activities are the two types of activities. Secondary activities are those that Enhance value independently or through core operations and additional support functions [26]. Primary activities have a direct impact on product or service development, customer distribution, and post-sales service provision.

In contrast to previous decades where companies valued independence, the next decade will be filled with business alliances across competing value chains across the board. The value chains of companies as business alliance partners will compete fiercely as a unit for customers. This will also happen within the context of smoked fish industry. All actors within the value chain will compete to provide the best service through the products and services offered to attract as many customers as possible. One strategy that can be used is to reduce production costs as well as other less important costs, such as food and drink costs and transportation costs. On the other hand, small and medium-sized smoked fish industries as processors can also develop their products, for example by using liquid smoke and more aesthetic packaging. According to [27], the competitive strength of Small and Medium-sized Enterprises (SMEs) can be improved through the creation of exceptional local products oriented towards resource and environmental conservation; the development should exclusively encompass products crafted from local raw

materials and distinctive regional characteristics, with development facilitated by the local communities.

Ambon Island as a small island also has abundant potential for natural resources in the fisheries sector and local smoked fish products exhibits unique characteristic which should receive attention to be developed. The smoked fish value chain model formed on Ambon Island can be applied to the fisheries industry on small islands that also have abundant natural resources in the fisheries sector. Furthermore, the utilization of the value chain model for the fisheries industry has several important implications, including increased efficiency, business sustainability, improved quality, social sustainability, increased added value, market development, monitoring and supervision, and strategic planning.

Value chain models assist in pinpointing zones where enhancements in efficiency are possible, both in the fishery process itself, and in the management and distribution of fishery products. This can increase productivity and profitability. By optimizing activities with the highest added value, companies can manage production costs more efficiently [28]. This allows stakeholders to better understand the environmental impacts of fishing activities. With this information, strategic steps can be taken to ensure sustainable fishing practices. Incorporating sustainable practices into the value chain will increase added value, market accessibility and local economic development [29].

Value chain models can help improve quality control along the entire production chain. This is important to ensure that fishery products meet food safety and quality standards required for export or local consumption. In addition, in order to maintain the quality of fishery products and support government policies in the fish consumption improvement program, it is necessary to involve the role of the logistics industry as an important part of the fishery product/commodity distribution process [30]. This model also aids in identifying how the fisheries industry can provide greater social benefits to the local community. This includes increased income, job creation, and empowerment of the local community. There is added value and utility from every development implemented [31]. With an improved comprehension of the value chain, it will be possible to exploit opportunities to increase added value in fisheries production, such as processing and increasing derivative products through product diversification. This is also in line with the opinion of [32] that processing fishery products is very important for increasing product diversification and in creating added value.

Value chain models can help identify new market developments or opportunities. They can also help diversify the marketing of fishery products and reduce the risk of dependence on a single market. Value chain models enable better monitoring and surveillance of the entire production chain, which can help detect illegal practices. In addition, value chain models contribute to long-term strategic planning for the fishing industry in small islands. This planning involves a better understanding of market trends and challenges faced by the fishing sector. The strategy's effectiveness hinges on the suitability of strategies employed within the fisheries sector to adapt to evolving environmental conditions and the intensity of business competition [33].

4 Conclusion

The outcomes of this research concluded that the participants engaged within the value chain for smoked fish on the island of Ambon are: fishermen, wholesalers, intermediary traders, industries/SMEs, retailers and consumers. The relationship created between each actor is that fishermen, wholesalers and small traders act as suppliers who provide fish raw materials for SMEs/smoked fish processing industries. In this case, the SMEs act as producers, as well as distributors who supply products to the market and retailers who sell products to end consumers. Meanwhile, retailers are entities that sell products directly to consumers. The final link in the sequence is the consumer who uses the product and influences demand and preferences in this value chain.

Based on the calculation results between the output value of smoked fish and the input value of fresh or frozen fish raw materials, at each node of the participants within the chain, the value-added analysis shows that all distribution channels have a high value-added ratio because it is >40%. This means that all marketing channels have the potential to enhancing the value addition within the smoked fish industry.

The implications of the value chain model for the fisheries industry in small islands, which also have plentiful natural resources within the fisheries sector, include: increased efficiency, business sustainability, improved product quality, social sustainability for the community, increased added value, market development, strict monitoring and supervision, and careful strategic planning for business sustainability.

This study recommends several strategic policies to improve efficiency, business sustainability, product quality, positive social impact, added value, market development, strict supervision, and strategic planning that can be taken by the government and businesses in the smoked fish industry chain as follows:

- Implement training programs for businesses in the smoked fish industry to improve skills in fish processing and preservation and focus on technological innovation and environmentally friendly production methods.
- Set high quality standards for smoked fish and enforce strict certification, then encourage businesses to comply with these standards to improve product competitiveness in the market.
- Develop empowerment programs for local communities involved in the smoked fish supply chain and ensure community participation in business

activities by providing equitable and sustainable benefits.

- Provide tax incentives to businesses that implement sustainable and environmentally friendly practices and consider subsidies for investments in modern technologies that can improve efficiency.
- Support active promotion of smoked fish products in domestic and international markets, and conduct market research to identify new opportunities and support product diversification.
- Enhance supervision and monitoring of the entire smoked fish supply chain to ensure compliance with applicable regulations and standards and apply strict sanctions for violations that could harm the sustainability of the industry.
- Engage stakeholders in strategic planning for the smoked fish industry and facilitate collaboration between government, businesses and research institutions to improve innovation and efficiency.

By implementing these measures, it is anticipated that an environment conducive to sustainable business practices, improved product quality, and value addition within the smoked fish industry will be created. Additionally, these policies aim to provide positive benefits to local communities and maintain market order through strict monitoring and oversight.

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Increasing organizational agility and innovation performance of tour operators from the relational view perspective
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Increasing organizational agility and innovation performance of tour operators from the relational view perspective

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Keywords: collaboration, agility, innovation tourism, pandemic, supply chain.
Abstract: Previous research based on the Relational View has four major issues. The first issue is the need to stabilise relational rent in the long-term collaboration which can be addressed through involving management commitment. The second issue is the absence of implementations of non-financial relational rent such as innovation performance. The third issue is a significant fact that the research has not been conducted in crisis situations, where companies face limited resources and require both agility and innovation for survival. The fourth issue pertains to the absence of implementations regarding non-financial relational rent, such as innovation performance. To bridge this gap, in consideration of existing literature, this research is required to formulate a theoretical model that involves supplier collaboration, operational agility, management commitment, innovation performance, and the calculation on the effect of the relationship. This research applies structural equation modelling as an analysis tool with the support of AMOS software. The participants are leaders of tour operator companies based in Central Java Province and the Special Region of Yogyakarta, both are the major tourism destinations in Indonesia. Analysing 198 observations, the results demonstrate a positive impact of supplier collaboration on both operational agility and innovation performance. Management commitment has been demonstrated to moderate the impact of collaboration on innovation performance. This research encourages leaders of tour operator companies to engage in collaborations with their suppliers to achieve operational agility and improve innovation performance, particularly in facing the conditions caused by the Covid-19 pandemic.

1 Introduction

The Covid-19 pandemic from 2019 to 2022 has significantly affected the economy and seriously contributed substantial changes in the business environment, even resulting in a crisis. This crisis is clearly reported in the contraction of Indonesia's economic growth in 2020 to -2.07% from the average of the previous five-year period at the 5% level. Tourism, contributing 4% to Indonesia's GDP, is experiencing the most significant impact. Tour operators encountered significant conditions, as during the pandemic they were going through challenging times in business and leading to serious financial conditions. The tourism sector met significant changes post-pandemic, such as a shifted towards domestic tourists and an increased reliance on online reservation service [1]. On the other hands, companies were also facing evolving consumer expectations, which 52% of tourists chose domestic tourist destinations, 66% chose natural tourist attractions as tourist destinations, 56% chose short tourist trips with a maximum visit time of 4 days, and 72% chose safe tourist destinations, especially from Covid-19 transmission [2].

In order to align with evolving consumer expectations within limited resources, businesses must engage in collaborative efforts [3], so that tour operators can redesign tour packages and provide unique experiences. In addressing the challenges caused by the Covid-19 crisis, companies are required to enhance their capacity for both perceptive awareness and effective response. Perceptive awareness involves the company's consciousness of a crisis, while effective response denotes the company's proficiency in undertaking appropriate actions during and following a crisis. Throughout this period, the company acquired valuable insights, experienced transformative changes, and ultimately achieved substantive acceleration to effectively address the crisis. Following the uncertainty post-Covid-19, companies must consistently engage in the processes of sensing and responding, as well as applying adaptability for continuous adjustments. Companies with

significant flexibility in changing product variety and volume proved to have the are said to have agility [4].

A theory that is relevant to explain the flow of information, knowledge, and resources in company collaboration is the Relational View (RV). RV explains that the resources a company requires to achieve a goal may be available outside the company, yet they can not be obtained in the secondary market. These resources are strategically located within a collaborative network, founded on the principle of resource compatibility among participating companies. This synergy leads to the generation of supernormal profits, commonly referred as relational rents [5]. Relational rents can manifest in both financial and non-financial forms. We address multiple research gaps within the scope of RV, creating the uniqueness of this research. First, the principal issue in RV research is considered caused by the absence of relational rents over the course of extended collaborations, due to opportunistic behaviours exhibited among participating companies [6]. We address this main issue by including management commitment, given its integral role as an integrator in aligning and harmonising organizational elements and upholding the enforcement of designated policies [7]. The purpose is to strengthen the influence of antecedents on relational rents. The integration of management commitment in the RV research has not been implemented in previous studies. Second, considering the post-COVID-19 pandemic scenario, we discovered that the application of collaborative resources forms operational agility [8] through knowledge acquisition, joint research and development. The integration of operational agility in RV research has not been carried out much in previous studies. Third, we recognize no significance in implementing non-financial relational rents [9] which in the context of this research refers to innovation performance. High innovation performance is required by companies experiencing environmental changes due to the Covid-19 pandemic and enabling them to maintain business sustainability. Fourth, majority of RV research has traditionally been conducted in the manufacturing industry. Hence, our study seeks to assist researchers in enhancing their comprehension of how a collaborative network can sustain relational rents in the service sector, namely hospitality industry. This research was conducted in the tourism sector of Central Java Province and the Special Region of Yogyakarta, which collectively accounts for 10% of tourism visits in Indonesia.

This research aims to address several research questions, those are: (1) To what extent can supplier collaboration improve operational agility and innovation performance? (2) To what extent do operational agility improve innovation performance? (3) To what degree does management commitment strengthen the impact of supplier collaboration on innovation performance? This research is structured into distinct sections. Initially, we conducted a comprehensive review on existing literature to determine the relationship between supplier collaboration, operational agility, innovation performance, and management commitment within the relational view framework. Secondly,we developed and formulated hypotheses and empirically validated it applying structural equation modelling. Following this, we presented discussions and drew conclusions, which contained the theoretical and managerial implications of this research.

2 Literature review

2.1 Relational view

In order to attain competitive advantage, it is significant for a company to acquire resources that may be owned by external parties in its business environment. Based on this, in gaining success to acquire access to these resources, companies must engage in strategic collaborations, for example by applying partnerships with business entities, consumers, and academic institutions. The theory developed based on this assumption is the Relational View (RV) [4]. Companies engaged in collaboration acquire supernormal profits that are unattainable outside the collaborative network, or referred to as relational rent. Relational rent is generated by four key factors: significant investment in relationship-specific assets, substantial knowledge exchange, the sufficient combination of complementary, but scarce, resources or capabilities, and effective governance mechanisms [5]. Relationship-specific assets include visible or tangible assets (eg. collaboration locations, and production facilities) and intangible assets (eg. knowledge and work processes) forming certain capabilities due to reciprocal relationships between collaborating companies. Substantial knowledge exchange involves a routine and regular sharing of information that results in the developing of superior and specialised knowledge in collaborative networks. The combination of complementary, but scarce, resources or capabilities creates unique collaborative resources that are not available in the secondary market. The nature of this resource proves challenging to emulate, with no viable substitutes available. The governance structure demonstrates a high level of efficiency and adaptability in accordance with the company's requirements for collaboration. This process has shown the possibility in lowering monitoring costs while preventing opportunistic company's collaborative behaviour.

2.2 Supplier collaboration

Supplier collaboration involves the process of two or more independent companies collaboratively coordinating to control and optimise supply chains to meet shared objectives and mutual benefits [10]. Trust and sharing risks plays an important factor in supplier collaboration [11]. Supplier collaboration includes various aspects such as the management of interdependence of operations, products, processes, designs, marketing efforts, and purchasing planning or projections. This process also includes formulating strategic decision-making between supply

chain members [12], and can result in integration of cooperation between participating companies to implement effective supply chain planning and operations. We concluded that supplier collaboration is a cooperation with suppliers across research, design, and production stages in order to effectively utilise shared resources and knowledge sustainably. This process also covers sharing risks, to achieve mutual benefits.

The dimensions of supplier collaboration have been established and mature and extensively applied in previous research, including the following : sharing knowledge, aligning goals, aligning decision-making, aligning incentives, sharing resources, implementing collaborative communication, and creating joint knowledge [13]. In this present study, the indicators applied to measure supplier collaboration are companies sharing information and knowledge with suppliers, aligning goals with suppliers, sharing resources with suppliers, and implementing collaborative communication.

2.3 Management commitment

Management commitment refers to the ability of company management to direct and organise all its employees to specified goals [14]. Additionally, management commitment is also characterised as the behaviour of company management, that includes involvement, influence, leadership, and support from senior management in a company's activities to achieve specific objectives [15]. Management commitment can also be defined as pressure from high-ranking executives on all company employees to develop the organization. This influence is accompanied by the involvement and support of high-position holders to attain a determined objective [16]. We concluded that Management commitment is the specific action of high-ranking officials of management in providing the resources and policies required to achieve specified objectives, as well as actively contributing as team players along side all members of the company.

Management commitment is assessed by various dimensions identified in previous literature. The first dimension includes several indicators, including : availability of sufficient budget and facilities (software and hardware), initiatives to motivate employees development, availability of required training, especially in the field of product development, and managing feedback from consumers. The second dimension includes various parameters, such as compensation adjustments for sales of new products and for employees who successfully acquire new customers. The third dimension relates to management as an integrator function, including the socialization of company strategies and targets, involvement of management in product development and marketing, as well as periodic joint evaluation of product performance [17].

2.4 Operational agility

Operational agility refers to part of organisational agility indicating the company's adaptability and acceleration in recalibrating business processes to dynamic environmental demands. Operational agility also reflects the ability of a company's business processes to swiftly, precisely, and efficiently exploit opportunities for innovation and enhancement of competitiveness. Operational agility allows companies to modify existing processes and establish a new one to exploit dynamic market environmental conditions effectively [18]. This involves a company's ability to effectively response to changes in competition, organise technical resources, as well as align managerial processes [19]. Operational agility allows companies to respond promptly and effectively towards uncertainty in consumer and market demand. Companies facilitate redesigning processes and quickly implementing improvised products and service parameters , as well as providing alternative products and services [20]. Operational agility also includes the ability to adjust product volume and variety [21], and ultimately contribute significant impact to organizational performance. The implementation of operational agility can be observed from the speed of finalyzing decisions to modify products (eg. features and packaging), the flexibility to add product variations; and adjust product prices.

2.5 Innovation performance

Innovation performance indicates the creation of new products and services and the revenue generated from these processes [22]. Innovation performance can be derived in the proportion of revenue from the sales of new products, as well as products with enhanced features [23]. Innovation performance also involves the product innovation perspective and refers to the speed and timeliness needed in introducing innovative products to the market [24]. It is assessed by the quantity of new services in a specific period and shown by the ratio of new product sales value to accumulation of company revenue [25]. In conclusion, in this research, we define that innovation performance is a visible achievement from the implementation of fresh ideas implemented in the number of new products or product differentiation. It also refers to the introduction of newly developed products to the market, and the proportion of sales value of developed products compared to the total company’s revenue.

2.6 Hypotheses development

Supplier collaboration benefits companies in increasing operational agility. First of all, intensive and effective exchange of communication in a collaboration accelerates the flow of information. This process enables companies and suppliers to share valuable knowledge [26] in order to appropriately and effectively provide the efficient amount and type of material, volume, and time of supply, according to new products or improvements criterias to recent products. Supply chain modification consists of preparing

the materials required, new technologies, product components, and production processes [27]. Supplier collaboration results in the formation of supply flexibility [28]. Collaboration guarantees effective flow of information and knowledge to provide a responsive supply network. This process allows the company to perform responsive adjustment to coordinate the supply with the production requirement. When a company performs an adaptation process, the supply network is required to formulate adjustments including modifying the amount of capacity in response to surge in demand, or implementing process changes in response to disruption. Supplier collaboration not only enhances supply flexibility but also accelerates supply networks to apply new production methods, product development, new product diversification, and changes in the company's business processes. We have reached the conclusion that supplier collaboration positively impacts operational agility **(hypotheses 1)**.

Suppliers play a significant part in providing resources required by companies to develop products according to market needs. Supplier collaboration significantly accelerates a company's innovation performance through access to essential materials, information about market and competitor strategies. Further optimization is established when the extensive network is formed to provide more expansive accessibility and opportunity to utilise such resources. Additionally, suppliers are able to contribute technology and financial resources to be synergistically utilised [29]. Knowledge transfer in supplier collaboration holds essential and potential contribution to enhance innovation performance [22]. Supplier collaboration positively impacts quality performances, product innovation, and flexibility in addressing the market needs. Furthermore, supplier collaboration provides a significant and positive impact on sustainable innovation performance [30]. Literature refers to the fact that the application of collaboration with suppliers provides companies knowledge and information to develop their products following evolving market expectations. This process not only accelerates the production of new items but also streamlines the decision-making process. In conclusion, supplier collaboration demonstrates a positive impact on innovation performance **(hypotheses 2).**

Operational agility refers to a company's proficiency in directing flexibility and speed of adaptation in business processes. Companies are able to modify current processes or formulate new processes and enhance innovation performance. The efficient and swift allocation of resources in context of specific requirements are the benefit for this process. The application of any modification in operational agility includes product variety and volume, that subsequently will affect the product features and price changes. Flexibility implemented in production processes and methods contribute significantly to improve innovation performance [31]. This process provides a significant contribution for the creation of new products and services, by implementing creative and unique ideas [32]. Innovation performance requires accelerated action punctuality in the context of distributing innovative products to the market. This process is supported by operational agility in allowing the enhanced implementation of new processes. This process will be implemented quickly, precisely, and efficiently in a continuous method in the production structure and process. The modification accelerates its possibility to result in higher revenue from new products launched. Operational agility also accelerates the distribution of new products to the market and increases product variety. Innovation performance appears on the speed in distributing the new products to penetrate the market, the variety of new product in a certain period, and the profit level of new products. Subsequently, operational agility indicates a solid form of positive impact towards innovation performance **(hypotheses 3)**.

Management commitment is an essential factor to increase innovation performance, particularly in establishing stronger impact of supplier collaboration on company's innovation performance. Management commitment enhances the collaborative synergy between the company's work processes, resource configuration, and provides the means to implement innovation and create new products. As a main and dominant part, company management determines various regulations and implements resource planning, as well as establishing cooperation to achieve specified targets [33]. Management commitment not only strengthens the learning process but also accelerates the implementation of new ideas [34]. In terms of highlighting the crucial need to increase the influence of supplier collaboration on innovation performance, management commitment focuses on emphasising the need to increase the company's flexibility to adapt to environmental changes. Several major points aligned by the company management, include modification of company strategy, the application of good governance, the speed of decision-making, the adjustment of business systems, control systems, incentives, human resource management, and product development [35]. Management commitment has consistently provided positive support to influence supplier collaboration on innovation performance. First, the company is able to provide adjustments between the process of creating new products and alignment with the availability of supplies from its suppliers. Second, both companies in collaboration establish faster methods to result in efficient decision-making in circumstances where sudden modification on product creation process or supply combination is required. Third, management actively encourages employees to acquire new methods in product innovations which are planned together with suppliers. In conclusion, management commitment significantly increases the

influence of supplier collaboration on innovation performance **(hypotheses 4)**.

3 Methodology

We use the quantitative inquiry to verify the developed hypotheses and address the research questions. The unit of analysis was an organisation, referring to tour operators in Central Java Province and the Special Region of Yogyakarta. The respondents for this research were directors or top leaders of tour operator companies. Heads of the branch or subsidiary are included to correspond for several branch-type companies. The research instrument applied was a survey questionnaire and distributed using google forms. Following the data collection, we conduct an analysis on structural equation modelling using AMOS for hypothesis testing and calculate the effect. We targeted 200 sets of responses to be able to implement AMOS [36].

3.1 Sample and data collection

According to data from the Indonesian Central Bureau of Statistics, there are 1,238 tour operators in Central Java Province and the Special Region of Yogyakarta,with 652 of them in Central Java Province and 587 units in the Special Region of Yogyakarta. This research sample focused on 284 units tour operators registered with Association of the Indonesian Tours and Travel Agencies/ ASITA. The target number of responses was 200 sets and by estimating a response rate of 75%, the total number of questionnaires sent was 267 sets. The sampling technique applied for this research is proportionate stratified random sampling which includes grouping the population based on a criterion. The total number of questionnaires distributed can be seen in Table 1.

Table 1 Questionnaire distribution

Provinces	Areas	Number of members	Proportion (%)	Number of questionnaires
Central Java 132 units	Semarang area	60	21.13	56
	Kedu area	5	1.76	5
	Pati area	18	6.34	17
	Pekalongan area	7	2.46	7
	Banyumas area	18	6.34	17
	Solo Raya area	37	13.03	35
Special Region of Yogyakarta 152 units	Sleman area	76	26.76	71
	Yogyakarta City area	46	16.20	43
	Bantul area	16	5.63	15
	Gunung Kidul area	1	0.35	1
Total		284		267

3.2 Analytical approach

The analysis used includes descriptive and inferential methods. Descriptive analysis exhibits the respondent's profile, which includes: the respondent's position, office location, head office or branch/subsidiary status, company age, and number of employees. Inferential analysis is **i**mplemented to examine the relationship between variables. We used structural equation modelling assisted by AMOS to be able to fully operate statistical data and test the research hypotheses.

The research instrument implemented needs to fulfil the requirement for validity and reliability. The validity criteria are shown by the loading factor value of the question item which is above 0.5, while Reliability is shown by the construct reliability (CR) value and average variance extracted (AVE) value. The question item is reliable if CR > 0.6 and AVE value > 0.4 [37]. To demonstrate the suitability of the research model with the theory applied, a goodness-of-fit test was performed, along with the key parameters of significance, including probability ≥ 0.05, and also GFI, CFI, and TLI each ≥ 0.90. Subsequently, a hypothesis test using the p-value is executed and if the p-value < 0.05 then the hypothesis is accepted [36].

3.3 Measure

This research applied several series of instruments for measuring supplier collaboration, management commitment, operational agility, and innovation performance from previous research and adapted to the characteristics of tour operator businesses. The operational definitions of the research variables are described below (Table 2). Supplier collaboration is where companies agree to share important information and budget to achieve the predefined target or objective. Management commitment refers to providing sufficient provision of the resources needed and active contribution of company management to achieve company goals. Operational agility is the speed in modifying product variations and prices according to market expectation. Innovation performance refers to the benefits resulting from a new product, the number of product variations, and the speed at which they are

penetrated to the market. The questionnaire was created in a Google form that attached with closed questions. Responses are formulated in the form of a Likert scale of 1 to 5, with an answer level of 1 indicating strongly disagree and 5 representing otherwise.

Table 2 Variables and indicators

Variables	Codes	Indicators
Supplier collaboration (KS)	KS1	Accuracy of information regarding product design.
	KS2	Agreement on goals with suppliers.
	KS3	Willingness to share budget with suppliers.
	KS4	Frequency of interaction with suppliers.
Operation agility (OA)	OA1	Speed of decision making.
	OA2	Ease of changing product variations.
	OA3	The speed of changing product prices.
Management commitment (KM)	KM1	Availability of budget for developing new tour packages.
	KM2	Periodic socialization of company strategies and targets to all parties within the company.
	KM3	Management involvement with the team that creates the tour package.
	KM4	Management involvement with the team to expand the market.
	KM5	Management role with all parties in the company to carry out periodic performance evaluations of new tour packages.
Innovation performance (KI)	KI1	The proportion of profits from new tour packages.
	KI2	A number of tour packages are offered.
	KI3	Speed in offering new tour packages to consumers.

4 Result and discussion

4.1 Descriptive analysis

A total of 201 (75.28%) questionnaires were responded and the majority were answered by directors (189 questionnaires) and only 12 questionnaires were answered by branch office heads. The largest number of respondents were in Sleman District (28.86%), followed by Yogyakarta City (21.39%), Semarang City (19.90%), and Surakarta City (8.46%). These areas are the main tourist destinations in Central Java Province and the Special Region of Yogyakarta. Responding companies are more than 15 years old (71.64%) and between 11 years and 15 years (17.41%), which shows that companies have been building relationships with their suppliers for a relatively long period. Several companies experienced the subprime mortgage crisis (2008) and the monetary crisis in Asia (1998) and managed to survive. Most of the companies are small and medium enterprises with 6 – 10 employees (44.28%) and 11-15 persons (26.87%).

4.2 Data normality

Based on the chi-square table, the Mahalanobis d-squared value > 34.81 are outliers that must be removed from operations. In this study, observations number 42, 24, and 56 had a Mahalanobis d-squared value > 34.81, therefore they were removed from data analysis. The multivariate value after subtracting these observations is 1.684, which shows that the data is normally distributed (between -2.85 and 2.85). In this way, the data can be forwarded for further analysis.

4.3 Validity and reliability of instrument

Based on the loading factor, valid question items were selected with a loading factor value of ≥ 0.5, and reliability was shown by CR value > 0.6 and AVE value > 0.4. Based on the loading factor, all questions had met the criteria, so 15 question items were used in the next analysis. Based on the CR and AVE calculation results, it was also found that all question items met the reliability requirements. The results can be seen in the table below (Table 3).

Table 3 Instrumet validity and reliability

Variables	Indicators	*Loading Factor*(λ)	*Construct Reliability*	*Variance Extracted*
Supplier Collaboration (KS)	KS1	0.655	0.746	0.469
	KS2	0.682		
	KS3	0.615		
	KS4	0.651		
Management Commitment (KM)	KM1	0.597	0.814	0.424
	KM2	0.631		

Variables	Indicators	*Loading Factor*(λ)	*Construct Reliability*	*Variance Extracted*
	KM3	0.739		
	KM4	0.759		
	KM5	0.684		
Operational Agility (OA)	OA1	0.647	0.674	0.408
	OA2	0.662		
	OA3	0.607		
Innovation Performance (KI)	KI1	0.721	0.814	0.594
	KI2	0.776		
	KI3	0.813		

4.4 Goodness of fit

The first step is to modify the research model (Figure 1) by following the modification indices in AMOS. The modified model fits Goodness of Fit Criteria: probability 0.060 (> 0.05), RMSEA 0.037 (<0.08), incremental fit that consists of GFI 0.941, TLI 0.971, CFI 0.977 are >0.90, and parsimony fit that consists of PGFI 0.636 and PNFI 0.705 are >0.60.

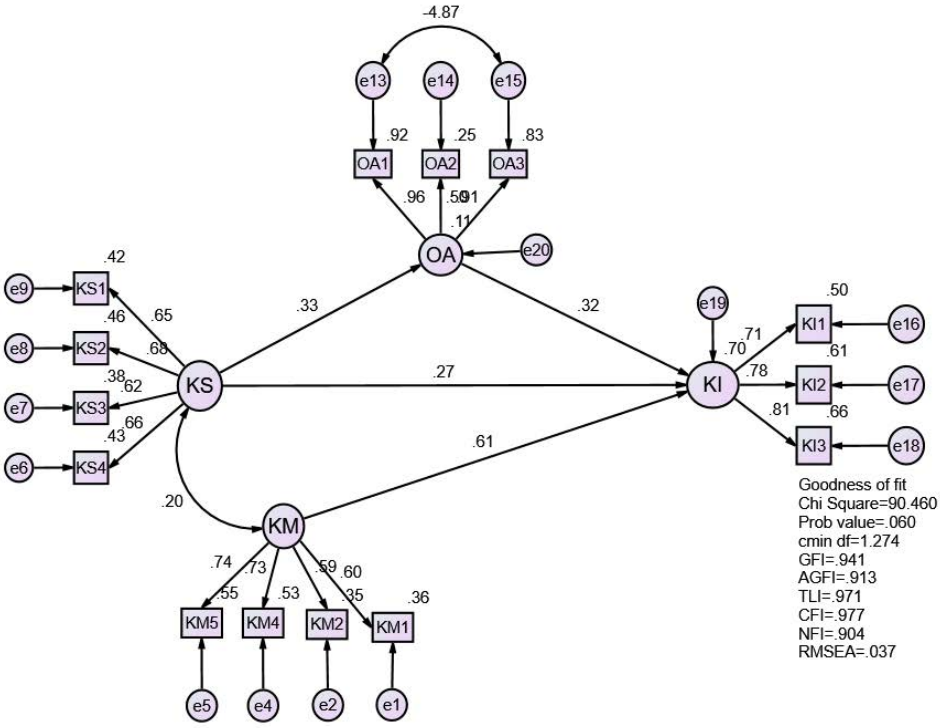

Figure 1 Modified research model

4.5 Hypotheses testing

Squared multiple correlation showed a figure of 0.701 for Innovation Performance, so it can be concluded that in this research the variation in innovation performance can be explained by 70.1% by the predictor variables. The results of the data analysis showed that supplier collaboration had an effect on operational agility with a p-value *** < 0.05, and the magnitude of the effect was 0.332. Therefore, hypothesis 1 was accepted. Supplier collaboration also influenced innovation performance with a p-value of 0.001 < 0.05, and the magnitude of the influence was 0.266. Therefore, hypothesis 2 was accepted. Operational agility influenced innovation performance with a p-value of 0.002 < 0.05, and the magnitude of the influence was 0.324. Therefore, hypothesis 3 was accepted (Table 4, Table 5).

Table 4 Hypotheses test

Variables	Estimate	S.E	CR	P	Label
K.S → OA	0.673	0.155	4.330	***	Significance
K.S → KI	0.292	0.092	3.178	0.001	Significance
OA → KI	0.176	0.057	3.097	0.002	Significance
KM → KI	0.796	0.129	6.159	***	Significance

Table 5 Standardized direct effects

	KS	KM	OA	KI
OA	0.332	0.000	0.000	0.000
KI	0.266	0.613	0.324	0.000

The moderation test is carried out by adding the interaction value between supplier collaboration and management commitment into the model and calculating the interaction loading factor and interaction error values using the formula below. The calculation will use loading factors based on standardised regression weight (Table 6) and variances (Table 7).

Table 6 Standardized regression weights

	Estimate
KS → OA	0.332
KS → KI	0.266
OA → KI	0.324
KM → KI	0.613
KM → KM1	0.604
KM → KM2	0.595
KM → KM4	0.728
KM → KM5	0.742
KS → KS4	0.658
KS → KS3	0.618
KS → KS2	0.676
KS → KS1	0.650

Table 7 Variances

	Estimate	S.E	CR	P
KM	0.110	0.026	4.227	***
K.S	0.153	0.034	4.493	***
e20	0.562	0.162	3.462	***
e19	0.055	0.015	3.668	***
e1	0.191	0.022	8.569	***
e2	0.191	0.022	8.637	***
e4	0.149	0.021	7.222	***
e5	0.131	0.019	6.984	***
e6	0.200	0.027	7.527	***
e7	0.224	0.028	7.993	***
e8	0.177	0.024	7.287	***
e9	0.178	0.023	7.635	***

We use the formula below to calculate the interaction loading factor (λinteraction) and interaction error values (Θq).

$$\lambda interaction = (\lambda X1 + \lambda X2 + \lambda X3) \times (\lambda Z1 + \lambda Z2 + \lambda Z3) \quad (1)$$

$$\Theta q = \{(\lambda X1 + \lambda X2 + \lambda X3)^2 \times Var(X) \times (\Theta Z1 + \Theta Z2 + \Theta Z3)\} + \{(\lambda Z1 + \lambda Z2 + \lambda Z3)^2 \times Var(Z) \times (\Theta X1 + \Theta X2 + \Theta X3)\} + \{(\Theta X1 + \Theta X2 + \Theta X3) \times (\Theta Z1 + \Theta Z2 + \Theta Z3)\} \quad (2)$$

We found that λ interaction is 6.945 and Θq is 1.812. We use those result to find the moderating effect to the model that is shown in figure 3 and hypothesis testing in Table 8. By integrating interaction variables into the research model (Figure 2), the model meets the marginal fit requirements with probability 0.011 (< 0.05), meanwhile other criteria meet the standard (GFI 0.933, AGFI 0.902, TLI 0.974, CFI 0.980, NFI 0.933 and RMSEA 0.045). The results of operational statistical data found that interaction influences innovation performance with p-value *** < 0.05, so it can be concluded that management commitment moderates the influence of supplier collaboration on innovation performance. Therefore, hypothesis 4 is accepted.

Table 8 Hypotheses testing

			Estimate	S.E	CR	P	Label
KS	→	OA	0.483	0.092	5.229	***	Significance
KS	→	KI	0.180	0.071	2.550	0.011	Significance
OA	→	KI	0.167	0.051	3.258	0.001	Significance
KM	→	KI	0.680	0.102	6.682	***	Significance
Interaction	→	KI	0.006	0.001	5.691	***	Significance

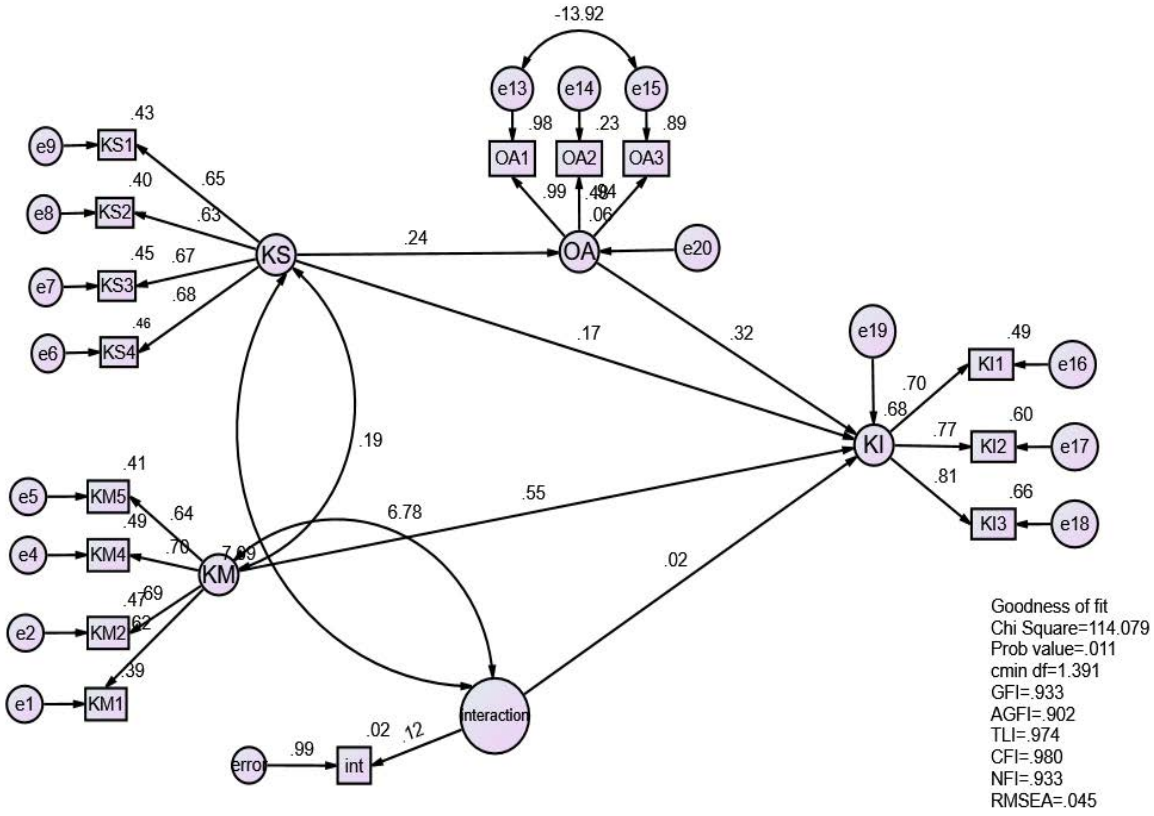

Figure 2 Research model with interaction

5 Conclusions

The primary objective of this research is to enhance our comprehension towards Relational View (RV) through providing explanation how supplier collaboration, operational agility, and management commitment effectively improve innovation performance. This research demonstrates that supplier collaboration has a positive impact on operational agility by providing companies with access to flexibility in raw material supply and maintaining the availability of required materials. Furthermore**,** supplier collaboration plays a vital role in accelerating innovation performance by facilitating the flow of valuable information and knowledge regarding materials supplied. It also features the effectiveness of this information to be applied appropriately in innovating tourism products. Collaborative resources are easily accessed, selected and combined into products that are accepted by consumers and subsequently increase innovation performance. Operational agility provides a positive impact on innovati**o**n performance; it enables companies to modify not only the operation but also implementation of new methods. The ability to adjust company operations, including designing tour packages, arranging the type of transportation to be used, and adjusting base prices to meet tourists' purchasing ability will also enhance innovation performance. Management commitment demonstrates the ability to moderate the influence of supplier collaboration on innovation performance. Management commitment enlarges the influence of external resources on the ability to perform innovation, which then enhances innovation performance. This process is demonstrated in the context of the availability of required resources and the teamwork of employees and leaders.

From a theoretical standpoint, this research has expand the RV literature by considering supplier collaboration and management commitment, and also the formation of organizational agility and innovation performance. We have reached a notable fact that there has been an applications of moderating role of management commitment in RV research in tour operator companies. Moreover, it also offers significant ideas for tour operator leaders to perform collaborative action with their suppliers and also increase the management commitment to recover their business after the Covid-19 pandemic. It is crucial for companies to increase operational agility through applying supplier collaboration in order to create new tour packages and penetrate new market possibilities**.**

This research emphasises several limitations to consider for enhancement in future research. First, customer collaboration has not been significantly involved, despite its integral role in the service industry sector, where substantial customer participation characterises the development of the value co-creation concept [38]. Future research requires the involvement of customer collaboration to perform significant comprehension towards its role in increasing operational agility and innovation performance. It is also crucial for the research model to be tested in other collaborative service industry, such as event organizers and construction services. This study currently applies only to tour operators in Central Java and the Special Region of Yogyakarta, both of which have been designated as main tourist destinations by the Indonesian government. Further research is to be implemented in various regions where economies are dominated by the tourism sector, to observe and study the generalisation of this research.

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Determining consumer demand patterns for production planning using a data mining approach
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Determining consumer demand patterns for production planning using a data mining approach

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Keywords: data mining, clustering, K-Means Algorithm, association, FP-Growth Algorithm.
Abstract: The bread industry faces significant risks of losses in case of excess inventory. The initial stage in the K-Means Clustering Algorithm involves forming two clusters: C1 for slow-moving product data and C2 for fast-moving. Clustering products using the K-Means Algorithm resulted in Group 1 as slow-moving products with 44 types of items and Group 2 as fast-moving products with 15 types of items. It can be concluded that the bakery is experiencing losses due to an excess of overstocked products. After categorizing data into slow-moving and fast-moving groups, the subsequent phase involves employing the FP (Frequent Pattern)-Growth association rule algorithm to recognize consumer purchasing patterns. This algorithm aims to uncover relationships between items in a dataset and assess the probability of a person purchasing bread concurrently. By establishing a minimum support of 3% and a minimum confidence level of 30%, a total of 13 rules were generated, meeting the criteria for strong association rules. With this data, the store owner can specifically enhance inventory planning for fast-moving products by analyzing demand data and market trends. For slow-moving products, the store owner can adjust item placement or create product bundling with best seller items.

1 Introduction

The existence of business opportunities in the food industry means that micro, small and medium enterprises (MSMEs) are able to create independent sources of income. However, competition in the food industry is currently very tight, so business people are required to produce creative and innovative ideas, as well as manage existing resources so that they can achieve their main goals. One of the products from the food industry is bread which generally has characteristics that are easily damaged and have a relatively short expiration date so that the bread industry has a high risk of loss if there is excess stock.

From the findings of the assessments, it is evident that having surplus inventory poses a disadvantage for the company. This excess inventory is due to overproduction. Overproduction is the activity of producing products in excess of the required quantity [1]. This is because inventory data management is still done manually and sales data is not analyzed so that there are products piling up because they are not selling and there are empty items [2]. One method that can be used is data mining techniques. Data mining is an effective way to obtain information for decision making, one of which is production planning decisions.

The approach to alleviate this issue involves employing the method of clustering. A cluster refers to a group of data objects sharing similarities within the same cluster and distinctiveness from objects found in other clusters. K-Means is an algorithm commonly used in the clustering process [3]. In this research, a rule or guide was developed that contains the relationship of interrelated items using the FP-Growth algorithm. Through this research, it is hoped that researchers can increase sales through technology-based production planning strategies [4].

Numerous prior research endeavors have utilized the K-Means algorithm, primarily for the purpose of categorizing items. For instance, a study applied this algorithm to group Telkomsel card sales regions into three clusters, delineated as high, medium, and low. This grouping served as the foundation for devising promotional procurement strategies [5]. Research was conducted to map technological capabilities by looking at the Davies

Bouldin Index (DBI) value as a basis for measuring cluster performance [6]. Furthermore, studies employing clustering techniques on retail sales data, categorizing them into high, medium, and low clusters, are utilized to formulate stock inventory strategies [7]. Several studies have been carried out, including research conducted by [8] suggests integrating information about customers' physical activity into conventional recommendation systems. Emphasis is placed on providing recommendations tailored to the individual who is jogging or running. These user categories were determined based on the most significant workout-related criteria. Using Orange software, various clustering and classification models were experimented with, leading to the establishment of fundamental criteria for segmentation. The research reveals the feasibility of achieving a fairly precise user segmentation and suggests avenues for refinement. The integration of diverse knowledge models detailing customer behavior and attributes from multiple viewpoints has the potential to yield valuable and distinctive marketing insights [9]. identify and assess the attitudes of the Polish business world towards sustainable entrepreneurship. The findings obtained are juxtaposed with independent assessments, thereby revealing different approaches to business operations. Through cluster analysis of the survey results, it is clear that the Polish SME sector can be categorized into five different groups, each of which shows different approaches and levels of commitment to sustainable development. In addition, the study concludes that Polish companies prioritize social aspects over environmental considerations. Research conducted by [10] Introduces a method to automatically recommend distance measurements for clustering algorithms. The recommendation process involves steps in the form of extracting metadata, which includes collecting meta features and identifying meta targets; building recommendation models using metadata; and suggests distance measures for new datasets through recommendation models. Two different types of meta targets and meta learning techniques are used to address potential variations in user needs. In contrast to prior studies, this research distinguishes itself by employing the K-Means Algorithm to group sales data, generating clusters based on the distinction between high-performing and low-performing sales. Subsequently, the study proceeds with the application of the FP-Growth Algorithm to examine consumer purchasing patterns associated with less popular products. This analysis serves as a foundation for decision-making in the production planning department. This serves as the foundation for conducting this research, aiming to ensure the optimal execution of production planning through the implementation of both the K-Means Algorithm and the FP-Growth Algorithm.

2 Methodology

2.1 Production planning

Production planning is an activity of evaluating past and present facts as well as anticipating future changes and trends to determine appropriate production strategies and schedules in order to achieve targeted goals effectively and efficiently. According to [11] the objectives of production planning and control are:

1. Ensure that the company can produce effectively and efficiently.
2. Ensure that the company can use capital as optimally as possible and can dominate a wide market.
3. Forecast product demand expressed in the number of products as a function of time.
4. Monitor actual demand, compare it with previous demand forecasts and revise these forecasts if deviations occur.
5. Determine the economical order size for the raw materials to be purchased.
6. Monitor inventory levels, compare them with the inventory plan, and revise the production plan at the specified time.
7. Make detailed production schedules, assignments, and machine and labor assignments.

Data mining encompasses a set of procedures designed to extract valuable, previously unknown information from a compiled database, transforming raw data into meaningful insights. The acquired information is derived through the extraction and identification of crucial patterns that contribute to business decision-making. In simpler terms, data mining is commonly described as the process of sifting through vast amounts of data to uncover relevant information. It is also commonly known as Knowledge Discovery in Database (KDD) [12].

2.2 Data mining

Data mining involves a sequence of procedures aimed at manually extracting hidden information value from a gathered database, with the goal of transforming this data into valuable insights. The information gathered is acquired through the extraction and identification of significant patterns essential for informed business decision-making. Put simply, data mining is often described as the process of distilling information from extensive datasets. Another term used to refer to data mining is Knowledge Discovery in Database (KDD) [13]. The initial category of open-source data mining tools, such as WEKA and Rapid Miner, is coded using the JAVA language. These platforms are capable of handling a variety of standard data mining tasks and include the implementation of scalable algorithms for data analysis and extraction [14].

2.3 Clustering

Clustering is a method used to discover and categorize data based on shared characteristics. In data mining, there are two main approaches to grouping data: hierarchical clustering and non-hierarchical clustering. As an unsupervised learning method, clustering partitions a dataset into clusters, with data within each cluster displaying comparable characteristics. Different forms of clustering encompass Hierarchical clustering, Partitioning methods, Density-based clustering, Constraint-based clustering, Fuzzy clustering, and Distribution-based clustering [15]. Hierarchical clustering is a method of classifying data that starts by grouping together two or more objects with close proximity. This process is then repeated, encompassing additional objects that share the next level of proximity. The repetition continues until a cluster structure is established, resembling a tree with a distinct hierarchy (level) among objects, ranging from the most similar to the least similar. Conversely, the non-hierarchical clustering methodology commences by defining the preferred number of clusters (two clusters, three clusters, etc.). Once the number of clusters is established, the clustering process unfolds without adhering to a hierarchical structure. This method is commonly denoted as K-Means Clustering [16].

2.4 K-Means algorithm

K-Means is a non-hierarchical technique for classifying data, aiming to partition the data into two or more groups. This approach segregates data into multiple groups, ensuring that data with similar attributes are assigned to the same group, while data with distinct attributes are allocated to other groups [17]. As mentioned in [18], the procedures for implementing clustering through the K-Means method are outlined as follows:

1. Establish the desired number of cluster centers (*k*) to be created.
2. Randomly initialize (*k*) cluster centers by selecting them from the available data.
3. Compute the distance from every object to each centroid using the Euclidean Distance formula, aiming to identify the closest distance from each centroid data, as expressed in equation (1).

$$D(i,j) = \sqrt{\begin{matrix}(X_{1i} - X_{1j})^2 + (X_{2i} - X_{2j})^2 + \cdots \\ + (X_{ki} - X_{kj})^2 \cdots (1)\end{matrix}} \quad (1)$$

Note:
$D(i,j)$ - document point,
X_{ki} - criteria data,
X_{kj} - centroid of the cluster *k-j*.

4. Categorize each data point based on its proximity to the centroid, considering the smallest distance.
5. Revise the centroid values, determining the new centroid by calculating the average of the respective cluster, as indicated in equation (2).

$$\mu j(t+1) = \frac{1}{Nsj} \sum j \in sj\ Xj \quad (2)$$

Note:
$\mu j(t+1)$ - new centroid in the th iteration (*t + 1*),
Nsj - the amount of data in cluster *sj*,

6. Iterate through steps 2 to 5 until each cluster attains a stable value.

2.5 Association rules

Association is a technique utilized in the data mining process to extract association rules, revealing connections between item combinations or relationships among attributes. Association rules are procedures for finding relationships between items in a predefined data set. Data mining technology based on association rules is a crucial method for discovering knowledge. Its objective is to identify correlations among characteristic variables and determine their level of proximity within extensive datasets. This technology aims to unveil potential, concealed, and valuable information in samples, thereby offering significant decision support. The findings of prior research suggest that data mining based on association rules can uncover insights that are difficult to extract using conventional statistical approaches. This approach proves to be practical and effective [19].

Association is a method for examining connections between specified pairs of items. It involves deriving associative rules from two metrics: support, which indicates the percentage of item combinations in the data, and confidence, which signifies the accuracy strength of the relationship between items. The fundamental methodology of association analysis comprises two stages designed to identify all association rules that satisfy the minimum support and minimum confidence criteria [20].

In the exploration phase for the most frequent pattern, the FP-Growth Algorithm is employed to discover combinations of items that fulfill the minimum support value criteria in the database. In the context of the support formula in data mining, P refers to an itemset or set of items (a collection of items or attributes) in a transaction or data set. the support value of an item obtains the calculation of the support value of two items written in equation (3).

$$Support\ (\mathrm{P}) = \frac{\text{Number of Transactions Containing P}}{\text{Total Transactions}} \times 100\% \quad (3)$$

Support (P) is the level of support for itemset P. Number of transactions containing Number of transactions containing P is the number of transactions in which itemset A exists.

Transaction totals Transaction totals are the total number of transactions in the data set. In the context of the

support formula for association rules, P and B refer to the two itemsets or sets of items that are being evaluated in a transaction or dataset (4).

$$Support\ (P \cap B) = \frac{\text{Number of Transactions Contains P and B}}{\text{Total Transactions}} \times 100\% \quad (4)$$

Support (P∩B) is the level of support for the combination of itemsets P and B.

The number of transactions containing P and B is the number of transactions containing P and B is the number of transactions in which both itemsets P and B occur together. Total transactions is the total number of transactions in the data set.

After identifying all high-frequency patterns, the next step is to search for association rules that satisfy the minimum confidence criteria, indicating how frequently an item appears concurrently with a combination of other items. Associative rule A → B The probability that B appears when P also appears can be obtained from equation (5).

$$Confidence\ Q\ (P \mid A) = \frac{\text{Number of Transactions Contains P and B}}{\text{Total Transactions Contain P}} \times 100\% \quad (5)$$

2.6 FP-Growth Algorithm

The FP-Growth algorithm, belonging to the associative data mining approach, is instrumental in efficiently handling frequent itemsets through the utilization of the FP-Tree structure. This algorithm is founded on the FP-tree concept. FP-Tree construction involves linking data from individual transactions along specific paths. This linkage allows transactions sharing common items to overlap on paths. The efficiency of the data structure layout process increases with a greater number of transactions featuring the same items. After the FP-Tree is formed, then carry out the three main stages of the FP-Growth Algorithm, namely [21]:

1. Stage of creating a conditional pattern base.
2. Stage of generating a conditional FP-Tree.
3. Stage of generating frequent items.

3 Result and discussion

3.1 Sales transaction data

In this study, the dataset utilized comprises sales transaction records spanning from January to December 2022. The objective of this research is to categorize products into two criteria, namely slow-moving and fast-moving items, and derive patterns from the formed clusters.

3.2 Data processing

In this study, the sales transaction data for XY Bakery covering a one-year period, from January to December 2022, is employed. Two methodologies, the K-Means Clustering Algorithm and the FP-Growth Algorithm, are applied to process the data. The purpose of employing these methods is to obtain production planning outcomes in alignment with the data mining approach. The data, organized through the utilization of the K-Means Clustering Algorithm, serves as foundational data to analyze consumer purchasing patterns through association rules. Both methodologies involve multiple stages of data mining, starting with the data selection process that focuses on gathering sales data specifically for products containing bread items. Based on the data selection results, the data cleaning stage continues, namely eliminating noise by removing duplicate data and correcting data errors such as transactions that only contain 1 type of item.

3.2.1 Bread grouping based on the K-Means Clustering Algorithm

The initial step in the K-Means Clustering Algorithm involves determining the number of datasets and conducting an initial performance test to identify the optimal k value. The selection of the most suitable number of classes is assessed by observing the smallest value on the Davies-Bouldin index. The Davies-Bouldin Index serves as a technique for assessing the appropriateness of the cluster count [22]. Based on the performance test results, 3 classes were formed. However, after clustering there are classes that only have one member. This category is deemed to lack a substantial impact on the configuration of clusters. Consequently, only two categories (k=2) were employed in this study. Out of this dataset, 59 samples were extracted that satisfied the research criteria for implementing the K-Means algorithm. The steps in the K-Means Clustering algorithm are outlined below:

1. Establish the initial centroid value. There are two clusters: C1 represents slow-moving product data, and C2 represents fast-moving products.
2. Determine the initial centroid by taking data randomly. The centroid is determined based on bread sales transaction data for 12 months, which is classified based on the name of the bread item and the bread sales period. Table 1 shows sales transaction data that has been randomly selected for centroids.

Table 1 Ccentroid selection

No	Item	Jan (pcs)	Feb (pcs)	Mar (pcs)	Apri (pcs)	May (pcs)	Jun (pcs)	Jul (pcs)	Ags (pcs)	Sept (pcs)	Oct (pcs)	Nov (pcs)	Dec (pcs)
1	Abon	276	134	193	106	143	166	177	223	245	255	296	256
2	Abon Gulung	478	337	400	211	288	281	292	346	724	256	486	361
*	****	*	*	*	*	*	*	*	*	*	*	*	*
11	Choco Ball W	6	4	9	1	1	4	1	1	1	20	8	10
*	****	*	*	*	*	*	*	*	*	*	*	*	*
59	Wool Roll Bread Tuna	57	41	48	83	74	74	60	59	70	55	98	62

Centroid 1 (11th data): {6, 4, 9, 1, 1, 4, 1, 1, 1, 20, 8, 10}
Centroid 2 (2nd data): {478, 337, 400, 211, 288, 281, 292,346, 724, 256, 486, 361}

After choosing the initial centroid value, the Euclidean distance theory is applied to calculate the proximity of data to the centroid. Each data will be calculated as the closest distance to each centroid that was determined in the previous stage using equation 1. In the first iteration, category C1 produces 51 members. Category C2 produces 8 members. Then proceed with calculating the 2nd iteration.

1. Update the centroid value by calculating the average of the cluster in question using equation 2.
2. The calculation procedure remains consistent with the previous step. If the cluster positions in the new iteration match those of the previous iteration, the process stops. However, if they differ, the process proceeds to the next iteration.

In the second iteration, C1 yields 45 members, while C2 produces 14 members. As the cluster positions in the second iteration differ from those in the previous iteration, the process advances to the third iteration, requiring an update to the centroid value.

In the third iteration, C1 generated 44 members, while C2 produced 15 members. As the cluster positions in the third iteration differ from those in the previous iteration, the process proceeds to the fourth iteration, necessitating an update to the centroid value.

In the fourth iteration, C1 generated 44 members, and C2 produced 15 members. The cluster positions in the fourth iteration are identical to those in the previous iteration, so the process is halted. A comparison of the index for the number of data objects in each cluster is illustrated in Table 2.

Table 2 Comparison of the number of objects for each cluster

Iteration process	Number of objects C1	Number of objects C2
Iteration 1	51	8
Iteration 2	45	14
Iteration 3	44	15
Iteration 4	44	15

The calculation ends in the 4th iteration because it has the same results as the results of the 3rd iteration, causing the ratio in the 4th iteration to remain unchanged. The data group is then declared convergent or considered optimal. The next stage is to carry out testing using Rapidminer to see consumer purchasing patterns over the year. The figure 1 is the sales graph display for XY bread products. Figure 1 consumer purchasing patterns within a year, the x-axis shows the demand period and the y-axis shows the amount of consumer purchases. The blue line graph shows slow moving bread products and the red line shows fast moving bread products. Group 1 as slow moving products has 44 types of items and group 2 as fast moving products has 15 types of items. Based on this graph, it can be concluded that XY bakery is experiencing losses due to the large number of overstock products.

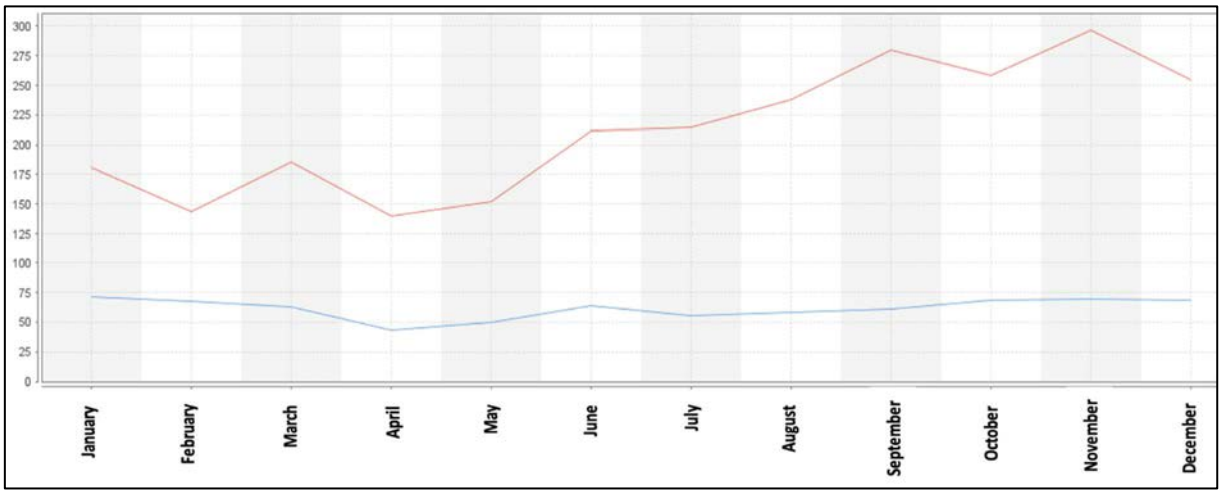

Figure 1 Graphic display based on testing using RapidMiner

3.2.2 Determining consumer purchasing patterns using the FP-Growth Algorithm

The identification of consumer purchasing patterns is derived from the categorization of slow-moving and fast-moving data. When establishing consumer purchasing patterns, the data mining stages parallel those of the K-Means Clustering method. Consequently, the outcomes from K-Means serve as the foundational material for processing FP-Growth data. The subsequent steps outline the stages of the FP-Growth Algorithm in handling sales transaction data [23].

3.3 Frequency of each item and support value selection

This research sets a minimum support value of 2%. After that, a data selection process was carried out and deleted data that had a support value below 2% with a total transaction of 58,802. The process of forming 1 itemset with a minimum support value of 2% uses equation 3 to obtain a support value as in table 2 which meets the minimum support of 2%:

Table 2 Pattern 1 itemset that meets minimum support

Item type	Frequency	*Support*	Percentage of support value
Tuna Fish Buns	901	(901/58802) x 100%	2%
Wool Roll Bread Coklat	1015	(1015/58802) x 100%	2%
Abon	2015	(2015/58802) x 100%	3%
***	**	***	**
Blueberry	2086	(2086/58802) x 100%	4%
Vanila Almond	901	(901/58802) x 100%	4%
Abon Gulung	3605	(3605/58802) x 100%	6%

After scanning items that have a support count frequency = 2%, the number of items will be entered into the FP-Tree. In this procedure, items failing to meet the minimum support requirement will be eliminated due to their negligible impact, and a data cleaning process will be conducted on transaction data containing only one item. The subsequent computation is executed to assess the occurrence frequency of each item after the data cleaning process. The table below displays the frequency of each frequent item in individual transactions, arranged in descending order based on their highest frequencies.

Table 1 Frequency of item appearance after data cleaning process

Item Name	Frequency of appearance
Abon Gulung	404
Abon	254
Blueberry	251
Brown Sugar	250
**	**
Pisang Keju	118
Cheese Roll	115
Tuna Fish Buns	113
Sosis Sate	109

The table above shows the frequency of appearance of items after going through the data cleaning process.

3.4 *FP-Tree formation*

FP-Tree is formed based on item categories which have been sorted based on priority for each transaction. The formation of this FP-Tree is based on the researcher's policy of compiling transaction flows based on transactions containing slow moving products in accordance with the research objective, namely to optimize production by minimizing wasted product.

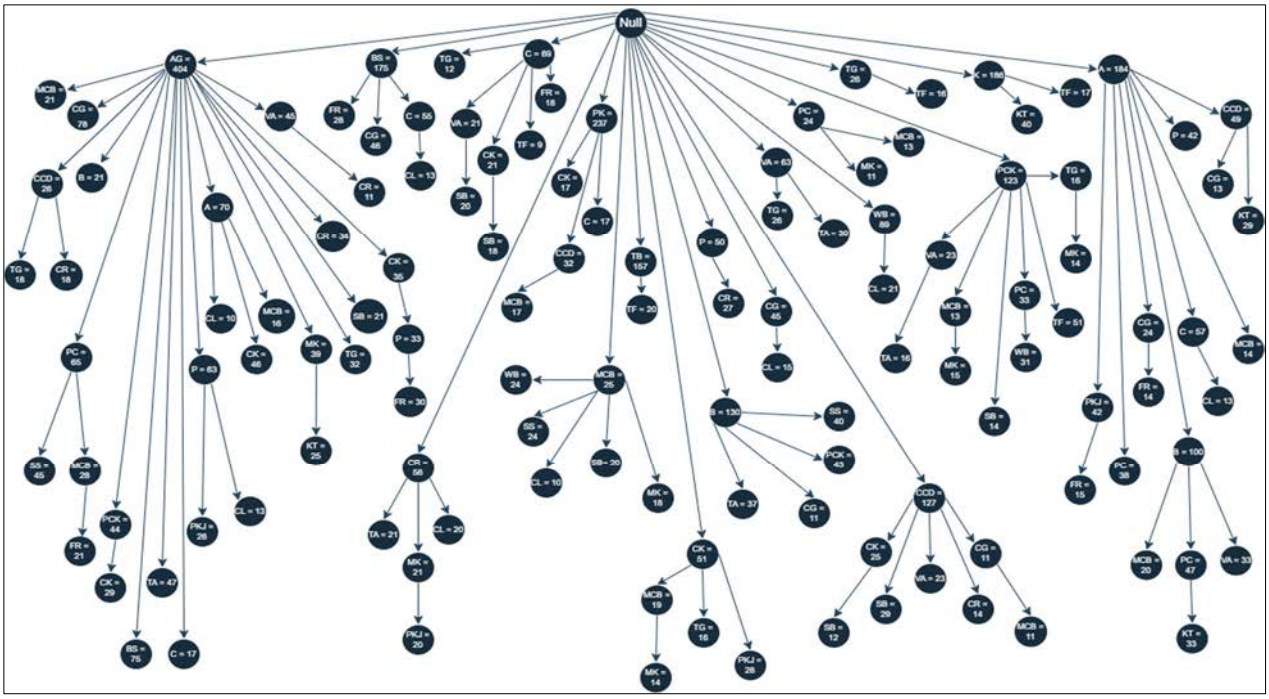

Figure 1 FP-Tree on reading all transactions

Generation of FP-Tree from all transaction data containing slow moving category items. Every node in the FP-Tree includes the initials of the item's name coupled with a support counter. Following this, a quest will be undertaken using the FP-Growth algorithm process to unearth noteworthy frequent itemsets. FP-Growth comprises three phases:

1. Conditional Pattern Base
   The Conditional Pattern Base is a subdatabase incorporating the prefix path and suffix pattern derived from the FP-Tree constructed in the preceding phase, beginning with the item featuring the lowest support count. Here are the outcomes of generating the conditional pattern base.

Table 2 Generation of Conditional Pattern Base

Suffix	**Generation of Conditional Pattern Base**
SS	(AG, PC : 45), (MCB :24), (B : 40)
TF	(C :9), (TB : 20), (K : 17), (PCK : 51), (TG : 16)
CL	(AG, P : 13), (BS, C : 13), (CR : 20), (MCB : 10), (CG : 15), (WB : 21), (A,C : 13)
PKJ	(CR, MK : 20),(CK : 280), (A : 42)
**	*****
BS	(AG : 75)
B	(AG : 21), (A : 100)
A	(AG : 70)
AG	-

2. Conditional FP-Tree
   During this step, the support counts for each item in each conditional pattern base are summed. For each category with a support count greater than or equal to the predefined minimum support count (25), it will be revived with a conditional FP-Tree. Categories with a support count less than the minimum support count will not be resurrected. Below is a table illustrating the results of the conditional FP-Tree search.

Table 3 Generation of Conditional FP-Tree

Suffix	**Generation of Conditional Pattern Base**
SS	(AG : 45), (B : 40), (PC :45), (AG, PC : 45)
TF	(PCK : 51)
PKJ	(A : 42), (CK : 28)
FR	(AG : 30), (A : 29), (BS : 28), (CK : 30), (P : 30), (AG, CK, P : 30)
**	*****
BS	(AG : 75)
B	(A : 100)
A	(AG : 70)
AG	-

3. Frequent Itemset
   In this step, the arrangement of items established by each conditional FP-Tree is implemented. If it doesn't shape a single path, the FP-Growth generation is conducted recursively. The results of the search for frequent item sets are outlined below:

Table 4 Frequent Itemset Formation

Suffix	**Generation of Conditional Pattern Base**
SS	(AG, SS : 45), (B, SS : 40), (PC, SS :45), (AG, PC, SS : 45)
TF	(PCK, TF : 51)
PKJ	(A, PKJ : 42), (CK, PKJ : 28)
FR	(AG, FR : 30), (A, FR : 29), (BS, FR : 28), (CK, FR : 30), (P, FR : 30), (AG, CK, P, FR : 30)
**	*****
BS	(AG, BS : 75)
B	(A, B : 100)
A	(AG, A : 70)
AG	-

Table 7 is the result of determining consumer purchasing patterns which provides information as a reference in determining marketing strategies. Following the creation phase, the subsequent step involves establishing the minimum support and minimum confidence.

3.5 *Determining support values and confidence values using Association Rules*

The outcomes of this association procedure furnish insights into items acquired together, determined by calculating the support and confidence values for each itemset using equations 4 and 5. Adhering to the stipulations of a minimum 3% support and 30% confidence, 13 rules are identified, classifying them as robust association rules. It can be seen in the following Table 8.

Table 5 Association Rule with Support Value and Confidence Value

Frequent	***Support***	***Confidence***
PCK ; TF	3%	45%
A; KT	3%	49%
AG;TG	3%	34%
AG;CR	3%	39%
AG;P	5%	51%
AG;MCB	3%	33%
AG;PC	3%	31%
A;PC	4%	41%
AG;VA	11%	100%
AG;CK	6%	49%
AG;CG	4%	34%
AG;BS	4%	30%
A;B	5%	40%

According to the Support Values and Confidence Values of the Association Rules, there are 13 rules that satisfy the association rule criteria, representing the conclusive rules for analyzing the XY bakery sales transaction dataset. The 13 association rules can be explained as follows :

1. If you buy the "Pisang Coklat Keju" (PCK) variant of bread, then there is a possibility of buying the "Tuna Fish Buns" (TF) variant with support of 3% and confidence of 45%
2. If you buy the "Abon" bread variant (A), there is a possibility of buying the "Keju Tabur" variant (KT) with support of 3% and confidence of 49%.
3. If you buy the "Abon Gulung" bread (AG) then you are likely to buy the "Tawar Gandum" (TG) variety with support of 3% and confidence of 34%.
4. If you buy the "Abon Gulung" (AG) variant of bread, there is a possibility of buying the "Cinnamor Roll" (CR) variant with support of 3% and confidence of 39%
5. If you buy the "Abon Gulung" bread variant (AG) then the possibility of buying the "Pizza" variant bread (P) is with support of 5% and confidence of 51%.
6. If you buy the "Abon Gulung" bread (AG) variant, there is a possibility of buying the "Mexican Coffee Buns" (MCB) variant with support of 3% and confidence of 33%.
7. If you buy the "Abon Gulung" (AG) bread variant, there is a possibility of buying the "Pisang Coklat" (PC) variant with support of 3% and confidence of 31%.
8. If you buy the "Abon" bread variant (A), there is a possibility of buying the "Pisang Coklat" variant (PC) with support of 5% and confidence of 41%.
9. If you buy the "Abon Gulung" bread (AG) then you are likely to buy the "Vanilla Almond" (VA) bread with 11% support and 100% confidence.
10. If you buy the "Abon Gulung" bread (AG) then you are likely to buy the "Coklat Keju" (CK) variant with support of 6% and confidence of 49%.
11. If you buy the "Abon Gulung" bread (AG) then the possibility of buying the "Coklat Gulung" (CG) variant is with support of 4% and confidence of 34%.
12. If you buy the "Abon Gulung" (AG) bread variant, there is a possibility of buying the "Brown Sugar" (BS) variant with support of 4% and confidence of 30%.
13. If you buy the "Abon" bread variant (A), there is a possibility of buying the "Blueberry" variant of bread (B) with support of 5% and confidence of 40%.

After consumer purchasing patterns are formed, the next stage is to carry out testing using RapidMiner. From the test results using RapidMiner, there are several patterns that are different from the results of calculations carried out manually. This is because in manual calculations the researcher prioritizes transactions with itemsets containing slow moving products, whereas in the RapidMiner test these are not input in processing the data. Figure 3 shows the test results using RapidMiner.

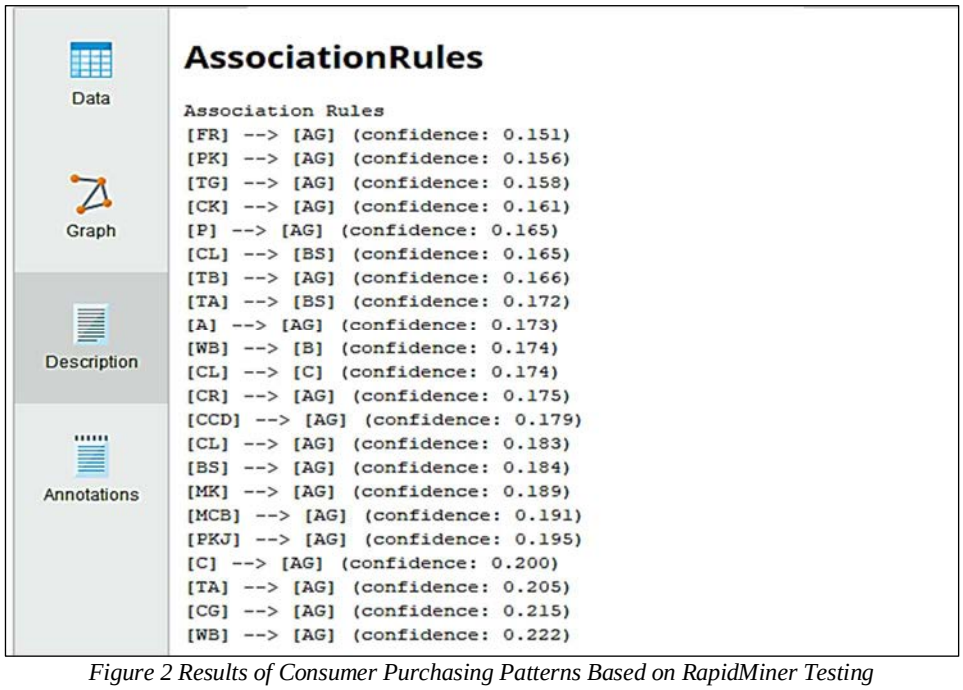

Figure 2 Results of Consumer Purchasing Patterns Based on RapidMiner Testing

3.5.1 Production planning based on the results of the K-Means Algorithm and FP-Growth Algorithm

According to the data mining analysis, it is evident that the sales data for bread at the XY bakery indicates a higher proportion of slow-moving products compared to fast-moving products. The data outcomes reveal that XY bakery faced significant losses attributed to a considerable overstock of products, indicating that the bakery did not achieve its sales target. In response to these challenges, the next step involves formulating a marketing strategy using the FP-Growth method.

Following the identification of patterns derived from the K-Means algorithm's grouping outcomes, the subsequent step involves implementing association rules to elucidate the connections among items in a dataset and assess the likelihood of simultaneous bread purchases. This known consumer purchasing pattern can be the basis for decision making in the field of production planning. In this case the researcher does not determine the actual value but can provide a pattern of 13 rules which produces a strong level of association. Through information from this data, especially for fast moving products, shop owners can improve inventory planning by analyzing demand data and market trends. For slow moving products, shop owners can arrange the placement of goods or create product bundling with best-selling products. Store owners can also design promotions for these item combinations by providing discounts or offering giveaways.

4 Conclusions

Through the application of the K-Means Clustering Algorithm, the formation of two distinct classes, namely slow-moving and fast-moving, was realized. The computational process extended up to the 4th iteration, where group 1, representing slow-moving products, encompassed 44 distinct types of bread items, while group 2, denoting fast-moving products, comprised 15 different items. These calculations were conducted both manually and using the Rapidminer software.

Based on the purchasing pattern that has been formed, the support value and confidence value are then determined to obtain a pattern that has a close relationship. Patterns that meet the minimum support and minimum confidence values as the final dataset rules include :

1. If you buy the “Pisang Coklat Keju” (PCK) variant of bread, then there is a possibility of buying the “Tuna Fish” buns (TF) variant with support of 3% and confidence of 45%.
2. If you buy the “Abon” bread variant (A), there is a possibility of buying the “Keju Tabur” variant (KT) with support of 3% and confidence of 49%.
3. If you buy the “Abon Gulung” bread (AG) then the possibility of buying the “Tawar Gandum” (TG) variant with support is 3% and confidence is 34%.

The employed method aids in offering insights and details concerning product availability or stock fluctuations of frequently purchased items by consumers. This information serves as a guide for anticipating product supply in accordance with demand, mitigating the risk of supply shortages.

The application of the K-Means algorithm can help develop strategies in determining stock of goods. It is hoped that this method can be combined again with other algorithms to get better results and the data that has been obtained shows that the bakery has not reached BEP (Break Even Point) in its sales so that a stage is needed continued by carrying out marketing strategies using the FP-Growth method for subsequent research opportunities.

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Measuring productivity using Data Envelopment Analysis and Multiple-Objective Programming in flows, logistic and transportation

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Abstract: The logistic and transportation plays an integral part in maintaining a well-functioning organization. One of the most extensively used, original, famous, and popular non-parametric methods for evaluating the efficiency of organizations is the Data Envelopment Analysis, DEA technique. Suppose we can formulate the concept of effectiveness in the DEA technique. In that case, we will be able to measure the productivity of organizations since productivity is a blend of efficiency and effectiveness. Several studies have been developed, e.g., the "Malmquist Productivity Index" (MPI) and the "Lunberger Productivity Index" (LPI), which assess the productivity of corporations through the DEA technique, but these models do not display all factors in a system. Also, they need at least two periods to appraise productivity. Furthermore, their two components of efficiency and effectiveness are not considerably evident. Moreover, sensitivity analysis is not possible in these models. Therefore, a model was presented that can measure the relative productivity of decision-making units through the technique of DEA, simultaneously in a period through the two elements of efficiency and effectiveness with the feature of sensitivity analysis and its solution method is more reliable due to the use of multi-objective planning method. In addition, a case study was used to indicate the application of the proposed model, which demonstrated that a branch could be efficient but unproductive.

1 Introduction

Productivity measures provide answers to important questions about the flows, logistic and transportation. For example, how efficiently transportation providers move people and goods, and whether the value of their services has grown more rapidly than the costs of the inputs they use. Evaluating the performance of similar organizations and examining the results of their performance in a certain period is considered an important and strategic process that determines the competitive position of organizations. It has a notable role in continuous improvement and increasing the quality and effectiveness of management decisions of organizations [1].

One of the main criteria for evaluating the performance of organizations is productivity. Research show that productivity is the most favourable criterion of performance in all evaluations. If organizations do not properly assess their productivity, their survival will be accidental [2]. The measurement provides the means to identify effective factors in improving efficiency and effectiveness, which in turn has a special role in determining the productivity of organizations. Productivity can be divided into two elements: efficiency and effectiveness. Efficiency refers to the ability to obtain output from fewer data, and effectiveness refers to matching the results obtained from work with predetermined goals [3]. Productivity is managing the set of activities that are carried out to enhance the efficiency and effectiveness of the companies.

The DEA is one of the most popular and major techniques for evaluating the relative efficiency of "decision-making units" (DMUs) [4]. Clermont and Schaefer state: "From the point of view of many researchers and users of operations research, the advantages of DEA outweigh its disadvantages". One of the DEA technique's weaknesses is that it only focuses on

evaluating the relative efficiency of DMUs. As a result, evaluating productivity through the popular and widely used technique of the DEA can be considered an important step in determining the performance of organizations [5].

Newly, studies have been developed to measure productivity through the DEA technique, e.g., the "Malmquist Productivity Index" (MPI) and "Lunberger Productivity Index" (LPI), which are mentioned below.

2 Literature review

Qu et al. [6], using the "Weighted Entropy Method" in the first step, calculated the comprehensive index of environmental pollution in different sectors and cities. In the second step, through the combined MPI-LPI, they evaluated the efficiency of different sectors and cities in terms of reducing pollution from 2012 to 2017. At the division level, two main factors affecting the total productivity of each division were determined. At the city level, it was determined that five cities have improved in terms of productivity, but the productivity of the three cities has decreased. Bansal et al. [7] proposed a model to evaluate changes in the "Total Factor Productivity" (TFP) of 60 Indian banks using the MPI-LPI from 2013 to 2017. Data had negative values and undesirable characteristics. Results showed that foreign banks fulfil better than their counterparts in terms of productivity. Giacalone et al. [8] used the MPI from 2011 to 2016 to evaluate and analyze the Italian Judicial System's productivity. Empirical studies showed that the inefficiency of the judicial system slows down the economy due to prolonged judgment and lack of legal certainty. Huang et al. [9] analyzed the dynamic trend of energy security performance of 30 Chinese provinces from 2008 to 2017 through the MPI. The results showed that the eastern and southern provinces perform better energy security than the western and northern regions.

Lu et al. [10] used the "Network DEA" (NDEA) technique and the MPI to evaluate the productivity of the machine tool industry in Taiwan during the years 2010 to 2014. The results showed that the productivity in the production and marketing sectors had rapid growth, and the marketing sector's productivity growth was more than that in the production sector. Amiri [11] presented a new approach to assessing the productivity of DMUs through the NDEA. They used "Multi-Objective Programming" (MOP) to solve network problems. Using the two concepts of efficiency and effectiveness in the DEA model is one of the important features of this research. Wang and Feng [12] analyzed the productivity of China's Industrial System and the subdivision of this industry using the NDEA method and the TFP index from 2004 to 2015. They found that the total productivity of China's Industrial System increased during this period. In the first stage, Ding et al. [13] used the NDEA technique to assess the "Circular Industrial Economic System" efficiency. Then they used the MPI technique to measure the dynamic productivity from 2012 to 2017. Their proposed method can decompose the circular economic system into 4 dynamic indicators and provide more details. Tavana et al. [14] utilized fuzzy NDEA and the MPI to dynamically measure the productivity of oil refineries in the existence of adverse outputs during the years 2013 to 2016. The results showed that the productivity score of 70% of refineries is lower than average.

Aduba and Asgari [15] used the MPI method to evaluate the Japanese Manufacturing Industry's TFP, technological, and efficiency changes. The results showed that the Japanese Manufacturing Industry's productivity declined from 2008 to 2014. Li et al. [16] used the MPI method to evaluate TFP from 1978 to 2016 under resource and environmental limitations in China. The results showed that China's TFP relates to fluctuations and rules of macro-economic, direction control, and economic system reform. Using the MPI method, Song et al. [17] investigated Chinese universities' productivity. They found that the productivity of Chinese universities increased between 2009 and 2016. Lu and Xu [18] utilized the three-stage MPI-DEA to measure TFP in provincial water resources in China from 2008 to 2015. They concluded that it is necessary to reform the existing water consumption system by strengthening government macro-control and strengthening efforts to purify pollution and environmental protection. The growth of TFP of water in China has not yet reached maturity. Liang Yang et al. [19] measured productivity changes in Chinese research universities from 2010 to 2013 using the LPI. The experimental results showed that LPI increased significantly during the period under review.

Falavigna et al. [20], in research entitled "DEA-based MPI for understanding courts reform", used a two-stage analysis to assess the productivity of the Italian tax judiciary from 2009 to 2011. The evidence showed that reducing the number of active divisions harmed the courts' productivity. Gandhi and Sharma [21] measured the productivity of private sector hospitals in India using DEA and MPI from 2010 to 2014. The results showed an improvement in the Indian hospital industry during this period. Fujii et al. [22] assessed the changes in productivity and efficiency in EU28 banks from 2005 to 2014 using "Weighted Russell Directional Distance" and the MPI. Then, they analyzed the share of private bank inputs in increasing productivity and efficiency. They concluded that productivity in EU banks is higher than in the old EU. Cadavid et al. [23] evaluated the productivity of public universities in Colombia through DEA and the MPI from 2011 to 2012. Universities were also ranked using a "Pareto Efficient Cross-Efficiency Model". The results showed an improvement in productivity during the mentioned years. Fernandes et al. [24] evaluated the productivity of European domestic banks and estimated the impact of banking risk factors on their performance from 2007 to 2014. The DEA technique used in this research is based on an MPI to calculate banks' productivity scores. The results showed that credit risk and liquidity hurt banks' productivity, and profit and capital risk harm their

performance. The results showed that some provinces had faced a decrease in the productivity of production factors. Research on optimization by heuristic algorithms in manufacturing and industries for measuring the efficiency of using optimization methods and techniques has been done so far, which can be mentioned [29].

The summary of these studies is given in Table 1. As can be seen, most of these studies use the MPI or LPI or a combination of these two indexes to evaluate productivity. First, studies of productivity through efficiency and effectiveness are very limited. Secondly, most of this research evaluate the performance of DMUs through DEA and NDEA using indicators such as MPI and LPI, in which the effectiveness is not evident clearly. Thirdly, these studies need at least two periods or two stages, and efficiency and effectiveness must be considered interdependent, which is not considered in these studies. Fourth, these studies do not have the advantage of sensitivity analysis in the model. In the study of Amiri [11], the method of solving their proposed model was done by converting the fractional model to a linear model, which, unlike that, our solution process in this study will be through the MOP technique.

As a result, to complete the defects in the studies, we proposed a model that can assess the productivity of DMUs through the DEA technique in one stage and one period while maintaining efficiency and effectiveness dependency. Also, the method of solving our model is through the MOP technique and can be used for sensitivity analysis and parametric programming. Also, a case study was used to show the utilization of our model.

Table 1 Summary of studies

Reference	Description of the research	Methodology
Qu et al. (2022)	Evaluation of efficiency in pollution of different sectors and cities for reducing pollution in the years 2012 to 2017	MPI-LPI and "Weighted Entropy Method"
Bansal et al. (2022)	A model to evaluate changes in the TFP of 60 Indian banks during the years 2013 to 2017	MPI-LPI
Huang et al. (2021)	Analyze the dynamic trend of energy security performance of 30 Chinese provinces during the years 2008 to 2017	MPI
Lu et al. (2021)	Evaluate the productivity of the machine tool industry in Taiwan during the years 2010 to 2014	NDEA and MPI
Esmaeeli et al. (2021)	A new approach to evaluating the productivity of DMUs	NDEA and MOP
Giacalone et al. (2020)	Evaluate and analyze the productivity of the Italian Judicial System From the years 2011 to 2016.	MPI
Wang and Feng (2020)	Evaluate the productivity of China's Industrial System and subdivision of this industry from 2004 to 2015	TFP index and NDEA
Aduba and Asgari (2020)	Evaluate the TFP changes, technological changes, and efficiency changes in the Japanese manufacturing industry from 2008 to 2014	MPI
Ding et al. (2020)	Measure the productivity of the "Circular Industrial Economic System" and evaluate the dynamic productivity from 2012 to 2017.	NDEA and MPI
Tavana et al. (2019)	Measure the productivity of oil refineries in the existence of adverse outputs during the years 2013 to 2016.	Fuzzy NDEA and MPI
Li et al. (2019)	Analyze the TFP from 1978 to 2016 under resource and environmental limitations in China	MPI
Song et al. (2019)	Investigate the scientific productivity of the Chinese Science System between 2009 and 2016	MPI
Lu and Xu (2019)	Measure the TFP in provincial water resources in China during the years 2008 to 2015	Three-stage MPI-DEA
Liang Yang et al. (2018)	Measure the productivity changes in Chinese research universities from 2010 to 2013	LPI
Falavigna et al. (2018)	A two-stage analysis to assess the productivity of the Italian tax judiciary during the period from 2009 to 2011	MPI
Gandhi and Sharma (2018)	Evaluate the productivity of private sector hospitals in India during the years 2010 to 2014	MPI
Fernandes et al. (2018)	Evaluate the productivity of European domestic banks and estimate the impact of banking risk factors on their performance during the years 2007 to 2014	MPI

Fujii et al. (2018)	Evaluate the changes in productivity and efficiency in EU28 banks during the period from 2005 to 2014 and analyze the share of private bank inputs in growing its productivity	"Weighted Russell Directional Distance" and MPI
Cadavid et al. (2017)	Evaluate the efficiency of public universities in Colombia during the years 2011 to 2012 and rank the Universities	"MPI and Pareto Efficient Cross-Efficiency Model"
Salarieh et al. (2016)	Study the effect of efficiency and technology changes on the changes in the productivity of the agricultural sector in Iran in the period from 2004 to 2013	MPI

3 Efficiency, effectiveness, and productivity

According to Richard Daft, efficiency is the force by which we must reduce costs and increase profits. Peter Drucker called efficiency the ability of a corporation to reach the desired level of outputs with the minimum level of inputs. Nevertheless, efficiency has also been defined as "the ratio between expected consumption resources and actual consumption resources". Efficiency is also defined as the optimal use of resources that leads to customer satisfaction. In addition, efficiency is defined as "the ratio of time dependent on the ideal system to the total time spent" [25]. A company is efficient if it produces the maximum output from a given input level. The common denominator of all the above definitions in the efficiency field is the maximum use of minimum resources, which is the ratio of output to input.

Effectiveness is the second word that is less discussed. A simple and appropriate definition of effectiveness is the organization's ability to achieve preset goals. Such a definition leads to an interesting concept of effectiveness: there is usually no limit to the effectiveness of an organization. Determining effectiveness is more difficult than efficiency because of its definition, which concerns the Relationship between inputs or outputs and outcomes. Figure 1 shows that some outputs and external environmental factors may affect the outcomes. Changes in effectiveness are mainly focused on changes in outcomes. In the same way, effectiveness establishes a Relationship between input and output with the obtained outcome (end goals) [25].

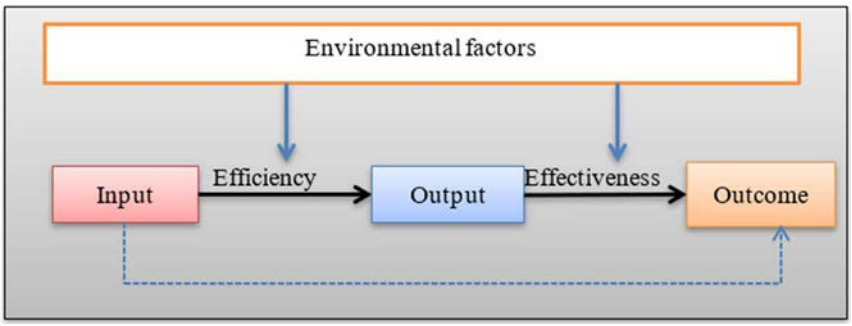

Figure 1 Input, output, and outcome

Effectiveness shows how a good organization works to achieve its goals, but inefficiency is related to waste and, therefore, ineffective operations.

The third word is productivity, which is more comprehensive and complete than the previous two. In the past, the terms productivity and efficiency were used interchangeably, but today these terms have different meanings. Productivity will follow the measurement and evaluation of the output and results of a corporation's activities concerning the goals and the number of consumed resources. Productivity is one of the most important indicators showing employee activities' effectiveness. In 1950, the Organization for "Economic Co-operation and Development" (OECD) defined productivity as "the ratio of output to one of the factors of production". In 1995, three definitions of productivity were shown, which are mentioned below [25]:

Productivity is equal to $\frac{output}{input}$, which is defined as the measurement of efficiency.

Productivity is a blend of efficiency and effectiveness, which is shown as $\frac{output}{input} + \frac{output}{goal}$, which is the concept of productivity [26].

It refers to a broader concept and is anything that improves the organization's performance.

In addition, the "Asian Productivity Organization" (APO) has defined productivity as "$Productivity = efficiency + effectiveness = doing\ things\ right + doing\ the\ right\ things$" [25]. Productivity can also be expressed as "measuring the organization's ability to convert input resources into goods and services". However, the combination of high efficiency and effectiveness in the product production process will lead to high productivity. Therefore, an efficient system may be ineffective, or an

effective system may be inefficient. Productivity has been introduced as one of the basic mechanisms for gaining a competitive advantage.

According to the information in this section, we find out that the evaluation of productivity is more complete than the evaluation of efficiency and effectiveness separately. Also, efficiency and effectiveness are two integrated elements of productivity, so using them to measure productivity is better. In addition, according to the information in this section, the productivity formula can be formulated as follows: productivity $= \frac{output}{input} + \frac{output}{goal}$.

4 DEA technique

Farrell [28] proposed non-parametric methods for efficiency estimation for the first time. His model for measuring efficiency included one input and one output. The linear form of their model was called the DEA, and the model they presented was known as the CCR model based on the first letters of their name. The CCR model was changed to a new model known as the BCC model. The DEA is a "Non-Parametric Frontier Evaluation Model" that evaluates the relative efficiency of a set of similar units. This frontier contains line segments that not only identify the most efficient DMUs but also provide an analysis of the inefficient units.

Evaluation of efficiency via the DEA technique is classified by three separate structures: "Overall Technical Efficiency" (OTE), "Pure Technical Efficiency" (PTE), and Scale Efficiency. The Relationship between these three structures is defined as follows (1):

$$\text{scale efficiency} = \frac{\text{OTE}}{\text{PTE}} = \frac{\text{CCR}}{\text{BCC}} = \frac{\text{"Constant Return to Scale" (CRS)}}{\text{"Variable Return to Scale" (VRS)}} \quad (1)$$

The scale efficiency specifies CRS or VRS for greater productivity. OTE, or CCR, is calculated by measuring how well a DMU can use its inputs to create outputs. The CCR model shows that a change in the number of inputs will cause a similar output change. For example, if the input values for a decision unit are doubled, it must produce double the output. PTE or BCC shows that a change in the value of the inputs produces a variable value in the outputs [23]. Usually, the efficiency score of the BCC model is higher than the CCR model.

Furthermore, DEA models need input-oriented and output-oriented solutions to reach the efficient frontier. The input-oriented model provides suggestions on reducing inputs to reach the efficient frontier. For example, an input-oriented efficiency score of 0.9 in an organization indicates that the organization can reduce the input level by 10% with the same output level. The output-oriented model offers suggestions for how to increase output to reach the efficient frontier [21]. In the output-oriented model, it is possible to increase the outputs to reach the efficient frontier without attracting more inputs. The output-oriented model is appropriate where the inputs are approximately constant. Also, the input-oriented model is appropriate when the outputs are closely aligned with the organization's goals or are limited by external factors. If the manager has little control over inputs and most of the managers' operations are to develop outputs, then the output-oriented measurement would be suitable. However, the choice of orientation has little effect on efficiency scores [15]. In general, the benefits of DEA include the following:

There is no need to specify a mathematical function.

It helps discover issues that are hidden from other techniques.

Inefficient resources can be analyzed for each DMU.

A DMU is directly compared to its peers by multiple inputs and outputs.

It uses quantitative and qualitative criteria to evaluate the efficiency of organizations.

The impact of subjective factors is reduced in this method [19].

Other measurement methods measure the company's performance only from a financial landscape. Still, the DEA method measures the company's performance both from a financial landscape and from a non-financial landscape.

The DEA technique allows each DMU to set its variable weight more favourably than other DMUs and can identify reference units for each DMU.

DEA is more flexible and applicable than other methods.

Based on the information given in this section, the reason for choosing the DEA method to evaluate the productivity of DMUs is determined. Also, the type of DEA model is obtained.

5 Productivity indexes

Measuring the index involves using five ratios to measure productivity: "Single Factor Productivity, Multi-Factor Productivity, TFP, Management Control Ratio, and Productivity Costing". The most common ratio is the TFP, where productivity is measured as a ratio of different inputs. These indicators have recently been combined with DEA and show changes in efficiency over time, and for this reason, they are interpreted as productivity indicators. One type of TFP index combined with DEA is the MPI. The MPI is an index that shows the growth of the TFP of an organization, and it can provide progress or regression in efficiency and show the changes in efficiency between two time periods. If the MPI value is higher than 1, it indicates that the efficiency is improved [20]. The required values of the MPI have been calculated using the DEA technique. By applying it, the changes in total productivity are calculated by separating the changes in efficiency and technological

changes. In fact, in the MPI, there is no cost minimization or income maximization assumption, and we only need to observe some inputs and outputs [3].

The MPI is related to "Russell's Measure of Inefficiency", which is multiplicative, while LPI is based on a "Slack-Based Measurement of Efficiency", which is cumulative. The DEA technique measures the efficiency of corporations for a specific year. The MPI or LPI approach is used to get changes in efficiency in more than one year [21].

Many productivity studies have recently been developed based on DEA-LPI and DEA-MPI techniques. When the DMUs follow homogeneous production technologies within groups but are compatible with heterogeneous production technologies at the whole society's level, the MPI-LPI scores and their components may be misleading [27].

In this part, we find that these indicators need at least two periods to analyze the efficiency of organizations, the effective formula is not evident in them, and sensitivity analysis is not possible in these models.

6 Multiple-Objective Programming technique

The Multiple-Objective Programming, MOP technique is done by a set of objective functions that must be optimized simultaneously, and a set of constraints is defined to be satisfied. In other words, MOP shows how to move toward several objectives simultaneously.

Considering that in this research, we will use two objective functions of efficiency and the objective function of effectiveness, the linear programming of this model will be multi-objective.

7 Methodology

According to section (4), the input oriented CCR modeling of the DEA technique is as follows (2):

$$\begin{aligned} &\mathrm{MaxE_0} = \frac{\sum_{r=1}^{s} u_r Y_{r0}}{\sum_{i=1}^{m} v_i X_{i0}} \\ &\text{S.t:} \\ &\frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i X_{ij}} \le 1; \quad j = 1,2,\dots,n \\ &u_r, v_i \ge \varepsilon; \quad r = 1,2,\dots,s, \quad i = 1,2,\dots,m \end{aligned} \tag{2}$$

However, as discussed in the previous sections, Equation (2) only evaluates the efficiency of DMUs. To evaluate the productivity of DMUs, which is more comprehensive than the efficiency evaluation, it is necessary to formulate the effectiveness in Equation (2). Referring to section (4), the effectiveness can be obtained as $\frac{output}{goal}$.

To combine this formula with Equation (2), we need to define the effectiveness of the DMU as follows (3):

$$\begin{aligned} &Effectiveness\ of\ DMU_0 \\ &= \frac{weighted\ outputs\ of\ DMU}{weighted\ standard\ outputs\ (goals)of\ DMU} \\ &= \frac{\sum_{r=1}^{k} u_r Y_{r0}}{\sum_{r=1}^{k} \eta_r g_{r0}} \end{aligned} \tag{3}$$

Where $\eta_r g_{r0}$ is weighted standard outputs (goals) of DMU0.

Now, according to section (4), where $productivity = efficiency + effectiveness$, we will combine Equations (2) and (3). Therefore, if we combine Equation (3) with the objective function of Equation (2), we can evaluate productivity through Equation (4).

$$\begin{aligned} &MaxE_0 = \frac{\sum_{r=1}^{s} u_r Y_{r0}}{\sum_{i=1}^{m} v_i X_{i0}} \\ &MaxE1_0 = \frac{\sum_{r=1}^{rk} u_r Y_{r0}}{\sum_{r=1}^{rk} \eta_r g_{r0}} \\ &S.t: \\ &\frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i X_{ij}} \le 1; \quad j = 1,\dots,n \\ &\frac{\sum_{r=1}^{rk} u_r Y_{rj}}{\sum_{r=1}^{rk} \eta_r g_{rj}} \le 1; \quad j = 1,\dots,n \\ &u_r, v_i, g_r \ge \varepsilon; \quad r = 1,\dots,s, \quad i = 1,\dots,m \end{aligned} \tag{4}$$

Equation (4) is in the form of a linear fraction, which can be converted into the linear model through Equation (5) as follows:

$$\begin{aligned} &MaxE_0 = \sum_{r=1}^{s} u_r Y_{r0} \\ &MaxE1_0 = \sum_{r=1}^{rk} u_r Y_{r0} \\ &S.t: \\ &\sum_{i=1}^{m} v_i X_{i0} = 1 \\ &\sum_{r=1}^{rk} \eta_r g_{r0} = 1 \\ &\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \le 0; \quad j = 1,\dots,n \\ &\sum_{r=1}^{rk} u_r Y_{rj} - \sum_{r=1}^{rk} \eta_r g_{rj} \le 0; \quad j = 1,\dots,n \\ &u_r, v_i, g_r \ge \varepsilon; \quad r = 1,\dots,s, \quad i = 1,\dots,m \end{aligned} \tag{5}$$

The following process has been developed to solve Equation (5):

Step 1: Every objective is optimized independently of other objectives. For DMU0, we maximize E0 individually to determine its ideal objective values E_0'',

Step 2: Every objective is computed oppositely regardless of the other objective. We minimize E0 to determine its anti-ideal solution $E_0^{-''}$,

Step 3: Define the membership function of every objective by its ideal and anti-ideal solutions as $uE_0(E_0) = \frac{(E_0 - E_0^-)}{(E_0^* - E_0^-)}$.

Step 4: Maximize the minimal membership function for all objectives as Equation (6).

$$\begin{aligned} &Max = \alpha \\ &S.t: \\ &\alpha \leq uE_0(E_0) \\ &in\ addition\ to\ all\ original\ constrains\ in\ eq1 \end{aligned} \quad (6)$$

So, α is the minimum of all member functions that are maximized. The overall score $E_0 = \sum_{k=1}^{K}(W_k E_0^k)$ is evaluated for the DMU0.

Equation (5) evaluates the productivity of DMUs through the technique of DEA and MOP, both of which have maximum validity and popularity. We can easily continuously evaluate the productivity of DMUs in one stage, in one period, and with the property of sensitivity analysis through Equation (5). The DMU will be productive if the equation (5) answer equals 2.

8 Case study

In this section, to apply Equation (5), we selected the branches of a bank to evaluate productivity. Most of the bank's activities are related to the flows, logistics and transportation industries. Collecting and attracting all kinds of deposits and allocating them to meet the financial needs of all economic activities is one of the most important banking operations. Analyzing the productivity of the banking industry and determining methods for this purpose is of interest to managers, politicians, economists, and academic researchers [24]. The DEA technique is accepted for performance evaluation in the banking industry. There are rich and extensive studies to assess performance in the banking industry, most of which used the DEA technique.

According to the research done by Amiri [11], the input and output processes in the banking industry were drawn in Figure 2, and its data was set in Table 2.

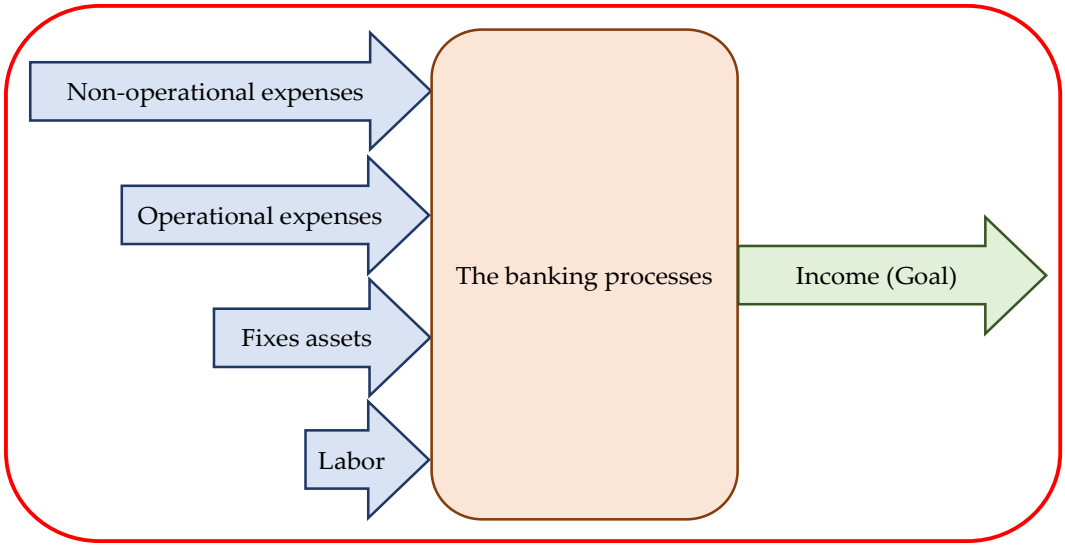

Figure 2 Input and output process in the banking industry

Table 2 Inputs, outputs, and goals

DMUs	Inputs				Output	
	Input1	Input2	Input3	Input4	Output	Goal
1	0.0634	0.0616	0.0378	0.0794	0.0607	0.0729
2	0.0563	0.0907	0.0383	0.0799	0.0463	0.0617
3	0.0563	0.0896	0.0243	0.0383	0.0253	0.0347
4	0.0563	0.0407	0.0277	0.0837	0.0462	0.0581
5	0.0634	0.0435	0.0389	0.0657	0.0435	0.0581
6	0.0563	0.0819	0.0299	0.0681	0.0400	0.0534
7	0.0563	0.0717	0.0338	0.0575	0.0436	0.0576
8	0.0634	0.0448	0.0307	0.0556	0.0408	0.0518
9	0.0775	0.0582	0.0465	0.0629	0.0466	0.0605
10	0.0493	0.0489	0.0295	0.0692	0.0433	0.0538
11	0.0563	0.1120	0.0280	0.0461	0.0298	0.0398
12	0.0563	0.0183	0.0273	0.0577	0.0540	0.0578
13	0.0352	0.0367	0.0151	0.0174	0.0123	0.0173
14	0.0563	0.0326	0.4855	0.0204	0.3336	0.1547
15	0.0563	0.0403	0.0352	0.0711	0.0441	0.0527
16	0.0845	0.0815	0.0457	0.0918	0.0643	0.0818
17	0.0563	0.0469	0.0259	0.0350	0.0256	0.0333

8.1 The results of measuring the efficiency of bank branches through Equation (2)

Using Equation (2), the efficiency scores of the branches are displayed in Table 3 by LINGO software. The results show that branches 12 and 14 are efficient.

Table 3 Efficiency scores of the branches by Equation (2)

DMUs	Efficiency	Rank
1	0.9321776	3
2	0.7626125	7
3	0.6336423	15
4	0.8517058	5
5	0.6612190	13
6	0.7195985	11
7	0.7521600	8
8	0.7426476	10
9	0.6663757	12
10	0.8540485	4
11	0.6309013	16
12	1.000000	1
13	0.5906874	17
14	1.000000	1
15	0.7497362	9
16	0.7660993	6
17	0.6576079	14

8.2 The results of measuring the productivity of bank branches using Equation (5)

Bank branch productivity scores are presented in Table 4 using LINGO software's Equation (5). The results show that branch 14 is productive.

Figure 3 shows the combination of Tables 2 and 3. Considering Figure 3, we find that unit 12 is efficient but unproductive. Also, the rating of some units in Equation (2) and Equation (3) is not the same.

Table 4 Productivity scores of the branches through Equation (4)

DMUs	Productivity	Rank
1	1.3182823	3
2	1.110597	8
3	0.9717502	16
4	1.2204542	5
5	1.0084171	14
6	1.0669611	11
7	1.1031771	10
8	1.1079013	9
9	1.023562	12
10	1.2272728	4
11	0.9781155	15
12	1.4332416	2
13	0.9203907	17
14	2.000000	1
15	1.1377903	6
16	1.1306198	7
17	1.0141083	13

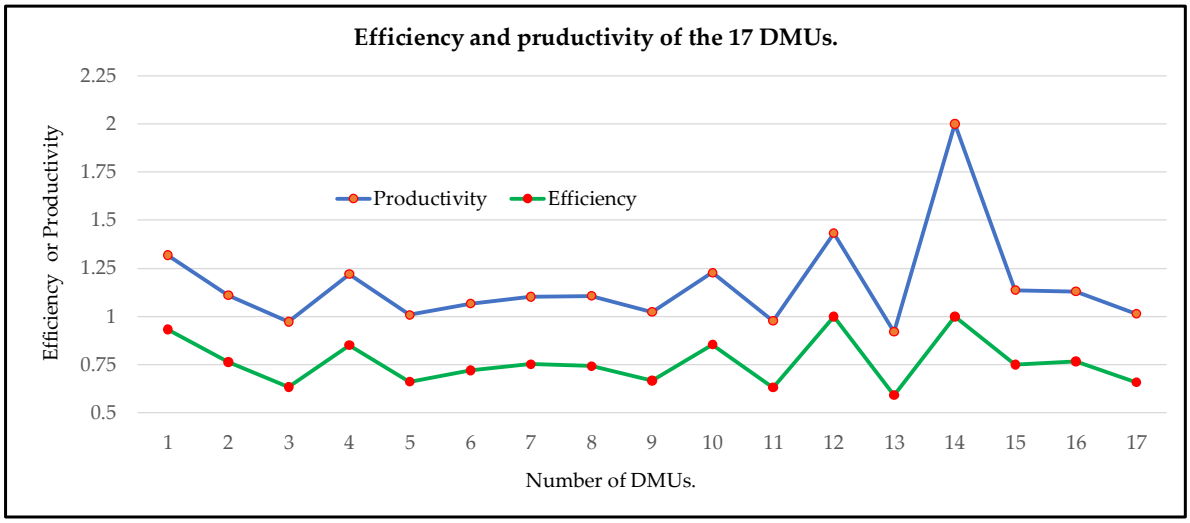

Figure 3 Efficiency and productivity of the 17 DMUs

9 Conclusion and recommendations

Evaluating similar organizations' performance and examining their performance in a certain period is considered an important and strategic process. One of the main criteria for measuring the performance of organizations is productivity. Productivity is a blend of effectiveness and efficiency. The DEA technique is one of the most popular methods and one of the main methods for evaluating the relative efficiency of DMUs. Recently, there have been studies to measure productivity through the DEA technique, which includes the MPI and the LPI. First, the effectiveness is not formulated in these studies. Secondly, they need at least two time periods or two stages. Thirdly, they do not benefit from sensitivity analysis in the model. To complete the shortcomings in the studies, a model was proposed that can assess the productivity of DMUs through the DEA technique and MOP in one stage and one period while maintaining the efficiency and effectiveness dependency. The proposed model is linear in such a way that the advantage of its linearity can be used for sensitivity analysis and parametric programming. For this purpose, effectiveness was formulated in the CCR model of the DEA technique, and MOP was used to maximize the two functions of efficiency and effectiveness. Then, to demonstrate the application of the model, a case study was conducted in the branches of a bank. The case study results showed that a productive branch must be efficient, but an efficient branch is not necessarily productive. Organizations with the same inputs and outputs can benefit from this study to evaluate their productivity, identify less productive resources, and manage their productivity. A DMU can include its predetermined goals in its productivity calculations through the proposed model. Also, a DMU can use sensitivity analysis in the model to determine what change in its productivity will be achieved by changing its predetermined goals. Also, the results showed that the use of this research can play a significant role in flows, logistic and transportation.

Some studies that can be suggested for the future include the following:

- The model's parameters are all precise and deterministic, which can be considered imprecise and qualitative and solved through the fuzzy technique.
- Considering that the proposed DEA model is of CCR type, another research of BCC type can be made.

Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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The role of the Internet of Things in increasing the efficiency of logistics companies

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Keywords: Internet of Things, logistical efficiency, logistics companies, Industry 4.0.
Abstract: Raising efficiency encourages logistics companies to use modern technologies. Using Internet of Things (IoT) devices improves logistical efficiency. The aim of the research is to determine the role of IoT in increasing the efficiency of logistics processes. The study was based on information about the logistics activities of the Supply Chain of one of the largest logistics companies in the world — DHL Group. The study covers the period 2009-2022. The research was conducted using linear regression models tested by the least squares method. The impact of the use of IoT devices was introduced into the model through the use of a dummy variable. It was established that the implementation and use of IoT devices has a positive, statistically significant effect on such indicators of logistical efficiency as Profit Margin and Operating Efficiency Ratio. It was proved that IoT positively affects logistical efficiency and does not entail reducing jobs, which is a socially important factor. The obtained results can be applied in developing and justifying the policy of implementing IoT in the activities of logistics companies. The conducted research opens up prospects for further studies, in particular regarding the impact of IoT on other performance indicators of logistics companies, particularly on their market capitalization.

1 Introduction

The key to the success of a logistics company is the ability to meet the customers' needs in fast, timely delivery of goods to the specified destination. Modern technologies contribute to ensuring fast and accurate address delivery of shipments and the ability to monitor the route of shipped goods. Moreover, they enable identifying and optimizing places where the efficiency of logistics chains decreases. The relevance of the research topic is determined by several key factors currently affecting the logistics industry and business in general. The volume of cargo transported around the world continues to grow. This challenges logistics companies to manage huge volumes of goods efficiently, and Internet of Things (IoT) can help to ensure this efficiency. Consumers and businesses expect faster and more accurate deliveries. IoT allows receiving real-time information about cargo status and location, which improves service and increases customer satisfaction. IoT offers many sensors and devices to collect data that can be used for analysis and strategic decision making. Considering these factors, research on the role of IoT in logistics remains relevant and important for the development of the logistics industry, increasing the competitiveness of companies and achieving greater customer satisfaction.

The Internet of Things can improve the efficiency of a logistics company in many ways, providing greater control and optimization of important processes. Sensors placed on goods or packaging allow logistics companies to monitor the location and condition of cargo in real time. This helps to avoid losses, monitor the delivery time and prevent bad conditions for the goods (for example, negative temperature). IoT can provide data on road conditions, traffic, etc. These data help companies to optimize delivery routes, which reduces travel time and fuel costs. IoT enables logistics companies to provide customers with an interactive consumer experience. This includes tracking deliveries in real time, receiving notifications of estimated arrival times, and providing a convenient way to communicate with customers.

Sensors and RFID tags provide real-time inventory tracking. This helps to avoid overstocking or shortage of goods. IoT can provide data on the status of equipment and vehicles. This enables planning preventive maintenance and avoiding accidents and stoppages, which reduces travel costs and downtime. IoT can help to resolve energy efficiency issues by monitoring and managing energy consumption in warehouses and vehicles. Data collected from IoT devices can be used to analyze and forecast trends in logistics, which helps companies make strategic decisions. Overall, IoT helps logistics companies make their operations more efficient, accurate, and cost-effective. It also opens up new opportunities to improve customer service and create competitive advantages in the logistics market.

So, the aim of this study is to determine the role of IoT in increasing logistical efficiency. The aim involved the fulfilment of the following research objectives:

- analyze the dynamics of the logistics company's performance indicators;
- determine the impact of the use of IoT devices on the company' performance;
- determine the impact of the use of IoT devices on the performance indicators of logistics activities.

2 Literature review

Growing demand is forcing the traditional logistics industry to transform into smart logistics. There are many recent technologies that have helped transform the logistics industry. In particular, researcher [1] examines the technologies required to implement smart logistics and determines the role of IoT and big data in developing the smart logistics industry. The author claims that the coronavirus pandemic has significantly accelerated the inevitable logistics digitalization process. Now, the implementation of digital technologies, particularly IoT, is not determined by the forced circumstances of the external environment but by the need to improve logistical efficiency.

Authors [2] examine the conceptual framework for the impact of IoT on supply chain management. The conceptual framework developed by the authors ensures the organization of the logistics company's supply chain management process, starting from determining its advantages and ending with the impact on the financial result. It is worth noting that the conceptual framework developed by the authors can be effectively implemented only if all supply chain links are fully provided with IoT devices, as the effects specified by the authors can be achieved through the availability of complete information.

A joint report by DHL and Cisco [3] is interesting, in which the authors identify promising directions for the implementation of IoT in the activities of logistics companies. It is noted that the greatest effect of the implementation of IoT will be in the field of last mile delivery. The fact is that last mile delivery is the most expensive in the entire supply chain. The authors note that the effective implementation of IoT requires the cooperation of managers at all levels - from top management to functional managers at delivery points.

The fourth industrial revolution (Industry 4.0) provides new resources for qualitatively changing how businesses and supply chains work. Authors [4] consider the unique potential of IoT, together with other technologies of Industry 4.0, in particular, blockchain [5], that can cause significant changes in the world. The authors argue that the IoT guarantees a massive revolution in logistics over the next decade. This creates new benefits for businesses by minimizing the price of device components, increasing the speed of wireless networks, and expanding the possibilities of receiving data on the network.

In the work [6], authors note that transport and logistics companies may have different goals for IoT implementation. On this basis, authors [7,8] consider it necessary to build a different architecture to implement IoT devices and determine the corresponding targets. However, the process of implementing the use of IoT is almost the same despite the difference in goals. That is why implementing this technology is worth considering competitors' experience and mistakes, which will increase the efficiency of using IoT to improve logistics activities [9].

The analysis of studies by [10] revealed a gap in the academic literature in the study of reverse logistics. It is worth noting that the use of IoT in this logistics segment has significant prospects for improving efficiency. Monitoring and tracking cargo is extremely important when a shipment is redirected, or other route changes occur. The use of IoT increases the accuracy of cargo movement and reduces the number of unproductive losses thanks to the optimal loading of container capacities. According to [11], IoT enables the creation of a virtual system for managing logistics flows. This system facilitates interaction between all participants of the logistics process in a new way. The virtual system automatically updates all data on logistics chains and allows for real-time evaluation of all cargo delivery parameters [12].

The work [13] shows that IoT affects not only the operational efficiency of a logistics company but also its strategic management. The authors conducted a study based on a survey of managers of logistics companies and found that the use of IoT leads to the transformation of approaches to strategic management of logistics flows. Besides, the authors found that the implementation of IoT itself had a greater impact on the growth of operational efficiency compared to changes in the strategic management of the studied companies.

Authors [14] state that the successful implementation of IoT in logistics requires close collaboration and a high level of participation between players and competitors in the supply chain. Clear interaction is required to exchange sensor information in heterogeneous environments at all cargo movement stages. There is a need to build trust and data ownership and overcome privacy challenges in the IoT-based supply chain. This requires a clear focus on a

reference architecture for IoT and a shift in business mindset to embrace the full potential of IoT.

IoT can also provide effective inventory management in warehouses, which is also extremely important for effective management in logistics [15]. The warehouse system becomes less dependent thanks to the automation of warehouse operations and responds to changes in human work. The flow of goods through warehouses becomes smoother by applying autonomous systems in transportation, handling and palletizing operations to the warehouse. However, stand-alone systems must be adapted to the storage environment to minimize the risk of overlays.

Authors [16] state that as more companies adopt IoT systems, their use will combine data and flows of real objects, revolutionizing real-time organizations. This is why logistics companies will turn into e-commerce companies, where cargo movement will be serviced thanks to the operation of automated systems. The authors point out that the costs and benefits of implementing IoT at different stages change according to the technology development. We can conclude that the development of technologies will ensure the growth of the economic feasibility of implementing IoT systems in logistics companies. Similar conclusions about the impact of the Internet of Things on the efficiency of logistics companies have also been reached by the authors of studies [17-19]. It is noted that the Internet of Things provides operational and accurate information in real time about the load of logistics facilities and the movement of goods. Such information makes it possible to optimize the use of container capacities and the loading of vehicles to avoid downtime and delays in the shipment of goods.

3 Methods

The research hypothesis is that the implementation and use of IoT contribute to improving logistical efficiency. Within the scope of this study, efficiency means a reduction in costs and an increase in income. One of the largest logistics companies in the world — DGL [20], which operates in 220 countries and territories— was chosen for the study.

The research will be conducted in two stages. The first stage provided for analyzing the dynamics of the main indicators of the working hypothesis of the study: Total Revenue; Profit (Loss) from Operating Activity; Expenses on fuel; Expenses on Aircraft Fuel; Wages, Salaries, Compensations. The indicators of Total Revenue and Profit (Loss) from Operating Activity are taken from reports by segments for DHL's departments. For the purposes of the study, the data were used only for the Supply Chain segment: only for those divisions of the company that are directly engaged in logistics operations. This made it possible to separate the influence of other company divisions engaged in other activities. At this stage, the methods of graphical display of time series and the trend method will be used to analyze the dynamics of changes in the indicators. Figure 1 shows the logic of the impact of the use of IoT on the resulting indicators is shown.

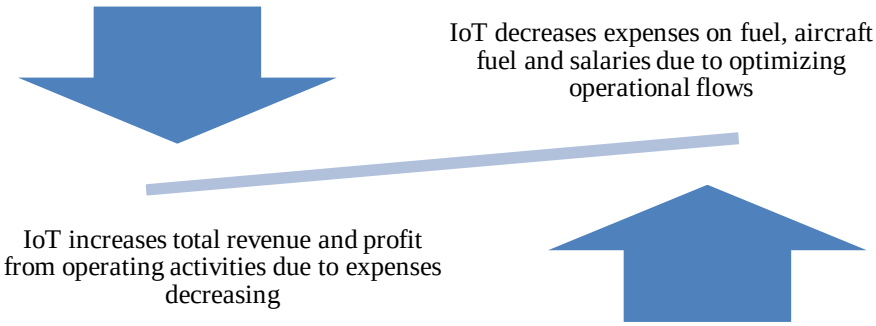

Figure 1 The logic of the impact of IoT on the resulting indicators

IoT provides an increased utilization efficiency of both warehouses and container capacities. This makes it possible to optimize the utilization of such facilities and reduce the number of air transport flights and the movement of ground transport for cargo transportation. As a result, it helps to reduce fuel consumption. IoT also replaces workers in the performance of certain operations for monitoring and registering the movement of goods, which leads to decreased labour costs. As a result, the reduced costs should lead to increased operating profit. Optimization of the use of storage facilities and transport capacities will lead to increased transportation volumes. This ensures an increase in the company's total revenue.

To achieve the research objective, IoT is considered as an independent variable influencing the resulting performance indicators.

The second stage provided for the analysis of the impact of the use of IoT on the resulting indicators. The OLS linear regression method will be used for this purpose, and the impact of IoT will be introduced into the model as a dummy variable. According to DHL, the use of IoT began in 2017 [21]. The IoT will be introduced into the model as a dummy variable from 2017:

Model 1: Total Revenue = f(IoT)
Model 2: Profit (Loss) from Operating Activity = f(IoT)
Model 3: Expenses on Fuel = f(IoT)
Model 4: Expenses on Aircraft Fuel = f(IoT)

Model 5: Wages, Salaries, Compensations = f(IoT)

The third stage involves the calculation of the performance indicators based on expenses, which are affected by the use of IoT:

ROI = Profit (Loss) from Operating Activity / Σ(Expenses on Fuel + Expenses on Aircraft Fuel + Wages, Salaries, Compensations)

Profit Margin = Profit (Loss) from Operating Activity / Total Revenue

Operating Efficiency Ratio = Total Revenue / Σ(Expenses on Fuel + Expenses on Aircraft Fuel + Wages, Salaries, Compensations)

The impact of IoT; Total Revenue; Profit (Loss) from Operating Activity; Expenses on Fuel; Expenses on Aircraft Fuel; Wages, Salaries, Compensations on efficiency indicators by the OLS linear regression method will be determined:

Model 6: ROI = f(IoT; Total Revenue; Profit (Loss) from Operating Activity; Expenses on Fuel; Expenses on Aircraft Fuel; Wages, Salaries, Compensations)

Model 7: Profit Margin = f(IoT; Total Revenue; Profit (Loss) from Operating Activity; Expenses on Fuel; Expenses on Aircraft Fuel; Wages, Salaries, Compensations)

Model 8: Operating Efficiency Ratio = f(IoT; Total Revenue; Profit (Loss) from Operating Activity; Expenses on Fuel; Expenses on Aircraft Fuel; Wages, Salaries, Compensations)

Data from DHL's annual financial statements [22] for 2010-2022 were used for the study.

4 Results

Analysis of the dynamics of DHL Group's performance indicators for 2009-2022 shows a long-term growth trend (Figure 2). However, different indicators show a different trend in different periods. The Total Revenue had a steady upward trend from 2009 to 2015 and a steady downward trend from 2015 to 2020. And a growing trend has been observed again since 2020.

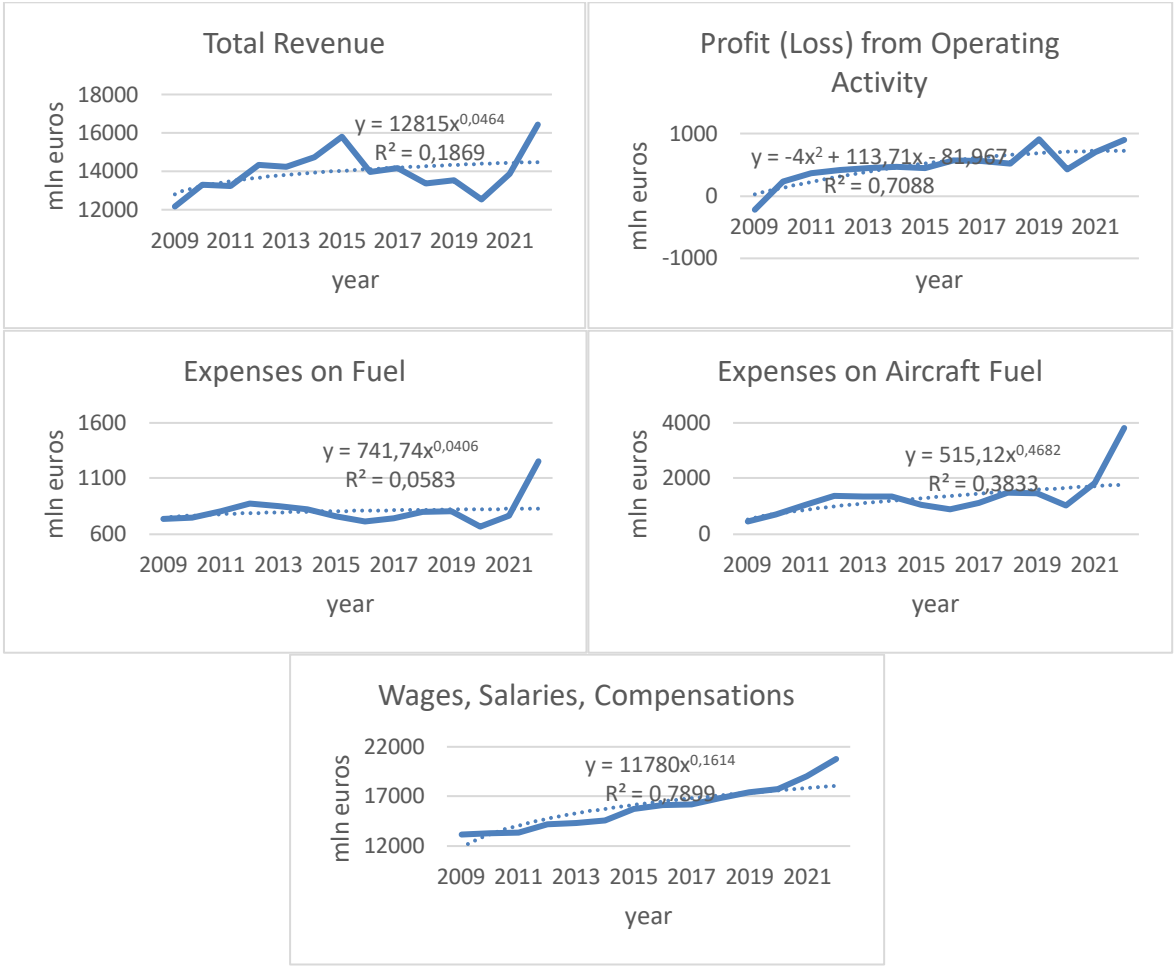

Figure 2 Analysis of the dynamics of DHL Group performance indicators for 2009-2022

At the same time, the Profit (Loss) from Operating Activity indicator does not have such volatility during the analyzed period. A significant decline in the values of this indicator is observed only during 2019-2020, after which the trend returns to growth. It is obvious that the drop in the Profit (Loss) from Operating Activity in 2019-2020 is explained by the Covid19 pandemic and the decreased volume of international transportation during this period.

So, although the Total Revenue has fluctuated, the Profit from Operating Activity in the long run is constantly increasing. It is worth noting that the growth dynamics of both indicators are decreasing gradually.

The analysis of Expenses on Fuel and Expenses on Aircraft Fuel shows that there has been a rapid increase in the volume of these expenses since 2020. During 2009-2020, the growth dynamics of these costs were insignificant. Such an abnormally sharp increase in fuel expenses against the background of revenue growth may indicate an increase in transportation volumes.

The company's labour costs have a steady upward trend throughout the 2009-2022. It did not decrease during the crisis periods for the world economy in 2013-2014 and 2019-2020, indicating that the company did not reduce staff. At the same time, the constant growth of labour costs indicates a regular revision of wages towards their increase.

The analyzed indicators show DHL Group's fairly good financial position regarding the Supply Chain.

Appropriate impact models were tested to determine the impact of IoT use on the resulting indicators. Tables 1-5 show the results of the tested models.

Table 1 Results of testing the IoT impact model on Total Revenue. Model 1: OLS, using observations 2009-2022 (T = 14). Dependent variable: Total Revenue

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	13969.9	421.255	33.16	<0.0001	***
Dummy IoT	7.95833	643.478	0.01237	0.9903	

Mean dependent var	13973.29	S.D. dependent var	1144.753
Sum squared resid	17035758	S.E. of regression	1191.489
R-squared	0.000013	Adjusted R-squared	-0.083320
F(1, 12)	0.000153	P-value(F)	0.990336
Log-likelihood	−117.9475	Akaike criterion	239.8950
Schwarz criterion	241.1731	Hannan-Quinn	239.7767
rho	0.342875	Durbin-Watson	1.015813

The following conclusions can be drawn based on the regression analysis results of Model 1. The P-value for the Dummy_IoT coefficient is 0.9903. This high p-value indicates that Dummy_IoT is not statistically significant. This means that no statistically significant effect of IoT on Total Revenue was found for the analyzed period. R-squared indicates the amount of variation in the dependent variable (Total Revenue) that can be explained by the model. In this case, the R-squared is very low (0.000013), which means that the chosen model cannot explain the variation in Total Revenue.

Table 2 Results of testing the IoT impact model on Profit (Loss) from Operating Activity. Model 2: OLS, using observations 2009-2022 (T = 14). Dependent variable: Profit (Loss) from Operating Activity

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	340.250	80.5356	4.225	0.0012	***
Dummy IoT	328.083	123.020	2.667	0.0205	**

Mean dependent var	480.8571	S.D. dependent var	276.1969
Sum squared resid	622654.8	S.E. of regression	227.7892
R-squared	0.372135	Adjusted R-squared	0.319813
F(1, 12)	7.112388	P-value(F)	0.020528
Log-likelihood	−94.78397	Akaike criterion	193.5679
Schwarz criterion	194.8461	Hannan-Quinn	193.4496
rho	0.022788	Durbin-Watson	1.380127

The Model 2 regression analysis results give grounds for drawing the following conclusions. The P-value for the Dummy IoT is 0.0205. This indicates that the Dummy IoT is statistically significant at the 0.05 significance level. This means that there is a statistically significant effect of IoT on profit (or loss) from operating activities for the considered period. R-squared indicates the variation in the dependent variable (Profit (Loss) from Operating Activity) that the model can explain. In this case, the R-squared is 0.372135, which means that this model can explain approximately 37.21% of the variation in operating profit (or loss). The F-statistic is 7.112388, and the p-value(F) is 0.020528. This indicates that the model is statistically adequate to explain Profit (Loss) changes from Operating Activity.

Table 3 Results of testing the IoT impact model on the Expenses on Fuel. Model 3: OLS, using observations 2009-2022 (T = 14). Dependent variable: Expenses on Fuel

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	785.375	50.4812	15.56	<0.0001	***
Dummy IoT	50.6250	77.1113	0.6565	0.5239	

Mean dependent var	807.0714	S.D. dependent var	139.6228
Sum squared resid	244641.9	S.E. of regression	142.7824
R-squared	0.034673	Adjusted R-squared	-0.045771
F(1, 12)	0.431016	P-value(F)	0.523881
Log-likelihood	−88.24459	Akaike criterion	180.4892
Schwarz criterion	181.7673	Hannan-Quinn	180.3709
rho	0.172961	Durbin-Watson	1.179201

The following conclusions can be drawn based on the Model 3 regression analysis results of the dependent variable Expenses on Fuel and the impact of Dummy IoT. The P-value for the Dummy IoT is 0.5239. This high p-value indicates that the Dummy IoT is not statistically significant at the conventional significance level of 0.05. So, no statistically significant effect of IoT on the Expenses of Fuel for the considered period was found. R-squared indicates the variation in the dependent variable (Expenses on Fuel) that the model can explain. In this case, the R-squared is very low (0.034673), which means the chosen model can hardly explain the variation in the Expenses on Fuel.

Table 4 Results of testing the model of the impact of IoT on the Expenses on Aircraft Fuel. Model 4: OLS, using observations 2009-2022 (T = 14). Dependent variable: Expenses on Aircraft Fuel

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	1019.25	252.806	4.032	0.0017	***
Dummy IoT	761.583	386.167	1.972	0.0721	*

Mean dependent var	1345.643	S.D. dependent var	790.5224
Sum squared resid	6135430	S.E. of regression	715.0426
R-squared	0.244780	Adjusted R-squared	0.181845
F(1, 12)	3.889415	P-value(F)	0.072085
Log-likelihood	−110.7989	Akaike criterion	225.5977
Schwarz criterion	226.8759	Hannan-Quinn	225.4794
rho	0.552980	Durbin-Watson	0.912934

The results of the Model 4 regression analysis of the dependent variable Expenses on Aircraft Fuel and the impact of Dummy IoT give grounds for the following conclusions. The P-value for the Dummy IoT is 0.0721. This value is close to but does not reach, the 0.05 significance level. This indicates that the Dummy IoT may be statistically significant at a certain significance level (e.g. 10%). As the chosen significance level is 0.05, we can state that IoT does not significantly impact the Expenses on Aircraft Fuel. R-squared indicates the variation in the dependent variable (Expenses on Aircraft Fuel) that the model can explain. In this case, the R-squared is 0.244780, which means that this model can explain approximately 24.48% of the Expenses on Aircraft Fuel variation. The F-statistic is 3.889415, and the p-value(F) is 0.072085. This shows that the model as a whole may be statistically adequate for explaining the Expenses on Aircraft Fuel.

Table 5 Results of testing the IoT impact model on the Wages, Salaries, Compensations. Model 5: OLS, using observations 2009-2022 (T = 14). Dependent variable: Wages, Salaries, Compensations

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	14332.3	483.347	29.65	<0.0001	***
Dummy IoT	3653.25	738.325	4.948	0.0003	***

Mean dependent var	15897.93	S.D. dependent var	2290.221
Sum squared resid	22427953	S.E. of regression	1367.112
R-squared	0.671079	Adjusted R-squared	0.643669
F(1, 12)	24.48294	P-value(F)	0.000337
Log-likelihood	−119.8725	Akaike criterion	243.7449
Schwarz criterion	245.0231	Hannan-Quinn	243.6266
rho	0.515449	Durbin-Watson	0.918698

The following conclusions can be drawn based on the Model 5 regression analysis results of the dependent variable Wages, Salaries, Compensations and the impact of the Dummy IoT.

The P-value for the Dummy IoT is 0.0003. This low p-value indicates that the coefficient of Dummy IoT is statistically significant at the 0.05 significance level. This means a statistically significant effect of IoT on Wages, Salaries, Compensations for the studied period. R-squared indicates the variation in the dependent variable (Wages, Salaries, Compensations) that the model can explain. In this case, the R-squared is 0.671079, which means that this model is able to explain approximately 67.11% of the variation in wages, salaries, and compensation. The F-statistic is 24.48294, and the p-value(F) is 0.000337. This shows that the model is statistically adequate to explain changes in Wages, Salaries, Compensations.

Analysis of the dynamics of DHL Group's estimated performance indicators shows that not all indicators have a positive long-term trend (Figure 3). The values of the ROI indicator grew rapidly during 2009-2010 and remained almost unchanged until 2018. In 2018-2019, this indicator rose and fell, and its value stabilized after 2021. The Profit Margin, which almost duplicates the ROI dynamics, demonstrates the ascending dynamics. However, the long-term trend has positive dynamics. As for the Operating Efficiency Ratio, it has a steady downward trend throughout the analyzed period. This is a negative trend.

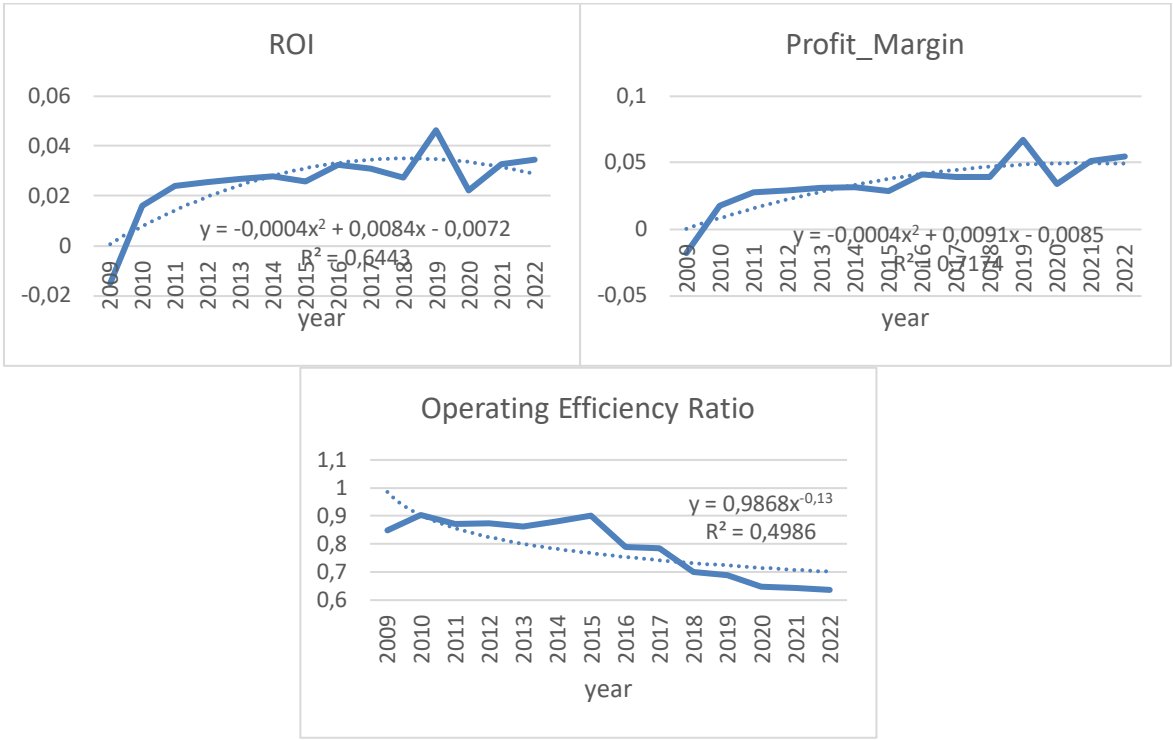

Figure 3 Analysis of the dynamics of DHL Group performance indicators for 2009-2022

Next, we will analyze whether IoT had a statistically significant impact on the calculated performance indicators (Table 6-8).

Table 6 Results of testing the IoT impact model on ROI. Model 6: OLS, using observations 2009-2022 (T = 14). Dependent variable: ROI

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	0.0203076	0.00446736	4.546	0.0007	***
Dummy IoT	0.0119471	0.00682401	1.751	0.1055	

Mean dependent var	0.025428	S.D. dependent var	0.013602
Sum squared resid	0.001916	S.E. of regression	0.012636
R-squared	0.203456	Adjusted R-squared	0.137078
F(1, 12)	3.065088	P-value(F)	0.105488
Log-likelihood	42.41123	Akaike criterion	−80.82246
Schwarz criterion	−79.54435	Hannan-Quinn	−80.94078
rho	0.059813	Durbin-Watson	1.225377

The results of the Model 6 regression analysis of the dependent variable ROI and the impact of the Dummy IoT give grounds to draw the following conclusions. The P-value for the Dummy IoT is 0.1055. This value exceeds the 0.05 significance level, indicating that the Dummy IoT is not statistically significant at the conventional significance level. So, there is no statistically significant effect of IoT on ROI for the studied period. R-squared indicates the variation in the dependent variable (ROI) that the model can explain. In this case, the R-squared is 0.203456, which means that this model can explain about 20.35% of the variation in ROI. The F-statistic is 3.065088, and the p-value(F) is 0.105488. This shows that the model as a whole is not statistically adequate to explain the ROI.

Table 7 Results of testing the IoT impact model on the Profit Margin. Model 7: OLS, using observations 2009-2022 (T = 14) Dependent variable: Profit Margin

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	0.0235177	0.00559709	4.202	0.0012	***
Dummy IoT	0.0239263	0.00854970	2.798	0.0161	**

Mean dependent var	0.033772	S.D. dependent var	0.019553
Sum squared resid	0.003007	S.E. of regression	0.015831
R-squared	0.394905	Adjusted R-squared	0.344481
F(1, 12)	7.831601	P-value(F)	0.016089
Log-likelihood	39.25493	Akaike criterion	−74.50986
Schwarz criterion	−73.23175	Hannan-Quinn	−74.62818
rho	−0.020421	Durbin-Watson	1.458632

Based on the results of the Model 7 regression analysis of the dependent variable Profit Margin and the impact of the Dummy IoT, the following conclusions can be drawn. The P-value for the Dummy IoT is 0.0161. This low p-value indicates that the Dummy IoT is statistically significant at the 0.05 significance level. This means that there is a statistically significant effect of IoT on profitability (Profit Margin) for the studied period. R-squared indicates the variation in the dependent variable (Profit Margin) that the model can explain. In this case, the R-squared is 0.394905, which means that this model can explain approximately 39.49% of the variation in the Profit Margin. The F-statistic is 7.831601, and the p-value(F) is 0.016089. This shows that the model as a whole is statistically adequate to explain the Profit Margin.

Table 8 Results of testing the IoT impact model on the Operating Efficiency Ratio. Model 8: OLS, using observations 2009-2022 (T = 14). Dependent variable: Operating Efficiency Ratio

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	0.866406	0.0161436	53.67	<0.0001	***
Dummy IoT	−0.183622	0.0246598	−7.446	<0.0001	***

Mean dependent var	0.787711	S.D. dependent var	0.104004
Sum squared resid	0.025019	S.E. of regression	0.045661
R-squared	0.822079	Adjusted R-squared	0.807252
F(1, 12)	55.44569	P-value(F)	7.78e-06
Log-likelihood	24.42504	Akaike criterion	−44.85007
Schwarz criterion	−43.57196	Hannan-Quinn	−44.96839
rho	−0.253729	Durbin-Watson	2.360651

Based on the results of the Model regression analysis of the dependent variable Operating Efficiency Ratio and the impact of the Dummy IoT, the following conclusions can be drawn. The P-value for the Dummy IoT is <0.0001, which is extremely low. This indicates that the Dummy IoT is statistically significant at any significance level. This means that there is a statistically significant effect of IoT on Operating Efficiency Ratio for the studied period. R-squared indicates the variation in the dependent variable (Operating Efficiency Ratio) that the model can explain. In this case, the R-squared is 0.822079, which means that this model can explain approximately 82.21% of the variation in the Operating Efficiency Ratio. The F-statistic is 55.44569, and the p-value(F) is 7.78e-06, which is extremely low. This shows that the model as a whole is statistically adequate to explain the Operating Efficiency Ratio.

The obtained results give grounds to state that IoT has a positive effect on the efficiency of DHL Group activities, which is confirmed by the corresponding calculations.

5 Discussion

Authors [23] argue that the modern logistics industry still incurs high costs and yields low efficiency. The development of smart logistics opens up opportunities to solve these problems. As one of the important information

and communication technologies, IoT can generate large amounts of data and explore the complex relationships between transactions represented by these data through various mathematical analysis technologies. These features contribute to the development of smart logistics. Our research supports this view. The results of our research prove the positive effect of the use of IoT on the efficiency of the logistics company.

In the work [24], the authors consider the ability to deliver cargo on time as one of the key factors in the competitiveness of a logistics company. Researcher [25] states that IOT data can be used to develop new or improve existing shipping algorithms, loading of warehouses or container capacity, as evidenced by the study results. The results of our research indicate an increase in logistical efficiency due to the use of IoT.

The research results indicate the possibility of constantly optimizing the geographical cargo delivery routes. This opinion is confirmed by the results obtained by the work [26], in which the authors note that optimizing geographic delivery routes is a key issue in increasing the efficiency of logistics companies. The solution to this issue is based on an extensive system of sensors that record all cargo movements and other events in logistics activities. The results obtained in this study about the statistically significant impact of IoT on the Profit from Operating Activity confirm the importance of geographical optimization of delivery routes. Route optimization reduces the time and resources spent on delivery, which directly affects the size of Profit from Operating Activity.

Research results from [27,28] show that technical services [29] are the most important aspect of applying IoT for smart logistics. Our research confirms that the more information is available, the wider the opportunities for optimization and increasing logistics efficiency. In particular, we found that IoT entails increased labour costs. This shows that the employees of the logistics company increase their productivity using IoT devices. As a result, their payment also increases, together with labour productivity growth. The use of IoT contributes to the improvement of the social function of entrepreneurship.

Optimization models and algorithms can be built based on data from IoT devices, as proven in several studies [17-19,30-33]. Optimization models are designed to detect non-productive losses of logistics activities. The widespread use of IoT devices can provide control points to detect such losses. The results of our research showed that such non-productive losses can be transformed into increased labour productivity thanks to the use of IoT devices.

6 Conclusions

Logistics companies use the IoT to increase logistical efficiency. The research results show that the implementation and use of IoT devices have a statistically significant impact on Profit (Loss) from Operating Activity and Wages, Salaries, Compensations. The positive significant effect of IoT on the wages of logistics company employees indicates that wages are increasing. So, using IoT does not mean technology replaces people and leads to their dismissal. IoT provides an increase in labour productivity, which entails an increased amount of payment.

It was established that the implementation and use of IoT has a positive statistically significant effect on such indicators of logistics efficiency as Profit Margin and Operating Efficiency Ratio. It was proved that IoT has a positive effect on increasing the efficiency of logistics activities and does entail a reduction in jobs, which is a socially important factor.

The obtained results can be applied in developing and justifying the policy of implementing IoT in the activities of logistics companies.

The conducted research has methodological and implementation limitations. A methodological limitation is that the study was conducted for one company. However, the large-scale use of IoT devices by logistics companies is not a common phenomenon, so it is impossible to form a representative sample of the study. The study used data on only one direction of the company's operations — Supply Chain. If the proposed model considers the data of the company's entire operational activity, the results may differ from those in this study. The implementation limitation is that the obtained results can be applied only in logistics companies engaged in transportation by road and air transport.

The conducted research opens up prospects for further research, in particular regarding the impact of IoT on other performance indicators of logistics companies, particularly on their market capitalization.

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Health supply chain forecasting: a comparison of ARIMA and LSTM time series models for demand prediction of medicines
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Health supply chain forecasting: a comparison of ARIMA and LSTM time series models for demand prediction of medicines

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Keywords: LSTM, ARIMA, health supply chain, medicines, prediction model.
Abstract: The ever-accelerating revolution along with digitalization of the healthcare industry has revealed the power of machine learning and deep learning prediction models in addressing health supply chain logistic issues. The purpose of this study was to predict the demand for medicines using autoregressive integrated moving average (ARIMA) and long short-term memory (LSTM) time series models while comparatively analysing their performance for medicine demand prediction to optimize the flow of supplies in the health system. Using data generated in Rwanda public health supply chain, in our study focused on predicting the demand of the top five medicines, identified as highly supplied (amoxicillin, penicillin v, ibuprofen, paracetamol, and metronidazole). We evaluated the models' outputs by root mean square error (RMSE) and the coefficient of determination, R-squared (R^2). In comparison to ARIMA, the deep learning LSTM model revealed superior performance with better accuracy and lower error rates in predicting the demand for medicines. Our results revealed that the LSTM model has an RMSE value of 2.0 for the training set and 2.043 for the test set, with R^2 values of 0.952 and 0.912, respectively. ARIMA has an RMSE value of 9.35 for the training set and 8.926 for the test set as well as R^2 value of 0.24 and 0.16 for the training and test sets, respectively. Based on these findings, we recommend that the LSTM time series model should be used for demand prediction in the management of medicines and their flow within health supply chain due to its remarkable performance for prediction task when applied to the dataset of our study.

1 Introduction

In the current digitally interconnected and high-technology driven world, the health system and clinical settings have challenges in successfully managing an enormous volume of health supply chain data with the aim of providing the high-quality healthcare services that consumers would expect [1]. Organizations must adopt advanced technologies and data science methodologies, such as deep learning and machine learning approaches including prediction models. In return, these approaches and technologies offer more accurate supply chain forecasting, operational efficiency and improved logistic function, while also optimizing the service delivery process, management of financial, logistic aspects and effective use of resources [2].

Time series predictions is a core part of data science that has numerous applications. Accurate predictions are imperative in health supply chain forecasting tasks to help in designing and implementing evidence-based decisions at operational, strategic, and tactical level [3]. Traditional econometric methods such as ARIMA may require comparative studies due to the increase in data complexity and their volume for achieving more accurate forecasts in the health supply chain. On the other hand, as digital technology builds up, deep learning prediction models, such as LSTM time series models, are being applied more frequently for time series prediction in the health sector and this include medicine demand prediction and supply planning [4]. According to a study focusing on deep learning LSTM models for COVID-19 forecasting using upgraded method published by Luyu Zhou et. al. 2023, LSTM -based models have been recognized as part of prediction models with the most advanced ability and accuracy for time series data [5]. Despite the increasing significance of machine learning models in health supply chain forecasting, research in this area is still lacking and limited, most notably in terms of how to adopt, integrate and accurately use machine learning and deep learning approaches. While most research has focused on using prediction models to predict disease burden or their occurrence, there is a need to advance the health supply chain by exploring the potential contribution of advanced prediction models for medicine demand prediction [6].

This study seeks to fill this void by undertaking a comparative examination of LSTM and ARIMA predictions models, with a particular emphasis on identifying which of them perform better in the framework of health supply chain forecasting. While LSTM and ARIMA models are both known for their ability to perform demand predictions, our study intended to compare them and determine which may contribute most effectively in health supply chain forecasting through reliable demand prediction for medicines with less complexity, greater accuracy, and prospective applicability [7]. The goal of this study is to make a comparative analysis of LSTM and ARIMA models' performance in health supply chain forecasting. With this aim, we will be able to improve the automation of demand for medicines and thus optimize supply chain forecasting tasks and logistic technical aspects. In the end, these achievements will culminate in boosting the delivery of healthcare services.

The rest of this paper is organized as follows: in addition to the previous first section, in section 2, we present the literature review and section 3 discusses the methodology with a brief description of the applied models for our study, ARIMA, and LSTM prediction models. While this section focused on the theoretical context and the ways we did the accuracy measurements, in sections 4, the results and discussions of the study are described with a contrast to what have observed in other similar studies. Finally in section 5, we wrap up the study and provide a conclusion and recommendations based on our study findings.

2 Literature review

Digital transformation in the health supply chain, along with the automation of demand prediction and supply planning have the ability to optimally allocate resources, resulting in considerable cost savings and improved service delivery. This change lowers human errors, speeds target achievement, and promotes the use of predictive algorithms in the demand and supply planning of important drugs in clinical settings [8]. Health products and medical supplies are crucial for preserving human health and well-being, but they also contribute significantly to healthcare expenses, particularly in LMICs with limited resources. Because of the importance of medicines and medical equipment in healthcare service delivery, as well as the issues of wastefulness and inconsistency in supply and demand planning, data-driven prediction models must be used to accurately predict their demand [9]. This also contributes to the management of logistics associated with both the supply and flow of medicines at different levels of healthcare delivery.

According to a study by Roy and Mitra in 2021, which concentrated on the use of machine learning for demand prediction of essential medicines, their findings confirmed that machine learning-based prediction models have the potential to optimize the pharmaceutical supply chain, resulting in reduced expenses as well as more affordable medicine [10]. Similarly, in their study Makridakis et al. 2020, emphasized a track-record of progresses in prediction performance over time, the need to capture the uncertainty in prediction tasks, and aspects that may be wrong for prediction tasks in social settings. They also discussed what is known and what is not clearly understood or still unclear and thus requires further research [11]. Additionally, the potential and efficacy of demand prediction models based on shallow neural networks, including deep learning neural networks such as LSTM, for estimating future medicine demand was confirmed by Rathipriya et al. 2023, who focused on demand prediction models for time-series pharmaceutical data with the goal of suggesting marketing and sales tactics in pharmaceutical companies [12].

A study conducted by Absar et al. 2022, on the usefulness of deep learning LSTM models for predicting the spread of infectious diseases, indicated that the models may provide insights and contributions to accurately predict the spread of infectious diseases' outbreaks such as COVID 19. Based on these findings, LSTM models could provide insightful forecasts and help to appreciate the trend and gravity of the diseases while informing decision-makers about how to proceed cautiously and take the needed measures to bring the situation under control at the most convenient time [13]. LSTM works particularly well with sequential data and typically excels at capturing long-term dependencies, putting them in the greatest position for time-series data, and therefore, may be applied in the health supply chain to predict demand, events or operations [14]. For example, when predicting the trend of patients to be admitted, LSTM models can be applied by a health setting to optimize the appropriate utilization of beds, the flow of personnel and materials including medicines or medical supplies and equipment. Furthermore, the LSTM and multivariate time-series models can be used in demand prediction and supply planning for lifesaving product such as blood donations, as they may be applied in health supply chain to ensure timely availability and accessibility of them [15]. Also, these may help in improving effective financial management and well-coordinated flow of medical supplies while keeping ideal inventory levels and preventing expiries, shortages, out of stock, and overstock

ARIMA is a time series prediction model with autoregression, differencing and moving average components. It is commonly applied for short to medium term predictions. ARIMA prediction models' applicability in the health supply chain, may be used to ensure effective inventory management and flow of accurate information while anticipating the consumption pattern of medicines, which may serve in preventing stock outs or wasteful resources with surplus stock [7,16]. A health institution can profit from the use of ARIMA models to predict the demand for medical supplies and thus anticipate patient needs. ARIMA models may also be used to anticipate the presence and severity of an outbreak using historical data, which can provide helpful information for planning suitable public health interventions. A prominent example of this may be the use of predictive models for a contagious

illness, which may help decision-makers allocate resources for containment, preventative measures, and treatment options, as occurred during the COVID-19 period and other infectious diseases [17,18].

ARIMA and LSTM models can both reliably perform the demand prediction task as they are enabled to depict complex trends in time-series data, and in this regard, they are increasingly being applied to health supply chain forecasting. While these advances in forecasting tasks are beneficial in terms of presenting competitive advantages, they contribute differently depending on how they are applied and the context or type of dataset applied to [7]. In the context of this study, both ARIMA and LSTM are contrasted in relation to their performance in the health supply chain, particularly their performance and accuracy for predicting the demand for medicines. The adoption and integration of machine learning and artificial intelligence in health supply chains such as the application of LSTM and ARIMA time-series models, provides a competitive advantage, particularly through the improved prediction accuracy and appropriate management of changing dynamics in medicines demand prediction [19,20]. For example, the use of LSTM and ARIMA in health supply chains may enable more dynamic and adaptive prediction, where LSTM time series model may typically target sudden changes in patient admission patterns, and then ARIMA models refine short-term predictions based on recent trends [7].

The adoption of LSTM and ARIMA models for the demand prediction of medicines provides a valuable contribution towards data-driven inventory management, resource allocation, and improved overall operations and efficiency in in health supply chains [7]. However, better accuracy from either LSTM or ARIMA models as well as the choice of which one to consider may be dependent on or suited to a kind of dataset or context [21]. Therefore, we have compared these two types of models to determine which one should provide better accuracy when applied to public health supply chain data generated by the electronic logistics management information system (e-LMIS).

3 Methodology

This section gives an overview of how we performed our research while establishing how to predict the demand of medicines using selected top five medicines supplied in Rwanda. The methodology involved several steps, such as collecting data, preprocessing data, choosing models, and figuring out how to interpret their performance for demand prediction of medicine as a core forecasting task in public health supply chain.

3.1 Study setting

Rwanda is a small landlocked country in East Africa with a t land area of 26,338 km2. According to the findings of the fifth population and housing census (PHC), Rwanda's population exceeded 13.2 million in December 2022 [22]. The country has promoted the delivery of health care through various initiatives, including streamlined supply and consistent availability of medical supplies. In relation to the flow of medicines, the eLMIS which a digital platform used in all public health facilities, helped in the record, storage and visibility of supply chain data.

3.2 Data collection and preprocessing

In our study, we used data from eLMIS for a period of 7 years, from January 2015 to December 2022, to perform demand prediction of medicine. The time frame for prediction has been set out in relation to use of the eLMIS as both a logistic and digital tool for the management of health products in Rwanda which was launched in 2015. The Figure 1 below, shows the trends of to five selected as top supplied medicines in quantity.

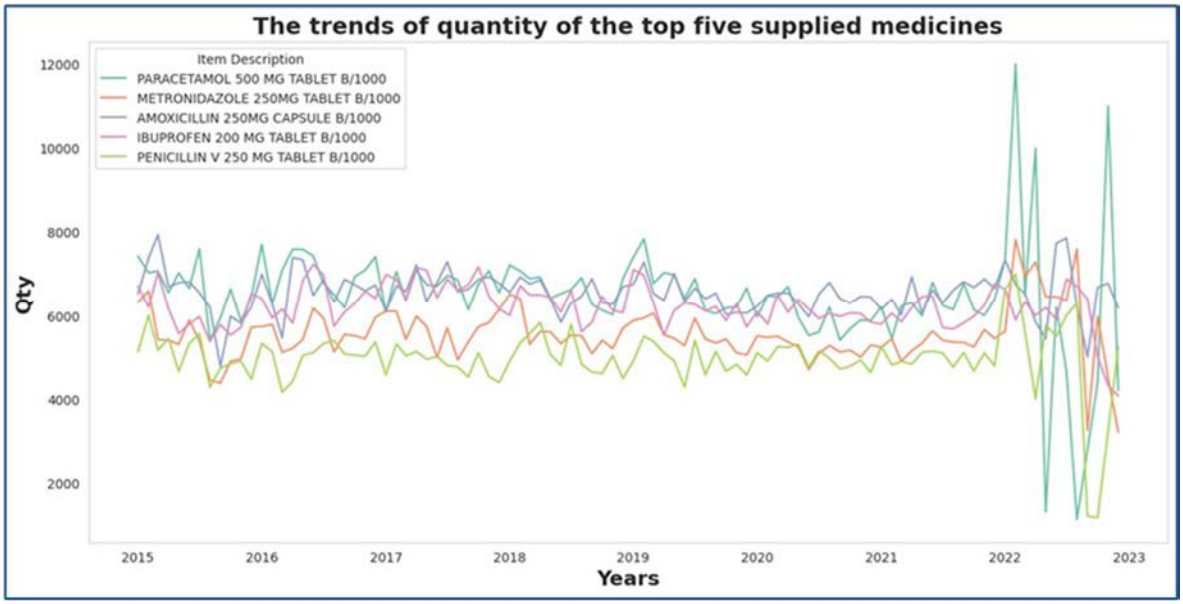

Figure 1 The trends of supplied quantity for each of the top five supplied medicines by time (2015-2022)

In terms of data cleaning, we removed outliers and handling missing numbers to ensure that the data was correct. Any mistakes or flaws in the data were fixed to maintain data's integrity. The table 1 presents the total quantities supplied during the study period and illustrates the category for each of the five selected medicines. As highlighted in the above Figure 1 but also illustrated in the above Table 1, we have considered the top five drugs that were supplied in high quantity in the Rwanda public health supply chain. After preprocessing our dataset, we identified that these top five medicines included amoxicillin 250 mg, paracetamol 500 mg, ibuprofen 200 mg, metronidazole 250 mg, and penicillin v 250 mg.

Table 1 The five selected highly supplied drugs

Name of Drugs	Quantity	Medicine's therapeutic group
Amoxicillin 250 mg capsule b/1000	79,167,273	Antibiotic
Paracetamol 500 mg tablet b/1000	74,623,247	Anti-inflammatory and analgesic
Ibuprofen 200 mg tablet b/1000	60,479,173	Anti-inflammatory and analgesic
Metronidazole 250 mg tablet b/1000	49,252,008	Antibiotic (nitroimidazole class)
Penicillin v 250 mg tablet b/1000	38,029,381	Antibiotic

3.3 Description of models

For model selection, we used LSTM, and an ARIMA for demand prediction of the five selected medicines as highly supplied. We were interested in contrasting LSTM and ARIMA to see which one works best when dealing with massive amounts of data generated by the supply chain for medicines. We were interested in the comparison of LSTM and ARIMA prediction models to see which one works better when dealing with massive amounts of data related to the flow of medicines and information in the health supply chain. While the LSTM Model is a deep learning framework that is made to find temporal patterns in data sequences, the ARIMA model is an econometric model using a time series forecasting method, in our study, we had to set up the model with the right factors for order. Both the LSTM and ARIMA models were selected because of their applicability in demand prediction tasks and thus we intended to validate their performance in advancing the management of health supply chain [19].

3.3.1 Description of the LSTM model

The application of LSTM models has become increasingly common as an advanced data analytical method to address a wide range of issues related to learning from time series data during demand prediction. LSTM is known as A type of RNN that has emerged as an effective and scalable model for many forecasting tasks that imply learning sequences of data [23]. The LSTM cell multiplies X, c, and h with various weight tensors and processes them with unique activation functions. Thus, cell memory and hidden state have been adjusted. The next input tensor time step will use the recalibrated c and h values. The LSTM cell will produce two outputs, namely the cell memory and the hidden state. These outputs will persist until the final time step is reached [24]. The equation 1 below provides a description of the LSTM model (1):

$$\begin{aligned} C_t^{\sim} &= \tanh(X_t Y_{xh} + G_{t-1} Y_{hh} + a_h) \\ C_t &= f_t C_{t-1} + i_t C_t^{\sim} \\ G_t &= o_t \tanh(C_t) \\ f_t &= \sigma(X_t Y_{xf} + H_{t-1} Y_{hf} + a_f) \\ i_t &= \sigma(X_t Y_{xi} + G_{t-1} Y_{hi} + a_i) \\ o_t &= \sigma(X_o Y_{xh} + G_{t-1} Y_{ho} + a_o) \end{aligned} \quad (1)$$

where the cell state is represented by $C_t^{\sim}$ which carries previous timestamp and current timestamp, forget gate $by\ f_t$ helps to decide wich informations to remember or to forget, input gate $by\ i_t$ quantifies the value or importance of information carried, and gate $by\ o_t$ helps to provide model output.

X_t: input to the current timestamp, H_{t-1}: hidden state of the previous timestamp, Y_{xf}: weight associated with the input, Y_{hf}: weight associated with the hidden state, and σ represent the sigmoid function. The sigmoid layer outputs numbers between zero and one, describes how much of each element should be passed through. A value of zero means "release nothing", while a value of one means "release everything".

The LSTM model is capable of acquiring knowledge and optimizing a mathematical function that takes a sequence of observations as input and generates a new observation as output. According to input-output patterns, observations are collected and organized. This context uses a single-step predictive model with numerous input time steps and one output time step. A Vanilla LSTM model with one hidden and output layer was used for prediction. The 200-layer LSTM model forecast. Every layer used ReLU activation. LSTM model input shape was determined by predictor dimensions. LSTM model also showed predictive consistency in steps and features [25].

While the incorporation of kernel (0.06), recurrent (0.05), and bias (0.02) regularizers successfully addressed the problem of overfitting in the model, the utilization of a dropout rate of 0.2 was discovered to effectively address the issue of overfitting by selectively eliminating layers at the specified rate. The aim was to clarify and understand the model. The RMsprop optimizer calculated the mean square error of the loss function. In each of the 200 iterations, the model was given X and Y coordinates. Using a trained model and the previous month's data, we can predict future values. Assuming a time step of 6, historical

medical data can be used to estimate the next six months. The basic functionality of LSTM models is maintained by a memory cell called the "cell state" throughout their lifetime. A horizontal line runs vertically from the highest to the lowest in the diagram. A conveyor belt transports the data.

3.3.2 Description of ARIMA model

The ARIMA model uses statistics to look at a set of times. Historical values from time series, such as lagging values and prediction errors, are used to extract useful information. The ARIMA model has three numbers: p, d, and q, where “p” is the order of the autoregressive terms, “q” is the order of the moving average terms, and “d” is the number of differences needed to show that a time series is stationary [16]. The ARIMA model, which stands for autoregressive integrated moving average, employs lagged data from its optimal results when the predictive variables are both independent and uncorrelated. The process of differentiation serves as the primary method for achieving stationarity in a series. In contrast, this procedure involves the subtraction of the previous value from the current value. The variable "d" represents the minimal number of differentiations necessary to achieve stationarity in the series.

It is crucial to note that the differentiation parameter, denoted “d”, assumes a value of zero in instances where the time series has already achieved a condition of stability. In the context of significance, the terms "p" and "q" refer to statistical measures commonly used in hypothesis testing and statistical inference. The variable "p" is used to denote the order of the autoregressive term. A "forecasted quantity of Y shifts" is a set number of Y shifts used as forecaster. The moving average verdict's position in the sequence is "q". Based on the parameters, the ARIMA model must compute the forecast error. Time series analysis often uses statistical autoregressive and moving average models. The ARIMA model merges autoregressive and moving average time series models. As presented through Equation 2, the autoregressive model describes a situation in which *Yt* value is decided only by its past values. Previous values of y_t, called "lags of y_t", affect its value [26].

Equation (2) below, provides a description of the ARIMA model.

$$\boldsymbol{Y_t = \sigma + \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + \cdots + \beta_p Y_{t-p} + \epsilon_1} \quad (2)$$

where, Y_(t-1) is the lag1 of the series, β_1 is the coefficient of lag1 that the model estimates and is ϵ 1 is the intercept term, which is also estimated by the model.

3.4 Analysis and interpretation of results

The study looked at how both LSTM and ARIMA models performed in demand prediction of medicines. Time series forecast plots were presented to show how well the models could be used in health supply chain forecasting for the selected medicines. This study followed ethical rules on data privacy, use and protection. Authors have secured the authorization to access the data as needed and they have ensured that all the data used were anonymized to preserve data privacy. It is also important to know that this study has some flaws. We acknowledge that the volume and reliability of data may affect the prediction tasks that our models did not take into account outside factors like policy changes or unpredicted events but in forthright terms, the methodology applied was appropriate in relation to the dataset we used during our research. In relation to the assessment criteria that we considered, we were able to conduct a thorough analysis and reached relevant conclusions regarding the accuracy and performance of the applied models. The evaluation metrics used to evaluate the model success are RMSE and R^2. With RMSE, the errors are approximately squared before. The RMSE gives more weight to larger errors and this may show that RMSE is much more useful when the errors are large and significantly affects the model performance. This avoids the absolute value of the error, and this notation is useful in many mathematical calculations. Even in this metric, the lower the value is, the better the model will perform. The R^2, also known as the coefficient of determination, is a metric indicating how well a model fits a given dataset. It indicates how close the forecasted value or quantity plotted is to the actual data values. The R^2 value lies between 0 and 1, where 0 indicates that this model does not fit the given data and 1 indicates that the model fits perfectly to the dataset provided.

4 Results and discussion

In this section of the article, we discussed the study’s findings, which involved LSTM, and ARIMA models to predict the demand for the selected five medicines, vastly supplied in the public health supply chain of Rwanda. The section provides a lookout on how well the models worked, highlight the most significant findings and which prediction model is recommendable model to be used for the demand prediction of medicines.

4.1 Evaluation of ARIMA and LSTM time series models

The findings of this research demonstrated that in comparison to ARIMA models, employing LSTM time series model for predicting the demand medicine is promising and more accurate based on its performance. To assess the performance and accuracy of the models, RMSE and R^2 metrics were used. These metrics offer insights into the accuracy and explanatory power of the model. The assessment metrics for several models, including both the training and testing sets, are displayed in Table 3. The LSTM model achieved a RMSE of 2.0 on the training set, accompanied by an R^2 score of 0.952. These results suggest a high level of accuracy for medicine demand prediction. The LSTM model demonstrated strong generalization

capabilities on the testing set, as evidenced by its attained RMSE of 2.043 and R^2 score of 0.912. The results indicate a relatively low level of demand prediction performance for ARIMA time series while the accuracy and performance were good and preferably recommendable for LSTM time series models. Our findings are congruent with what was shown in a study conducted by Lou et. al. 2022, who examined the ARIMA, deep neural networks (DNN) and LSTM models in predicting the burden of diseases. According to their study, LSTM models perform well as a novel approach for making accurate foreacasts of the burden of pneumoconiosis [21]. On the training set, the ARIMA model similarly fared poorly, with an RMSE of 9.35 and R^2 value of 0.24. As presented in Table 3, the findings of the testing set were equally disheartening, with an RMSE of 8.926 and R^2 value of 0.16, which indicated that the model was unable to capture the underlying patterns in the data.

Based on a comparative viewpoint of the models' results, we understand that the LSTM model does better than the ARIMA model. The small drop in performance from training to testing shows that the LSTM model does not overfit and performed well through a reworking of a similar trend and adaptation to new information. Based on these results, the LSTM model can be recommended as a useful tool for demand prediction of medicines.

Table 3 Presentation of results from the evaluation of models

Model	Set	RMSE	R Square
LSTM	Train	2.0	0.952
	Test	2.043	0.912
ARIMA	Train	9.35	0.24
	Test	8.926	0.16

4.2 Presentation of plots for time series model prediction

The plots resulting from LSTM and ARIMA time series predictions are showed in Figure 2, Figure 3. Notably, the LSTM model consistently generated more accurate predictions than the ARIMA models as the predicted and actual amount overlays for LSTM time series prediction only.

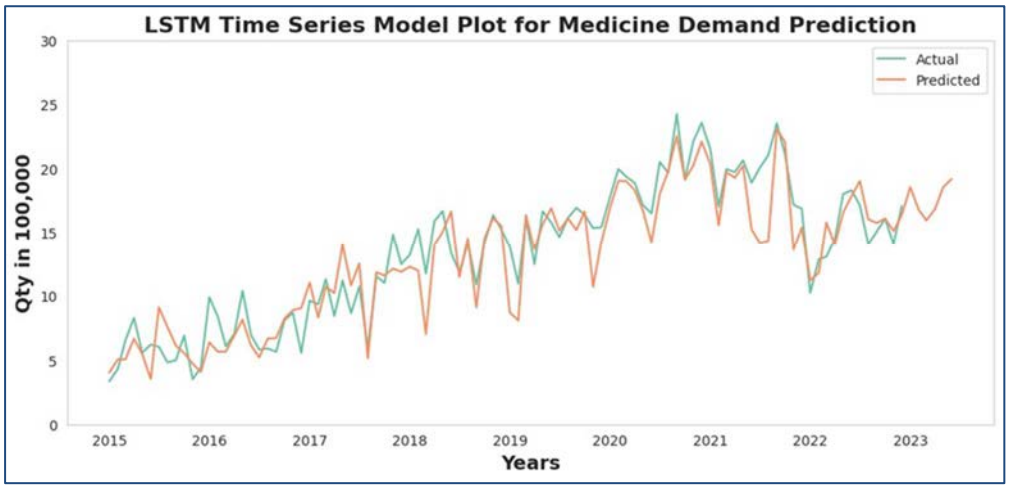

Figure 2 Presentation of the plot for demand prediction of medicines with LSTM model

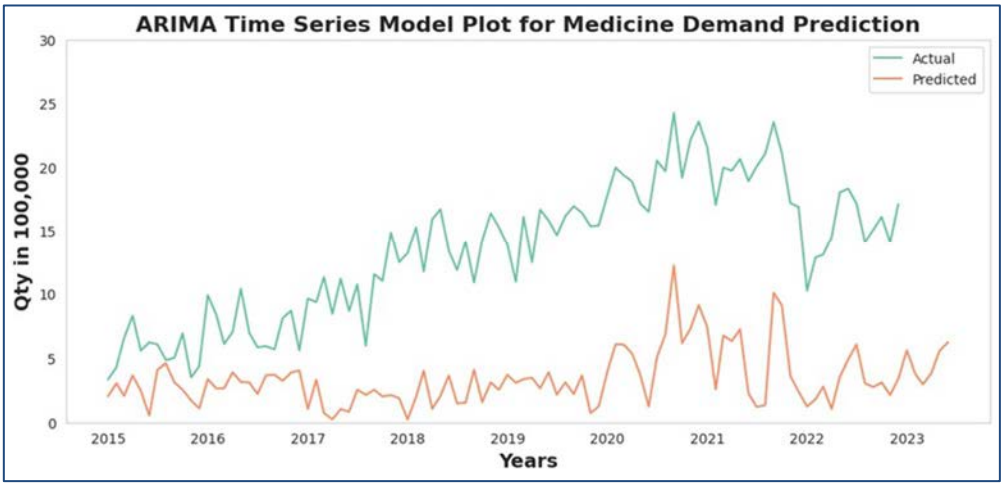

Figure 3 Presentation of the plot for demand prediction of medicines with ARIMA model

4.3 LSTM forecast model results for the selected medicines

In figures (Figure 4-Figure 8), we present the prediction outcome that the LSTM model made for the five drugs that were prescribed the most frequently in Rwanda. The capacity of the LSTM model to effectively predict future trends in medicine demand is demonstrated by these visualizations. The LSTM model ability to predict the demand for selected medicines overlaps with regularly observed behaviour and trends. Overall, our findings showed a higher performance of the LSTM model in comparison to ARIMA model, in demand prediction of the selected medicines. Thus, LSTM models make a best option that is recommended for predicting the demand of medicine in the health supply chain. The ARIMA model, despite its widespread application, demonstrated only moderate degrees of accuracy for our forecasting task and from this perspective, at this step, only the LSTM prediction plots are presented in figures (Figure 4-Figure 8), as follow:

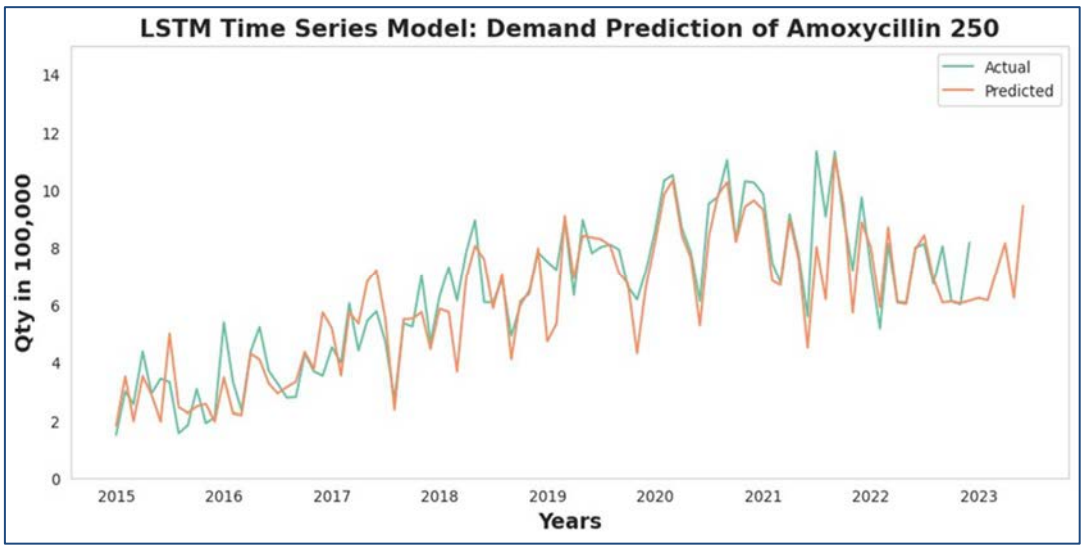

Figure 4 Demand prediction of Amoxicillin 250 mg using LSTM time series model

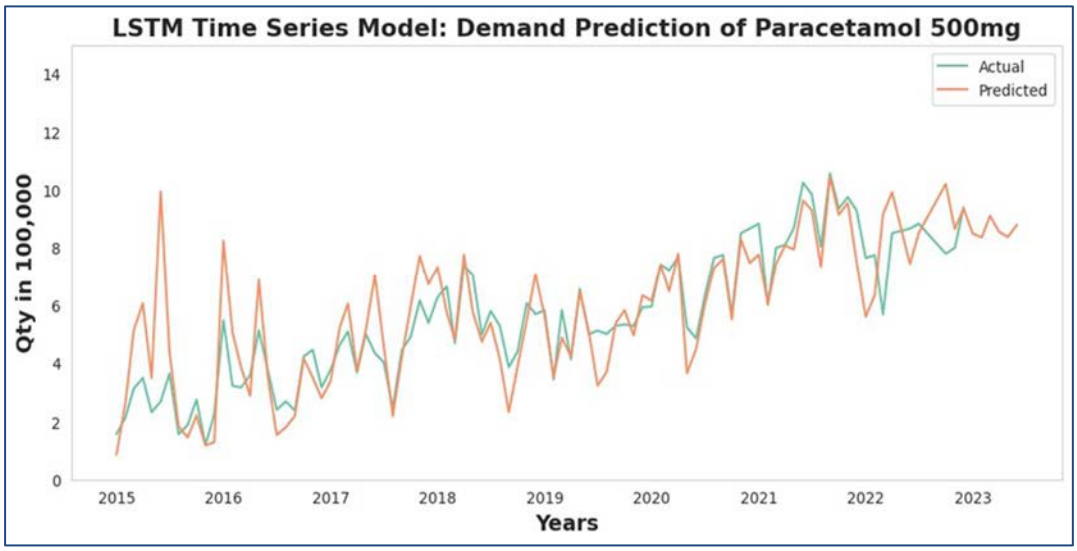

Figure 5 Demand prediction of Paracetamol 500 mg using LSTM time series model

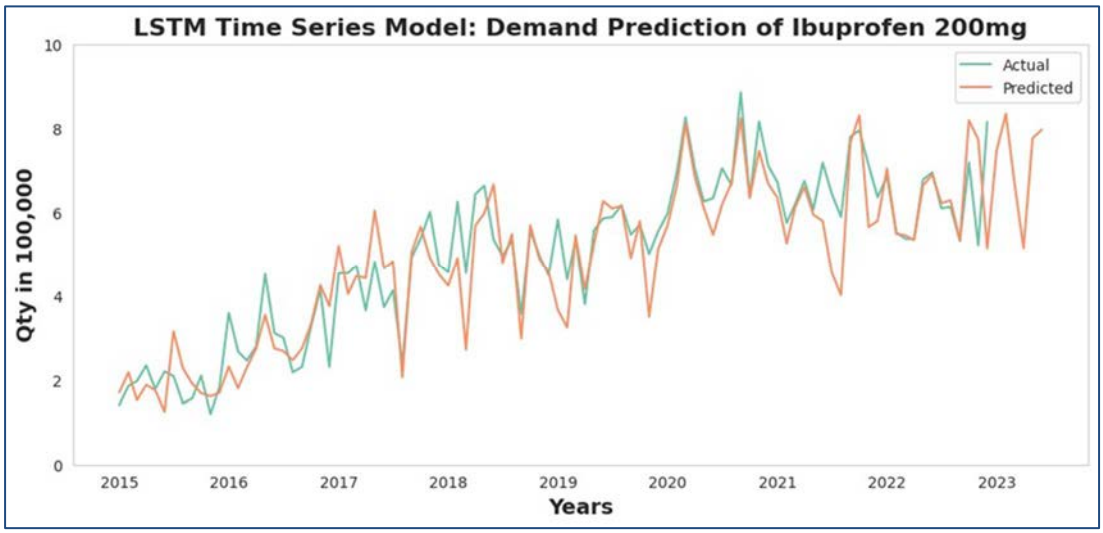

Figure 6 Demand Prediction of Ibuprofen 200 mg using LSTM time series model

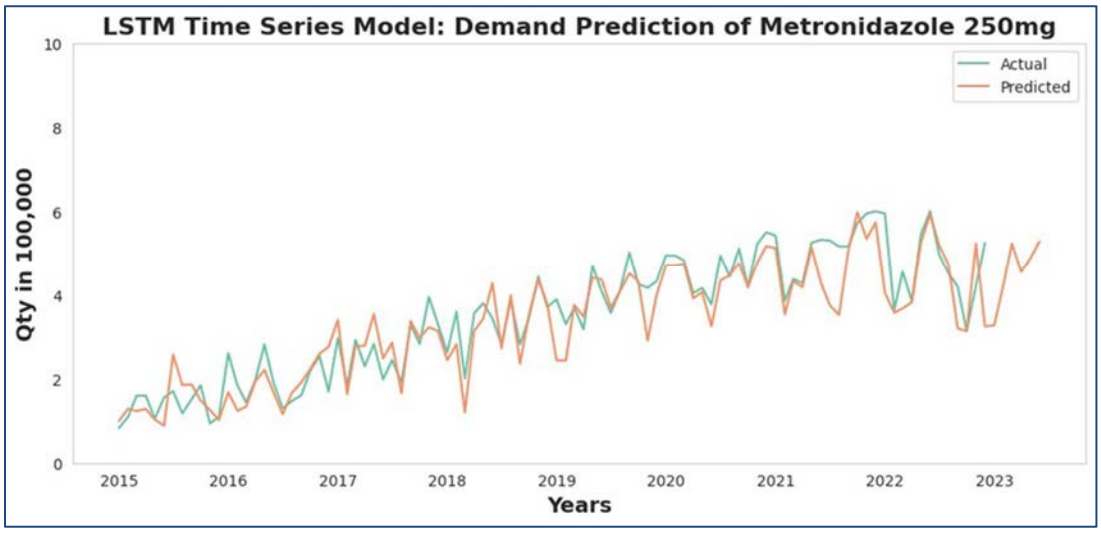

Figure 7 Demand Prediction of Metronidazole 250 mg using LSTM time series model

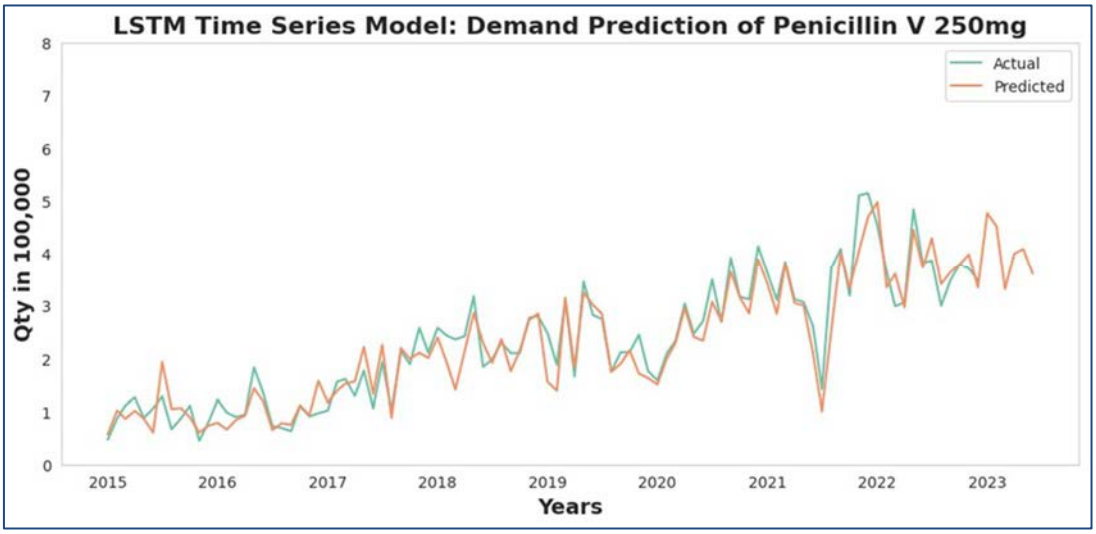

Figure 8 Demand prediction of Penicillin v 250 mg using LSTM time series model

The LSTM prediction plots in figures (Figure 4- Figure 8) are consistent with our model's performance measurements as presented in Table 3 where the quantitative assessment of our models gives important information about how the LSTM and ARIMA models worked. With an RMSE of 2.0 on the training set and 2.043 on the testing set, LSTM was very accurate. The model's ability to explain differences in the data is shown by the high R^2 values of 0.952 and 0.912 for the training set and test set, respectively. On the other hand, the ARIMA model did not show good performance, which was clear from the fact that their RMSE values were higher and their R^2 scores were lower. This stark difference shows that LSTM is better to recommend in medicine demand prediction for public health supply chain tasks.

4.4 Discussion of the results and analytical viewpoints on models' performance

Our study looked at how LSTM and ARIMA predictive models can be integrated in health supply chain forecasting tasks for demand prediction of medicines. Our research gave us valuable information about how well these models worked and their implications for health supply chain management. Additionally, our study had a broad goal: to compare the ability of different models to guess and find the most accurate model for demand prediction of medicines. The LSTM model showed a better prediction performance, illustrating how well it can be used in predicting the future demand of medicines. This level of performance in demand prediction is of great importance in the healthcare industry, especially regarding to effective handling and management of health-related supplies, including medicines.

When viewed alongside earlier studies, our findings are congruent with previous research investigating or making a comparison of LSTM and ARIMA models' demand prediction abilities. Azzouni et al. 2020, in their study, confirmed the LSTM model's performance for time series prediction as having greater accuracy when compared to other methods they used. In their study, the LSTM model was compared to some well-known time series predictive models from both statistical and computational intelligence methods, including ARIMA, exponential smoothing (ETS), artificial neural network (ANN), K-nearest neighbors (KNN), RNN, support vector machines (SVM), and single layer regression (SLR). In terms of accuracy measurements, the experimental results demonstrated that the LSTM model had a prediction power that surpassed the other approaches studied [24]. In a similar way, our findings, which focused on time series demand prediction of medicines, can be supported in the same context as similar findings were reported in other studies conducted in different contexts or using different dataset types. For instance, Hsu et al. 2022, published a study that focused on the prediction of adherence to medical treatment with temporal modelling in cardiovascular disease management. The study highlighted that temporal models that use sequential data outperform non-temporal models, with LSTM showing better performance in prediction and achieving an area under the curve (AUC) of 0.805 [3]. Another study carried out by Nasseri et al. 2023, looked at the use of LSTM networks and extra tree regressors (ETRs) in tree-based ensemble prediction. The study's findings paved the way for future research by suggesting an investigation of the comparison of deep learning techniques and tree-based ensembles in various prediction instances. The findings of a such study may inform decision-making in sales management, product flow, operational and other logistic aspects, as well as promotional tactics with the goal of strengthening supply chain management [27].

Because medicines and health products are usually so costly, it is paramount to point out, in relation to the findings of our study, that the use of data-driven prediction models is a foregone decision to recommend in the health supply chain as this will optimize the accuracy of demand prediction for selected medicines. This is of utmost importance especially in LMICs, where a lack of resources exacerbates existing barriers to health access [28,29]. The implications of our study's findings regarding the enhancement of health supply chain management are substantial and may make a significant contribution to the availability of medicines while streamlining investment strategies in the supply of medicines and preserving cost-effectiveness. Accurate demand predictions are crucial for optimizing inventory levels, minimizing shortages, or overstocks, and ensuring that medicines are readily available to meet patient requirements [10]. The success of the LSTM model in this regard suggests that deep learning techniques can considerably boost the efficiency of health supply chains. Additionally, the practical implications of our research are substantial as for effective health supply chain management, accurate prediction of demand of medicines is needed. As demonstrated, the higher accuracy of the LSTM model provides health professionals with a valuable tool for optimizing inventory levels, ensuring that medicines are always available when needed, and minimizing inefficiencies.

The LSTM Model performed better and presented a notable finding of our study with a higher performance in demand prediction of the selected medicines. Our study's findings are important for assuring efficient and effective management and flow of medicines, while also contributing to budget allocation and financial aspects of health supply chain. With a 95.2% performance rate in demand prediction, the LSTM model exhibited remarkable precision. This accuracy was consistent across different types of medicines, demonstrating the model's adaptability and applicability to a variety of pharmaceuticals. In contrast, the ARIMA model exhibited less accurate forecasts. ARIMA, a conventional time series method, expressed difficulty capturing the complex temporal patterns inherent in our health supply dataset for medicine

demand prediction, resulting in less precise forecasts. Our findings are consistent with the findings of a study conducted by Wang et al. 2021 that focused on the use of ARIMA and LSTM for demand prediction based on short lead time and on-time delivery supply, and another study by Siami-Namini et al. 2018, in which he compared ARIMA and LSTM time series models. Both studies' findings revealed that LSTM models outperformed ARIMA models in terms of prediction accuracy [7,20]. The accuracy of ARIMA model was inferior to that of LSTM model, when using the dataset from e-LMIS in to predict the demand of the selected medicines. This, however, does not intend to question the prospective use of ARIMA models in different settings of very suitable datasets, particularly when it is used in combination through hybrid model as illustrated in a study conducted by Siamba et. Al. 2023, which concluded that a hybrid ARIMA-ANN model produces better predictive and forecast accuracy compared to a single ARIMA model [17].

Our research shows that the LSTM model showed potential added value for demand prediction of medicines and this makes it a must-have for health professionals who want to handle their inventory more effectively. Our study highlighted the application of LSTM predictive models in public health supply chain, showing the possibility for more accuracy in demand prediction and reliable options to optimize financial management and appropriate use of the budget allocated to medicines. The research outlined important insights and showed the necessary supply chain improvements and advances that enable a smooth flow of health product within the health supply chain while also indicating areas that necessitate further study. Our study has limitations, such as the size of the sample and the time span, which we referred to when building our dataset. Future researches should employ larger samples in future studies and investigate additional aspects that may influence the demand prediction of medicines. Further research on a hybrid time series models which may incorporate bigger sample size and diverse data sources, might provide more insights into making accurate forecasts for the demand of medicines. The integration of machine learning and deep learning models in health supply chain provides notable progress health supply chain forecasting by enabling an accurate prediction of medicines' demand which is a critical component to ensure a well-coordinated logistical function and health service delivery. It is deemed pertinent to streamline the flow of medicines and relevant logistic information for optimizing the availability of and accessibility to medicines, especially in LMICs' public health settings, as highlighted by Kaushik et. al, after examining the benefits of time series prediction models in their study [30,31]. The findings of this study are unquestionably intriguing and have confirmed the bridge between specific fields such supply chain, logistics and information management. Similarly, the findings of our study validate the potential use of machine learning and deep learning for medicine demand prediction in health supply chain forecasting.

5 Conclusions

In summary, our research indicates that deep learning models, specifically LSTM, exhibit significant and potential added values in health supply chain forecasting tasks. The measurement of our models provided important insights into how the investigated models performed the demand prediction for the five selected medicines. With an RMSE of 2.0 on the training set and 2.043 on the testing set, LSTM performed well and thus showed a better accuracy for demand prediction in health supply chain and therefore, performed well the demand prediction for the selected medicines. The model's performance and ability to detect variations in the data were demonstrated by the high R^2 values of 0.952 and 0.912 for the training and test sets, respectively. The ARIMA model, on the other hand, did not perform well, as demonstrated by its higher RMSE values and worse R^2 scores. The difference in prediction performance suggests that LSTM is the best option for predicting demand of medicine and thus contributing to health supply chain forecasting tasks.

These models have the capacity to fundamentally transform the manner in which health institutions predict their demand of medicines and lifesaving products, resulting in financial savings, improved aspects of logistics, and more effective use of resources. Health professionals and supply chain managers ought to consider the adoption of an LSTM time series model as a means to guarantee the continual flow of medicines within different levels of supply chain. The importance of accurate predictions using machine learning predictive models has become progressively crucial as the demand for health services continues to expand alongside high budget implications. We are persuaded that our study's findings have a significant impact in health supply chain forecasting, especially for the demand prediction of medicines. The study proposes LSTM as a deep learning time series prediction model, for addressing one of the primary concerns of health sector settings, which relates to how the demand of medicines is accurately performed. We would want to call more study focusing on machine learning and deep learning approaches and their use in health supply chain forecasting for ensuring an open to trust and reliable evidences to inform decision-making processes on their adoption and implementation. Finally, improving health supply chain forecasting through accurate demand prediction of medicines will facilitate the delivery of health services, optimized resource allocation and improved logistics throughout the entire healthcare system.

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Optimizing JIT production and maintenance strategies for material management in the presence of quality decline and random demand fluctuations

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Abstract: Material management is a critical component of any organization, as it encompasses the efficient and effective handling of materials throughout the entire supply chain process. Just-in-time (JIT) strategies play a vital role in streamlining the supply chain process and minimizing waste. The paper examines the optimization of JIT production management, quality, and maintenance planning in the context of material management. An integrated model is proposed based on optimal control theory to formulate a set of innovative systems dynamics that consider quality decline in a stochastic context. The model also includes random demand fluctuations through a stochastic diffusion process. The objective of the model is to enhance company competitiveness by satisfying a service level constraint and jointly optimizing the JIT production and maintenance control parameters to minimize inventory levels and reduce the total cost. The findings reveal significant interactions between costs and control parameters of both JIT production and maintenance strategies due to their close relationship, leading to the conclusion that the development of an integrative model is more cost-efficient than managing them independently. A comparative analysis further enhances the study by highlighting the potential cost savings in implementing the suggested collaborative control strategy. Overall, the paper contributes to the literature on material management by addressing the research gap in the optimization of JIT production management, quality, and maintenance planning under a stochastic context.

1 Introduction

Delays and extra expenses may be incurred if the materials required for specific activities are unavailable, highlighting the importance of ensuring a timely flow of materials. For effectively managing and controlling materials, it is essential to measure the performance of materials management, devise effective maintenance strategies, cope with quality issues, analyze the effects of deterioration, consider the effect of random demand, etc. In the next paragraphs, we review the literature regarding these common production disturbances.

Maintenance activities have traditionally been viewed in conflict with production activities. To minimize these negative effects, considerable efforts have been made to devise approaches to better align such practices. For example, in [1], an integrated model was developed that examines demand predictions, machine variance, production rates under energy restrictions, and the relationship between production cadences and maintenance techniques. The aim is to determine the ideal lot size while minimizing overall production, energy, and maintenance expenses. [2] developed an integrated production and trading control strategy for unstable manufacturing systems subject to cap-and-trade legislation. The policy directs managers to decide whether to buy or sell permits or increase/decrease production rates to minimize overall costs and reduce carbon emissions. [3] analyzed a proportional risk model and maintenance strategy with many maintenance activities and dynamic control limitations. Condition monitoring is used to detect system degradation, and corrective maintenance activities are established using the system age at failure and deterioration at the start of the production run. [4] compared push and pull disposal inventory controls for a hybrid system with manufacturing and remanufacturing functions and concluded that increasing the disposal rate results in reduced variance values. [5] examined the management of a hybrid production system that handles new or returning materials during the manufacturing process. An intuitionistic model was created to explain

financial benefits and make judgments about employing remanufactured components in production processes.

In the sphere of manufacturing, organizations consistently face difficulties in overseeing their activities and procedures related to the management of material, meeting production goals, and maintaining high-quality standards, as in [6], who proposed a paradigm for increasing production quality performance throughout the system ramp-up phases of manufacturing. They studied two strategies, predicting difficulties during design and continually improving the performance metrics. [7] investigated production and maintenance scheduling for an unstable manufacturing system, with an emphasis on just-in-time strategies. This study underlines the value of JIT approaches in reducing the total production cost. [8] provided an effective stochastic analytical model for integrated production and preventive maintenance control in manufacturing systems that experience degradations in reliability and quality. The model optimizes the production and maintenance settings while minimizing the overall cost. [9] presented an effective control strategy that integrates four key choices to coordinate remanufacturing, manufacturing, return replenishment, and quality control while reducing the overall cost and achieving client quality requirements. [10] introduced a model that seeks to develop optimal production plans, preventive maintenance measures, and control chart criteria for quality monitoring. Non-conforming items are available for rework, resulting in lower average costs.

Traditional optimization models for maintenance strategies for sophisticated systems must consider the effects of dependency, such as the degradation of components. Several works address deterioration aspects, such as the article of [11], which focused on production planning for an unreliable, degrading system, with an emphasis on machine deterioration on availability and quality. They determined the production rate and replacement strategy to reduce the total discounted costs. In [12], a hybrid manufacturing system was proposed that divided the production time between manufacturing and remanufacturing. Equipment is prone to degradation owing to the variety of returned items. [13] proposed a model for integrating maintenance plans and spare parts management in a manufacturing system with a constantly growing deterioration rate. This model considers the influence of variations in production rates on system deterioration and demand for replacement components. [14] presented a mathematical model for preventive maintenance that considered inventory, maintenance, and backlog costs. The control policy comprises switching and hedging points, preventive maintenance activation, and production rate management to reduce the surplus of a system with degrading machines. [15] optimized a production system with a machine that deteriorates with time, affecting machine availability and increasing the defective product rate. The objective was to develop a combined policy for production, maintenance, and quality control to increase machine availability, improve product quality, and reduce production costs.

Material management is crucial to ensure a timely flow of materials and avoid unnecessary delays and expenses, which can be achieved through the application of just-in-time strategies that focus on on-time delivery, inventory turnover ratio and reduced lead time, such as the paper of [16], who suggested numerous routing options for just-in-time completion in hybrid flow shops. These solutions employ distributed computing to anticipate the completion durations of unfinished activities in real-time. [17] introduced a novel manufacturing paradigm that attempts to decrease warehouse space while eliminating non-value-adding procedures. They focused on synchronization and uncertainty hedging and employed a manufacturing platform with Internet of things-enabled infrastructure. [18] presented an optimization model for single-machine scheduling that reduces weighted earliness/tardiness penalties and work-in-process expenses for a just-in-time manufacturing system. The model was tested against an existing model and shown to produce optimal solutions for up to six tasks with significantly less computing time than larger models. [19] provided a strategy for optimizing the efficiency of an existing mixed-flow assembly line using an upgraded genetic algorithm and simulation. The technique consists of a multi-objective mathematical model based on the minimal production cycle, part consumption balance, and just-in-time supply of parts. [20] employed a task batching method to divide jobs into batches, an optimum shifting algorithm to determine start timings and a dominance rule for early/late scheduling for just-in-time production scheduling.

The role of logistics operations has grown to become a critical aspect of a firm's competitive strategy. Various elements, including the expansion of global business, limited internal capabilities, and uncertainty can significantly influence businesses. Numerous researchers have examined the impact of demand uncertainty on operations. For instance, [21] addressed a stochastic dynamic distribution issue in which products are shipped from a warehouse to a distribution center with random demand. They provided an optimum selection policy based on inventory thresholds and used a simulation model to illustrate its resilience and performance. [22] investigated the optimal production flow control for a manufacturing company with random demand and uncertainties in price and cost. Their best production strategy is a state-dependent hedging policy that produces only when costs are low and the surplus falls between the two hedging thresholds. [23] proposed a supply chain management model that includes a configurable production rate and price discount for backorders. The model seeks to reduce supply chain costs by optimizing the production rate, lot size, and number of shipments under random demand. [24] the study looks at a capacitated periodic inventory review problem, with an emphasis on the optimal management of raw material and final product stocks, considering random

demand and supply. [25] Combined nonperiodic preventive maintenance and production planning optimization for a manufacturing system that includes many machines placed in series with random demand. Experimental findings were provided to investigate the effect of failure rate thresholds on preventative maintenance measures.

As can be seen from the above papers, the connection between production and maintenance strategies is crucial, but further research is necessary in this domain. Existing studies have not fully explored their impact on critical factors such as the presence of uncertainties, product quality, and the use of JIT strategies to minimize costs. Therefore, this study focuses on developing a comprehensive optimization approach for determining the control parameters of a just-in-time production strategy and perfect maintenance policy. The analysis examines the intricate interactions among key strategies, such as production, quality control, and maintenance management, under conditions of high uncertainty. Furthermore, the model considers service-level constraints and random demand modeled through stochastic diffusion processes. Despite the existing models in the literature, none appear to holistically consider all the points addressed in this study.

The remainder of this paper is organized as follows. The second section outlines the suggested control model formulation, while Section 3 introduces the methodology used in this study. Section 4 describes and validates the simulation model developed. Section 5 presents the results and discusses a numerical example along with an extensive sensitivity analysis to highlight the technical benefits of the proposed approach. Finally, Section 6 concludes the study.

2 Formulation of the production model

A Markov process Ω = {1,2,3} defines the system's uptime and downtime. The process is governed by the generator $Q(\cdot) = \{q_{\alpha\alpha'}\}$, where $q_{\alpha\alpha'}$ are the transition rates for states α to α', with $q_{\alpha\alpha'} \geq 0$, and $\alpha, \alpha' \in \Omega$. When the stochastic process $\alpha(t)$ is in state $\alpha(t)$=1, the machine is operational; at $\alpha(t)$=2, the unit is in minor maintenance, leaving the machine in as-bad-as-old conditions (ABAO); and at $\alpha(t)$=3, major maintenance is performed, rejuvenating the unit to its initial settings. The dynamics of stock level x(t) are described as follows (1):

$$\frac{\partial x(t)}{\partial t} = u(t) - \frac{D(t)}{\left(1-\beta(a)\right)} \tag{1}$$

Where $u(t)$ is the production rate, $D(t)$ is the customer demand, and $\beta(a)$ is the faulty rate. Given such a production model, we hypothesize that demand displays random behavior, as represented by a stochastic diffusion process. We used an Ornstein-Uhlenbeck process with white noise, which defines the following stochastic differential equation (2).

$$\begin{gathered} dZ_D(t) = -b_1 dZ_D(t) + \sigma_1 W_1(t) \\ Z_D(0) = Z_D^0, Z_D^0 > 0 \\ Z_D^0 \sim N\left(0, \frac{{\sigma_1}^2}{2b_1}\right) \end{gathered} \tag{2}$$

Where $Z_D(t)$ is the random component of the demand, b_1 is the coefficient of variation, σ_1 is the diffusion coefficient and $W_1(t)$ represents the Wiener process (3).

$$D(t) = \mu_D + Z_D(t) \tag{3}$$

To simplify matters, we define μ_D as a constant component of the demand. The age of the producing unit $a(t)$ is a function of the operating time, and this age returns to the original value according to the most recent major maintenance conducted, as follows (4), (5):

$$\frac{\partial a(t)}{\partial t} = \eta_0 \cdot u(t) \tag{4}$$

$$a(T) = 0 \tag{5}$$

Parameter η_0 is a constant and T represents the lastest restart of the unit. The quality degradation effect is represented by the following equation (6).

$$\beta(a) = b_0 + b_1\left[1 - e^{-\eta_1 a(t)^{\eta_2}}\right] \tag{6}$$

In the following equation, b_0 represents the defective rate at the initial conditions, b_1 denotes the maximum limit of deterioration, and η_1 and η_2 are nonnegative constants. The system's availability in the operating mode is defined as (7), (8).

$$\Pi_i \cdot Q(\cdot) = 0 \quad \text{and} \quad \sum_{i=1}^{3} \Pi_i = 1 \tag{7}$$

$$\Pi_1 = \frac{1}{1 + q_{12}/q_{21} + q_{13}/q_{31}} \tag{8}$$

Furthermore, decision-makers should ensure that the manufacturing unit can satisfy the demand even when it is severely deteriorated. Consequently, the following feasibility requirement must be satisfied (9).

$$u_{max} \cdot \Pi_1 \geq \frac{D(t)}{\left(1-\beta(a)\right)} \tag{9}$$

The model also included a service-level constraint (10).

$$NS(\cdot) = 1 - \left[\frac{T_{no}}{T_{sim}}\right] \tag{10}$$

Fundamentally, T_{sim} represents the simulation time, whereas T_{no} denotes the period when the client demand is not met. The fundamental hypothesis of the model is to develop a just-in-time (JIT) production policy. The

hedging point policy supplements the production of JIT policy as follows (11), (12):

When $a(t) \leq B_{JIT}$,

$$u^*(1,x,a) = \begin{cases} u_{max} & if \quad x(t) < 0 \\ D/(1-\beta(a)) & if \quad x(t) = 0 \\ 0 & if \quad x(t) > 0 \end{cases} \qquad (11)$$

When $a(t) > B_{JIT}$,

$$u^*(1,x,a) = \begin{cases} u_{max} & if \quad x(t) < Z_p \\ D/(1-\beta(a)) & if \quad x(t) = Z_p \\ 0 & if \quad x(t) > Z_p \end{cases} \qquad (12)$$

In Equation 12, as the system deteriorates and reaches age B_{JIT}, some inventory Z_p is maintained as a safeguard against defects and breakdowns. According to the specification of the maintenance policy, major maintenance occurs when age $a(t)$ exceeds trigger point A_0. Therefore, the plan for major maintenance implies that (13).

$$\omega^*(1,x,a) = \begin{cases} 1 & if\ a(t) \geq A_0 \\ 0 & otherwise \end{cases} \qquad (13)$$

In practice, A_0 is the age that which major repair is initiated. The optimization parameters are also important considerations for the model. The inventory-backlog cost IB(t) in period [0,T] was determined using the following equation (14):

$$IB(t) = \frac{1}{T}\int_0^T \left(C^+x^+(t) + C^-x^-(t)\right)dt \qquad (14)$$

with

$$x^+ = max(0,x)$$
$$x^- = max(-x,0)$$

Constants C^+ and C^- punish inventory costs and shortages, respectively. The average overall quality cost $QC(t)$ is calculated using the average cost of defects C_{def} per unit of time as follows (15):

$$QC(t) = \frac{1}{T}\left(C_{def}\int_0^T (\beta(t)\cdot d)dt\right) \qquad (15)$$

The average MC(t) for the maintenance cost includes both the cost of minor maintenance and the cost of major repairs (16).

$$MC(t) = \frac{1}{T}\cdot\left(C_R\cdot N_R(t) + C_M\cdot N_M(t)\right) \qquad (16)$$

In the current problem, $N_R(t)$ and $N_M(t)$ represent the number of minimal repairs and major maintenance performed throughout the period [0,T]. Minimization implies the following stochastic model (17):

$$Min\ TC(Z_p, B_{JIT}, A_0) = \lim_{t\to\infty}\left(IB(t) + QC(t) + MC(t)\right) \qquad (17)$$

Subject to:

$NS(\%) \leq NS_L$

Equations (1)-(9) (Inventory and quality dynamics)

Equations (11)-(13) (Control policy)

$Z_p, B_{JIT}, A_0 \geq 0$

The practical implication of NS_L is that it indicates the service level required by customers.

3 Methodology

Owing to its flexibility and capacity to reproduce stochastic dynamics, a simulation-optimization technique has proven to be effective in establishing the best control settings when dealing with such uncertainties. This section outlines the selected method. We specifically used simulation and optimization approaches to properly model the dynamic behavior of the production unit. We created an analytical model and then used the high flexibility of the simulation approaches to find a solution. Statistical studies, including experimental design and response surface approaches, have also been utilized to optimize the model parameters. This method has been successfully utilized in earlier research on systems with challenging analytical solutions [7]. The suggested control model was solved using the technique described below, taking these actions into account.

I. **Mathematical formulation:** in this phase, the mathematical formulation of the manufacturing unit under analysis is carried out through a series of equations that define the dynamics for inventory and machine age; it is also determined the stochastic differential equation used to model random demand, as well as the equations used to define production and repair control policy. Equations (1)-(17) are used to model the industrial system analytically.

II. **Simulation model:** in this stage, a simulation model is created that includes both discrete and continuous components, with the goal of capturing the dynamics of the production system. The control parameters (Z_p, B_{JIT}, A_o) specified in the preceding phase defined the input of the simulation model. Additionally, the simulation model was validated during this phase.

III. **Statistical analysis:** this phase entails conducting an ANOVA study to determine the relevant control factors and their interactions that must be addressed in the minimization. Consequently, simulation results are required to perform such an analysis, which leads to the definition of a second-order regression model for total cost. Statistical analysis was performed using an experimental design with three replicates.

IV. **Optimization:** in this stage, we specify the experimental domain for the control parameters

(Z_p, B_{JIT}, A_o). The goal is to apply the response surface approach to optimize these parameters while lowering total costs. Consequently, the regression model employed in the previous phase was optimized, which required several simulation runs. The response surface determines the optimal control factors $(Z_p^*, B_{JIT}^*, A_o^*)$ and optimal cost.

V. **Sensitivity analysis:** in this stage, a variety of actions are performed to validate the chosen approach and ensure that accurate results are produced. The initial task is to track various important simulation model performance indicators to ensure that the simulation model accurately captures the dynamics and stochastic behavior of the manufacturing unit. Furthermore, the variability of many costs and system factors was examined to analyze the robustness of the proposed control strategy. This section is supplemented by a comparative analysis that focuses on the economic cost reductions provided for our approach.

4 Simulation model

The idea behind the procedure involves creating a combined discrete-continuous simulation model (Figure 1) to replicate the dynamics and flow of the proposed production system. The Arena simulation software is used to develop the model, which uses control parameters and the Runge-Kutta-Fehlberg algorithm to update differential equations for the stock level and machine age. The model estimates the random duration of failures and maintenance actions, and a C++ subroutine defines the continuous part of the model that simulates the trajectory of the stochastic differential equation of random demand. The discrete and continuous sections were synchronized to imitate uncertain manufacturing system features. Production and maintenance strategies are implemented based on the control rules denoted in Equations (11)-(13), and several modules detect the machine's stock level and age to trigger major maintenance and adjust the production rates. After the simulation run, the indicators define the average stock level, backlog, defective cost, and repair cost using Equations (14)-(16). Simulation-optimization approaches are an efficient alternative for providing adequate solutions within a reasonable time.

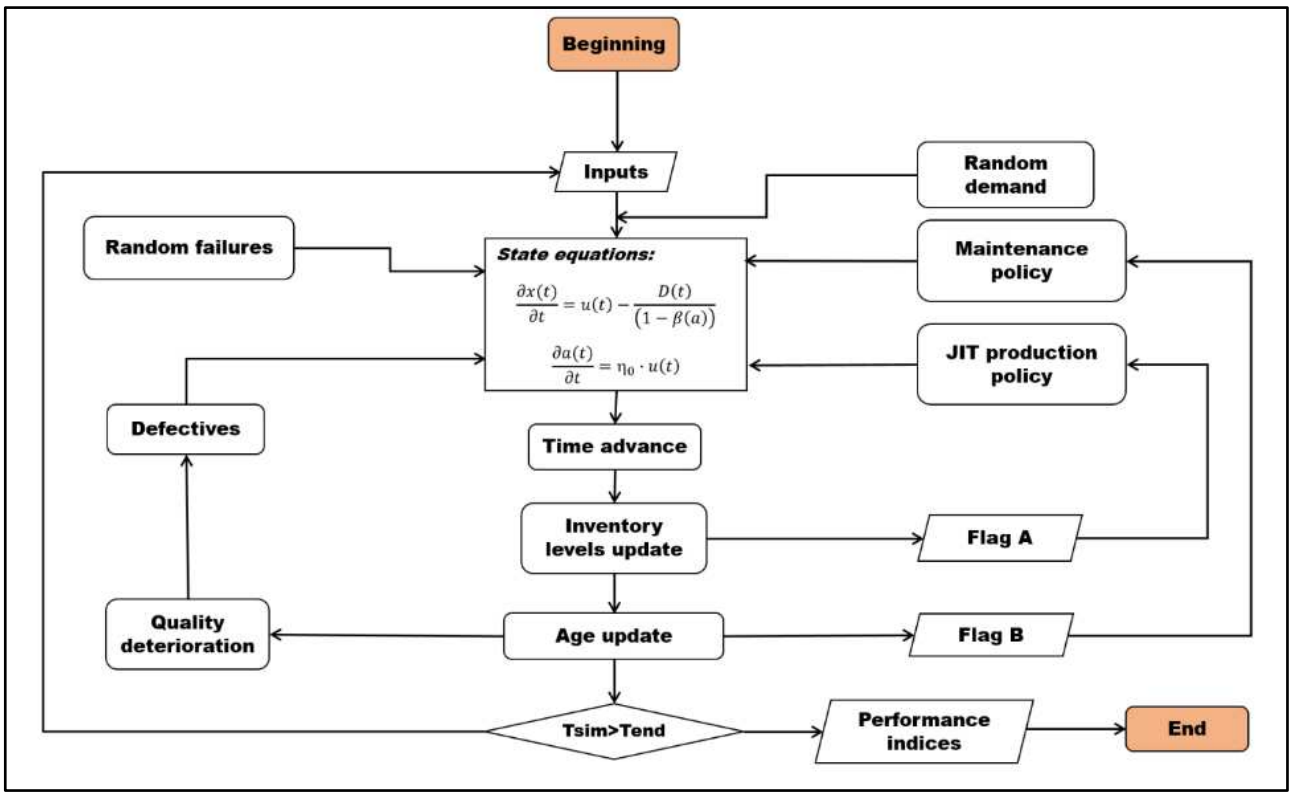

Figure 1 Simulation model

4.1 Evaluation of the simulation model

The simulation model was evaluated to ensure accuracy of the results. The key metrics of the system's performance are monitored, and Figure 2 shows the dynamics of the production system when the control parameters are set to Z_p=20, B_{JIT}=150 and A_o=250. The system is in AGAN conditions when $t = 0$ (see circle 2 in Figure 2) and then experiences malfunctions and failures at $t = 90$ (see circle 2). Then, at $t = 150$, the system reaches $B_{JIT} = 150$ and inventory increases from zero to $Z_p = 20$ (see circles 4 and 5). Changes in inventory thresholds indicate that cumulative degradation leads to increased defects, requiring more inventory to satisfy the demand using defect-free units. At $t = 240$, the system produces at a rate

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$d/(1-\beta(a))$ (see circle 6), which is given to mitigate the generation of non-conforming units originating from the deterioration process (see circle 7). When the system surpasses age $A_o = 280$, it performs a major repair (see circle 8), thereby reducing inventory. The rate of defects significantly decreased after the major repair, as it rejuvenated the system and removed the defects. The inventory level was set back to zero, indicating the start of a novel degradation cycle (see circles 9-11). The assessment of the dynamics in Figure 2 demonstrates that JIT production and the major repair strategies function correctly. Once the system surpasses the reference age B_{JIT}, some inventory is required to mitigate shortages; if the system ages above A_o, major maintenance is conducted.

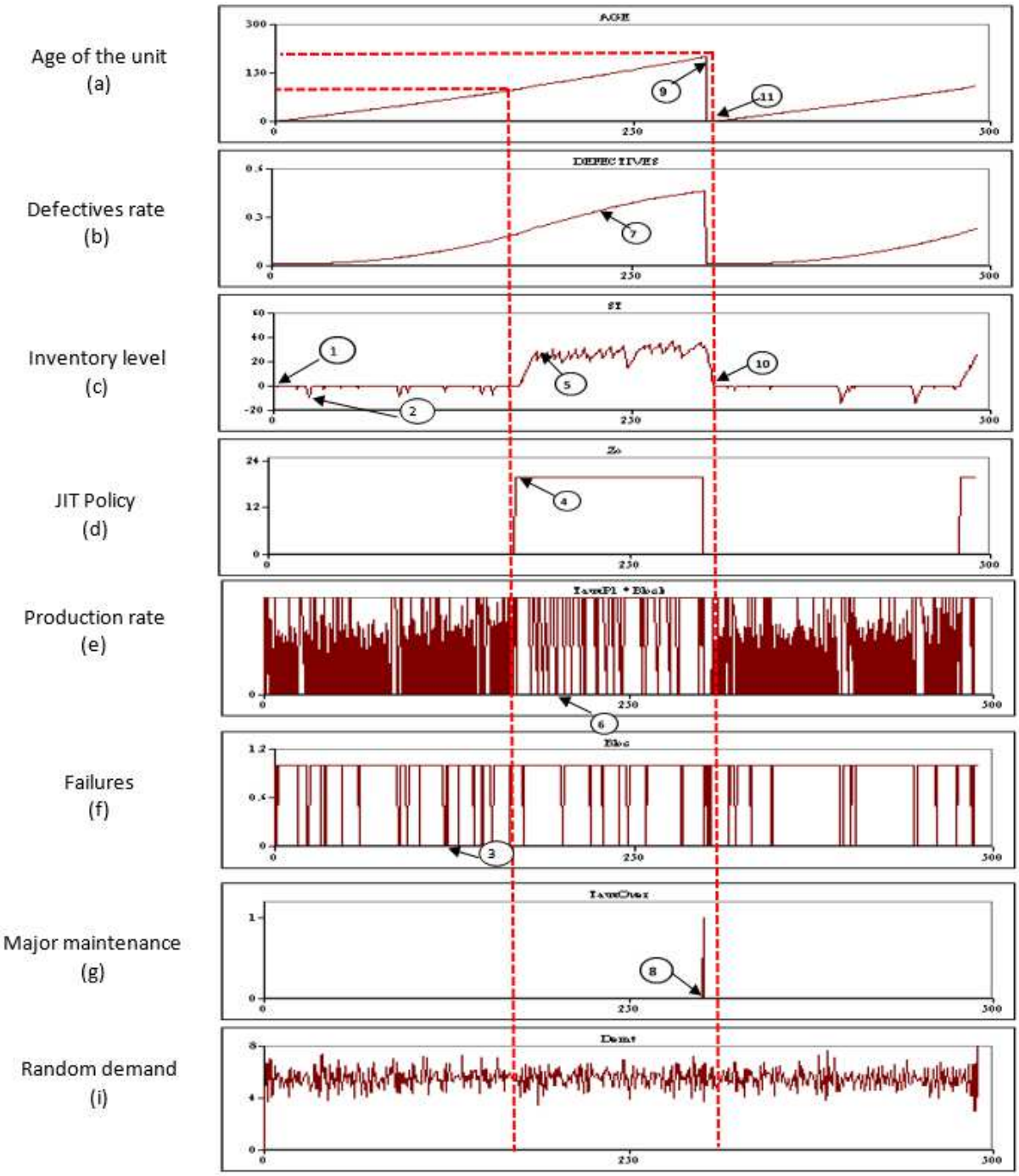

Figure 2 Graphical validation of the simulation model

5 Result and discussion

For illustrative purposes, 108 simulation runs were performed using a design of experiments replicated four times: $(3^3x4) = 108$. The simulation was set to 100,000 time units to ensure steady-state conditions. The parameters of the numerical example are listed in Table 1.

Table 1 Data for the simulation model

Parameter:	q_{12}	q_{21}	q_{13}	q_{31}	θ	
Value	0.1	1.5	5	0.15	0.08	
Parameter:	u_{max}	d'	η_0	b_0	b_1	C_M
Value	9	5.5	0.1	0.01	0.49	3000
Parameter:	η_1	η_2	C^+	C^-	C_R	C_{def}
Value	15x10^ -6.2	2.4	1	50	100	20

Table 2 shows the levels of the independent variables (Z_p, B_{JIT}, A_o) utilized in the simulation instance, which were determined by offline executions. To ensure that $B_{JIT} < A_o$, we define $B_{JIT} = k \cdot A_o$, where k ranges from 0 to 1.

Table 2 Control parameters

Factor	Lower level	Higher level	Description
Z_p	10	150	Optimal inventory level
k	0.1	0.9	Auxiliary variable
A_o	40	300	Reference age for major maintenance

The simulation model produced sufficient data to construct a second-order regression model for total cost.

$TC(Z_p, k, A_o) = 540.589 - 3.80285*Zp - 353.417*k - 2.20742*Ao + 0.0117889*Zp^2 + 1.18843*Zp*k + 0.00374364*Zp*Ao + 477.796*k^2 - 0.225722*k*Ao + 0.00522249*Ao^2$ (18)

Table 3 shows the ANOVA results for the aforementioned equation, indicating a correlation value of R^2= 0.902. This statistic indicates that the regression model explains 90.20 percent of the observed variability in total cost.

Table 3 ANOVA results

Source	Sum of Squares	Gl	Medium Square	F-Ratio	P-Value
A:Zp	83008.7	1	83008.7	22.01	0.0000
B:k	188873.	1	188873.	50.09	0.0000
C:Ao	36562.0	1	36562.0	9.70	0.0033
AA	40042.7	1	40042.7	10.62	0.0022
AB	26575.2	1	26575.2	7.05	0.0111
AC	27853.6	1	27853.6	7.39	0.0094
BB	70130.5	1	70130.5	18.60	0.0001
BC	3306.48	1	3306.48	0.88	0.3543
CC	93478.0	1	93478.0	24.79	0.0000
blocks	562.859	1	562.859	0.15	0.7011
Total error	162139.	43	3770.68		
Total (corr.)	732532.	53			

Table 3 presents the P-values of the main factors and interactions included in the ANOVA, where we identify in red the significant factors that must be included in the optimization phase. A P-value lower than 0.05 indicates strong evidence that such factor has a significant impact on the total cost. Figure 4 presents the regression model projection for the total cost in two-dimensional space. Figure 4 shows the optimal solution, which is presented in Table 4. The variable k^* = 0.2609 leads to B^*_{JIT} = 45.35. The optimal parameters presented in Table 4 are the proposed values for concurrently regulating production pace and major maintenance performance.

Table 4 Optimal value of the control parameters

	Zp^*	k^*	Ao^*	Estimated Total Cost
Control factor	120.539	0.261	173.771	73.47

5.1 Sensitivity analysis

In the sequel, we evaluate the sensitivity of various costs. Table 5 presents the results of the sensitivity analysis of the most typical costs.

- Variability of the shortage costs: as the shortage cost increases (case 4), the lack of product is punished more harshly. As a countermeasure against shortages, inventory levels increase, resulting in an increment in Z_p as a safety reserve. Furthermore, we discovered that product shortages resulted in a drop in the critical age B_{JIT}, implying that the unit applies the JIT approach for a shorter amount of time, allowing inventory to be maintained for longer. The increase in the shortage cost puts huge pressure on the system's performance; thus, major repairs are postponed to guarantee that the machine remains in operation for a longer duration and to prevent shortages.

Table 5 Variability of the cost parameters (↑ and ↓ indicate the impact of varying the cost element)

Par.	Value	Case	Optimal control parameters				Total cost	Effect
			Z_p	k	B_{JIT}	A_o	($)	
		Base case	*120.53*	*0.261*	*45.35*	*173.77*	*73.47*	-
C+	0.5	case 1	139.48	0.118	20.72	175.50	28.18	Zp↑,Bjit↓,Ao↑
	2	case 2	97.13	0.417	72.82	174.71	127.54	Zp↓,Bjit↑,Ao↑
C-	20	case 3	88.37	0.463	82.55	178.36	80.55	Zp↓,Bjit↑,Ao↑
	70	case 4	130.33	0.188	32.69	174.06	55.26	Zp↑,Bjit↓,Ao↑
C_R	20	case 5	120.51	0.261	45.43	173.98	66.16	Zp↓,Bjit↑,Ao↑
	500	case 6	120.69	0.260	44.91	172.70	110.03	Zp↑,Bjit↓,Ao↓
C_M	1000	case 7	122.30	0.256	42.03	163.95	65.98	Zp↑,Bjit↓,Ao↓
	5000	case 8	119.12	0.265	48.08	181.69	80.21	Zp↓,Bjit↑,Ao↑
C_{def}	5	case 9	118.76	0.265	48.31	182.15	60.25	Zp↓,Bjit↑,Ao↑
	50	case 10	124.11	0.252	39.53	156.56	97.82	Zp↑,Bjit↓,Ao↑

- Variability of the cost of major repair: The increase in the expense of major repairs CM (case 8) causes delays in maintenance and increases the age of A_o. This result is explained by the fact that the system must attain greater degrees of deterioration to compensate for the high expense of major repairs. Furthermore, the goal of performing fewer major repairs is to allow the system to run for longer periods of time without interruption, resulting in an increased production capacity and a lower priority for stock maintenance. Thus, this operation lowers stock level Z_p. Furthermore, when the production time increases, the JIT approach is extended, which increase the age of B_{JIT}. The reduction in the major repair cost had the opposite impact (case 7).
- Variability in cost of defectives: With the increase in the cost of faulty components, C_{def} (case 10), it is observed that major maintenance is carried out more frequently to rejuvenate the system faster and limits the number of non-conforming units found by the end user. Furthermore, a careful study of the rise in the cost C_{def} demonstrates that the system has opted to increase the inventory level to ensure that consumers are satisfied with faultless units. This strategy was supplemented by lowering the critical age of B_{JIT}, allowing for a longer time for inventory policy implementation. When the cost of faulty items is reduced (Case 9), the opposite consequences occur.

An argument can be made to assert that the structure of the control strategy in Table 5 is robust and consistent throughout the analysis.

5.2 Sensitivity of the Ornstein-Uhlenbeck process

Our primary concern in the present subsection is the analysis of the variability of the stochastic differential equation parameters σ_1 and b_1, which describe the dynamics of random demand. Table 6 presents the results of the sensitivity analysis.

Table 6 Sensitivity for the Ornstein-Uhlenbeck process parameters

Case	σ_1	b_1	Z_p^*	k^*	B_{JIT}^*	A_o^*	Cost*	Service level
Base case	*0.6*	*1.5*	*120.539*	*0.261*	*45.351*	*173.771*	*73.474*	*0.910*
Sensitivity for σ_1								
case 11	0.15	1.5	120.052	0.266	46.484	174.607	74.772	0.907
case 12	0.7	1.5	121.032	0.259	44.906	173.285	73.614	0.912
case 13	1.25	1.5	122.044	0.252	43.206	171.566	71.460	0.920
Sensitivity for b_1								
case 14	0.6	0.25	126.928	0.168	27.531	163.879	51.103	0.942
case 15	0.6	1	121.037	0.256	44.346	173.343	73.049	0.911
case 16	0.6	1.75	120.146	0.262	45.483	173.746	73.612	0.913

- Variation of parameter σ_1: As parameter σ_1 increases (case 13), major repairs are performed more frequently to reduce the production of defective units. Additionally, increasing σ_1 indicates that the production unit tends to increase inventory level Z_p to ensure that demand is met with defect-free products. This step is paired with lowering the reference age B_{JIT} to extend the amount of time during which the inventory strategy maintains more stock to guard against demand fluctuations. This action allows for the availability of a greater stock to replace faulty units as needed. Increasing the parameter σ_1 results in an increase in inventory owing to increased demand fluctuation and the requirement for greater protection. When parameter σ_1 declines, there are inverse impacts (see case 11).
- Variation of parameter b_1: By increasing parameter b_1 (case 16), it is observed that major maintenance is performed less frequently because there is less variation in the fluctuation of demand in the short term, which increases age A_o. Additionally, the just-in-time policy is used more frequently, which increases the age B_{JIT}, because demand varies less in the short term, and less inventory is required for protection. As a result, the stock level Z_p decreases. When parameter b_1 is reduced (case 14), the converse occurs.

5.3 Service level constraint sensitivity

In the following subsection, Table 7 examines the impact of service-level constraints. The resulting service-level regression equation is as follows.

$$\begin{aligned}\mathrm{NS}(Z_p,k,A_o) = {} & 0.747988 + 0.00223376*\mathrm{Zp} - \\ & 077464*\mathrm{k} + 0.00121354*\mathrm{Ao} - 0.00000650*\mathrm{Zp}\hat{}2 \\ & -0.00109992*\mathrm{Zp}*\mathrm{k} - 0.00000094*\mathrm{Zp}*\mathrm{Ao} - \\ & 0.175613*\mathrm{k}\hat{}2 - 0.00044982*\mathrm{k}*\mathrm{Ao} \\ & -0.00000281*\mathrm{Ao}\hat{}2 \end{aligned} \quad (19)$$

Further investigation shows that varying the service-level parameter NS_L leads to the following implications.

- Variation of the service level constraint: As the service level parameter NS_L, drops (case 22), major maintenance is conducted less often, increasing A_o. This is because of the need to keep the system operating for a longer duration to prevent product shortages. As the service level decreases, the inventory level Z_p is expected to decrease, as the requirement for greater safety stock decreases. Furthermore, when the service level is lowered, the just-in-time strategy is postponed, because maintaining inventory at low service levels is unnecessary. When the service level increased, the outcomes were inverse (case 17).

Table 7 Sensitivity of the service restriction

Case	Service level NS_L (%)	Z_p^*	k^*	B_{JIT}^*	A_o^*	Cost*
case 17	94%	120.270	0.264	45.988	173.943	73.480
case 18	92%	116.422	0.314	55.456	176.768	74.709
case 19	90%	112.740	0.361	65.063	180.158	77.938
case 20	88%	109.219	0.407	74.863	184.081	82.947
case 21	86%	105.836	0.450	84.892	188.488	89.545
case 22	84%	102.620	0.492	95.183	193.351	97.563

5.4 Comparative study

For the sake of completeness, we evaluate the performance of the suggested policy (Z_p,B_{JIT}, A_o), also known as Policy-A, to other policies found in the literature.

- Policy-B: This option does not implement the JIT policy. In this case, the production strategy focuses only on establishing the appropriate Z_p inventory level, which remains constant across the time period under consideration. This option does not include

control factor B_{JIT} in the optimization. Thus, Policy-B includes only the parameters (Z_p,A_o) in the control policy, which are jointly optimized. This policy assumes random demand.

- Policy-C: The control policy does not apply the major maintenance strategy; instead, inventory level and age are used to implement the just-in-time policy. Therefore the control parameters are just (Z_p,B_{JIT}). This policy assumes a random demand.
- Policy-D: In this policy, a constant demand is considered, and the just-in-time policy is not applied, therefore there are only two control parameters (Z_p,A_o), one devoted to the optimal value of the stock level and another parameter to indicate the age at which the major repair is performed.
- Policy-E: This policy uses constant demand and just two control parameters, one for stock level and one for age, to execute the just-in-time policy (Z_p,B_{JIT}). Parameter A_o for major maintenance is discarded.

Table 8 shows the findings of the comparison analysis.

Table 8 Comparative study

Descripción	Z_p^*	k^*	B_{JIT}^*	A_o^*	Cost*	Cost difference
Policy-A	120.27	0.2643	45.98	173.94	73.47	-
Policy-B	104.07	-	-	159.75	113.82	54.92%
Policy-C	90.99	0.5006	100.13	200	128.03	74.25%
Policy-D	103.71	-	-	161.18	112.13	52.62%
Policy-E	90.759	0.5062	101.25	200	128.00	74.22%

Regarding Policy-C, had the greatest cost of the comparison because it separates maintenance decisions from the optimization; this policy exclusively optimizes the production parameters (Z_p,B_{JIT}). Policy-III reduces inventory levels and extends the zero-inventory policy. However, postponing major maintenance has significantly increased the total costs by generating more defects. The cost increase of Policy-E is observed as a result of separating the optimization, manufacturing, and repair control factors. Table 8 validates the key economic benefits of Policy-A, as it clearly indicates that Policy-A always had the lowest cost compared to other choices.

6 Conclusions

This study explores the optimization of just-in-time (JIT) production, maintenance strategies, and quality control for material management in organizations. The main objective of this study is to fill the research gap by investigating the impact of JIT strategies on the efficiency and effectiveness of organizations. Four key factors motivated this research: the consideration of the interaction of the strategic functions of production-quality-maintenance, the determination of optimal factors of production and repair strategies based on system degradation levels, the implementation of a zero inventory just-in-time strategy before the system reaches a certain age, and the need for repair policies based on product quality data that consider the relationship between system deterioration and non-conforming units. To achieve this objective, an integrated model based on optimal control theory was developed to formulate a set of innovative system dynamics that considers quality decline in a stochastic context with random demand fluctuations. The findings of the research revealed significant interactions between the costs and control parameters of both JIT production and maintenance strategies, leading to the conclusion that an integrative model is more cost-efficient than managing them independently. However, the limitation of the study is the assumption that quality deterioration follows a certain known pattern, whereas in practice, the generation of defectives exhibits random behavior. Therefore, in future studies, random generation of defectives will be explored.

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Strategic company sustainability: optimize firm resource management through innovation efficiency

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Keywords: sustainable growth, innovation efficiency, corporate governance, resource management.
Abstract: This study intends to investigate the effect of a company's corporate governance aspects, measured by the size of the board of directors, on sustainable growth and the role of innovation efficiency as a moderating variable. The samples were taken from manufacturing companies listed on the Indonesia Stock Exchange (IDX) for the 2017-2021 period using purposive sampling. There were 44 companies that met the criteria. The technical analysis used is Partial Least Square (PLS-SEM) with WarpPLS 8.0 software, which is reliable for processing small samples. Stochastic frontier analysis (SFA) analysis through Frontier 4.1 is used for the measurement of innovation efficiency. The results of this study show that corporate governance has positive and significant effects on sustainable growth. Furthermore, innovation efficiency is a moderating factor that can strengthen the influence of corporate governance on sustainable growth. The novel of this study provides evidence relating to the importance of management in human resources and management in innovation to increase the company's productivity through innovation efficiency, which has an important role in increasing the company's sustainable growth.

1 Introduction

Nowadays, companies need to have the ability to operate their business activities in a challenging and competitive business atmosphere, so it is important to consider sustainability aspects in a company's strategic planning to maintain long-term survival, growth, and profitability [1,2]. One of the company's goals is to gain maximum profit, so the aspect of how the company can maintain its sustainability to gain profit becomes a crucial concern for the company's management [3]. It becomes important to know the company's sustainability prospects in the future by considering several aspects. Furthermore, the topic of sustainable growth as one of the instruments to predict a company's going concern has become a crucial aspect that management must focus on. Rapid growth in a company can exhaust resources, but a slow-growing company may show that the resources are not utilized effectively [4]. The sustainable growth concept describes that a company's growth can maximally increase if the company's financial performance can be maintained. Sustainable growth reflects the company's asset utilization efficiency and financing strategy, which are all key determinants of company performance [5]. Sustainable growth is a company's financial policy that is in line with the company's growth, and its concept describes how, by maintaining the existing capital structure without the issuance of new legalities, the company can still increase sales [6].

Sustainable growth has become a global issue and has received attention from various researchers around the world, such as [7-13]. Boards of directors are one of the main components of a company's corporate governance, which is an important aspect of a company's sustainability [14]. The board of directors has a vital role related to its duties in managing the company to generate profitability and decide the strategy to maintain the company's continuity [15]. Based on previous research, it can be identified that there are differences in the influence of the board of directors on sustainable growth. If the relationship between the independent and dependent variables was inconsistent, then there may be other factors that can strengthen or weaken this relationship [16].

A study by [17] shows that innovation efficiency is a moderating factor between various market distortions and sustainable growth. Innovation efficiency is defined as the capability to transform innovation inputs into innovation outputs [18]. The main principle of efficiency is the allocation of inputs to produce maximum output so that maximum profit with minimum costs can be achieved and the company's ability to be sustainable can be maintained [19]. This research was conducted on manufacturing company objects in Indonesia on a general scale and is experiencing problems in maintaining their sustainability due to the COVID-19 pandemic, as stated in the previous study [20]. Based on these arguments, this study examines the effects of corporate governance on sustainable growth and the role of innovation efficiency in moderating this relationship. The research questions presented in this study are: How does corporate governance affect sustainable growth? And how does innovation efficiency moderate the relationship between corporate governance and sustainable growth?

2 Literature review

2.1 Theoretical framework

Stakeholder theory describes individuals, groups, or organizations that have the power to affect the achievement of an organization's objectives and/or can be affected by the organization [21]. Stakeholders include investors, creditors, suppliers, consumers, governments, and communities that are influenced by the company. Stakeholder theory describes the relationship between an entity and the environment in which it operates [22] so that the company can operate and become a sustainable company.

Sustainable growth is a concept where companies are able to achieve optimal growth as a sustainable company [23]. Sustainable growth is important and has become a major interest for stakeholders and analysts [24]. The company's sustainable growth capabilities play an important role in supporting sustainable national economic development and long-term business development [25].

2.2 Hypothesis development

2.2.1 Corporate governance and sustainable growth

Corporate governance defines the role of the board of directors as a leader that has a role in setting the organization, protecting a firm by directing its operational activity, and supporting its decision-making [26]. Corporate governance is a control system applied to achieve maximum performance without disserving its stakeholders, and this implementation will determine the company's management practices within the company [27]. In this study, corporate governance was measured from the perspective of the board of directors for its important role in controlling all aspects of management in the company. Boards of directors have an important role in strategy identification, which is needed in the decision-making process. The board of directors typically determines general business management and sustainability strategies that integrate each other to support the company's goals, which in turn guide operational decisions and strategic matters.

In general, corporate governance is the most important aspect of a company's sustainability. A study by [28] shows that the board of directors has an important role in enhancing sustainability performance. The role of the board of directors in the company can determine its long-term sustainability because of its role in setting the company's strategic aspects. A study by [29] shows that board size, as a measurement of corporate governance, has a positive effect on a company's sustainable growth. The higher board of directors can increase the company's sustainable growth. Based on these arguments, hypothesis 1 (H1) is formulated as below:

H1. *Corporate governance positively influences sustainable growth.*

2.2.2 The moderating effect of innovation efficiency in the relationship between corporate governance and sustainable growth

A company's sustainable growth is affected by financial indicators, employees, equity structures, and other company governance factors that must be considered when pursuing sustainable growth [30]. The board of directors, one of the corporate governance factors, plays a central role in internal mechanisms to set strategic aspects of a company and monitor its corporate management effectively [31]. Companies must be able to optimize the function of corporate governance mechanisms to increase their sustainable growth by optimizing the use of efficiency in their operations, especially innovation efficiency. The essence of efficiency is the allocation of inputs to produce maximum output so that maximum profit with minimum costs can be achieved and improve the company's ability to be sustainable. Optimal innovation efficiency can increase the company's ability to maintain sustainable growth. Based on these arguments, hypothesis 2 (H2) is formulated as below:

H2. *Innovation efficiency strengthens corporate governance's influence on sustainable growth.*

2.3 Research model

The model for this research can be described in the equation below (1):

$$SG = \rho_1 \text{ DIRECTOR} + \rho_2 \text{ IE*DIRECTOR} \quad (1)$$

Explanation:
SG = Sustainable Growth,
DIRECTOR = Board of Directors,
IE = Innovation Efficiency.

3 Methodology

This research is a causal study to examine factors that are causing a problem and test the effect of corporate governance on sustainable growth and the influence of innovation efficiency as a moderating factor in the relationship between these variables. The analytical technique used in this research was Partial Least Squares (PLS-SEM) using WarpPLS 8.0 software. The sample of this study included 44 samples collected from manufacturing companies listed on the Indonesian Stock Exchange for the 2017-2021 period. The data in this study was secondary data collected from financial statements that were published on www.idx.com and categorized as quantitative data. The sampling selection used in this study was purposive sampling, as below (Table 1):

Table 1 Sampling selection

Number.	Purposive Sampling	Total
1.	Manufacturing companies listed on the Indonesian Stock Exchange during the 2017–2021 period	154
2.	Companies that do not provide the indicator data required in this study during the 2017–2021 period	(110)
Number of samples that meet the criteria		44
Year of observation		5
Total sample in this study during the year of observation		220

The measurement and operational aspects of variables in this study can be explained as follows:

3.1 Sustainable growth

The sustainable growth rate is measured as below (2), (3), (4) [2]:

$$SG = ROE \times \text{Retention Ratio} \quad (2)$$

$$ROE = \frac{Net\ Income}{Total\ Equity} \quad (3)$$

$$\text{Retention Ratio} = \frac{Retained\ Earnings}{Net\ Income} \quad (4)$$

3.2 Corporate governance

The board of directors typically determines general business management and sustainability strategies that integrate each other to support the company's goals, which in turn guide operational decisions and strategic matters. The board of directors is measured as below (5):

$$Board\ of\ Directors = \sum Number\ of\ members\ of\ the\ board\ of\ directors \quad (5)$$

3.3 Innovation efficiency

The moderating variable in this study is innovation efficiency (IE). Innovation efficiency measurement uses the stochastic frontier analysis (SFA) method to measure the input-output combination, which is the gross operating revenue of enterprises as the output, then the number of employees and R&D expenditure as the input. Stochastic Frontier Analysis (SFA) is a parametric approach to measuring efficiency that considers stochastic noise in the data. SFA output produces an efficiency score in the range of 0 to 1. The higher the score, the higher the company's efficiency based on the input-output formulation processed.

4 Result and discussion

4.1 Descriptive data explanation

Based on the descriptive statistics in Table 2, it can be seen that the standard deviation score for the board of directors was 1.95, which was smaller than the average score of 6, which indicates that the board of directors data in this research is relatively less varied. The innovation efficiency has a standard deviation score of 0.41, which is smaller than the average score of 0.69, which indicates that the innovation efficiency data in this research is relatively less varied. The sustainable growth standard deviation of 0.32 was smaller than the average score of 0.54, which indicates that the sustainable growth data in this research is relatively less varied. The data description in this study shows less varied data for variables, which can be explained by the fact that this object only includes manufacturing companies in Indonesia that have fairly similar characteristics.

Table 2 Descriptive statistics

Variables	Max.	Min.	Mean	Standard deviation
Board of directors	10	3	6	1.95
Innovation Efficiency	1	0.04	0.69	0.41
Sustainable Growth	1.33	0.01	0.54	0.32

4.2 Model fit

The first stage is to analyze whether this research model complies with the criteria of goodness of fit. Based on the model of fit indicators output that is summarized in Table 3, it can be seen that the six indicators used in this study are satisfying, and it can be concluded that this model is fit based on the significant P value at the 0.05 level on the three indicators APC, ARS, and AARS. This model also has no collinearity issues based on the path coefficients of the two indicators, AVIF and AFVIF. Another indicator is the criteria for GoF value = 0.520, which means that the predictive powers of the model are categorized as large because the value is higher than 0.36.

Table 3 Model fit

Model fit	Value	Sign.	Rule of thumb	Notes
Average Path Coefficient	0.434	P < 0.001	P < 0.05	Satisfy
Average R-Square	0.270	P < 0.001	P < 0.05	Satisfy
Average Adjusted R-Squared	0.246	P < 0.001	P < 0.05	Satisfy
Average Variance Inflation Factor	3.944		≤5, ideally ≤ 3.3	Satisfy
Average Full Collinearity VIF	2.120		≤5, ideally ≤ 3.3	Satisfy
Tenenhaus GoF	0.520		*Small* ≥ 0.1 *Medium*≥ 0.25 *Large* ≥ 0.36	Large

4.3 Explanatory power

The next stage is to evaluate the model's explanatory power. Based on the latent variable coefficients that are summarized in Table 4, the coefficient of R-Squared determination is 0.270, which shows that 27% of the variation of the endogenous variable (sustainable growth) can be explained by the exogenous variables corporate governance (board of directors) and moderating innovation efficiency, while the remaining 73% can be explained by other variables outside this model. Another explanatory power indicator is the value of Q-Squared, which has a value of 0.250; this value is larger than 0. This shows that this model has predictive relevance. Another indicator of explanatory power is the effect size. The effect size value of the board of directors at 0.375, or 37.5%, means that the absolute value of the individual contributions of the board of directors to the R-Squared value of the sustainable growth variable is considered medium from a practical point of view. The effect size value of IE*DIRECTOR at 0.075, or 7.5%, means that the absolute value of the individual contributions of innovation efficiency moderation to the R-Squared value of the sustainable growth variable is considered weak from a practical point of view.

Table 4 Explanatory power

R-Squared = 0.270			
Q-Squared = 0.250			
Effect size			
Variables	Path coefficients	Explanation	Rule of thumb
DIRECTOR	0.345	Medium	> 0.02 weak > 0.15 medium > 0.35 large
IE*DIRECTOR	0.075	Weak	

4.4 Path coefficients and P-values

The next stage is to evaluate the path coefficients and P-value values from the output summarized in Table 5. The path coefficient of the corporate governance variable (DIRECTOR) is 0.676 and significant with P < 0.001, and the path coefficient of the moderating variable, which is the interaction of innovation efficiency with corporate governance (IE*DIRECTOR), is 0.192 and significant with P = 0.017.

Table 5 Path coefficients and p-values

Variables	Path coefficients	P-value	Rule of thumb	Notes
DIRECTOR	0.676	<0.001	P < 0.05	Accepted
IE*DIRECTOR	0.192	0.017	P < 0.05	Accepted

5 Conclusions

5.1 Conclusion

Based on the path diagram, the board of directors has a positive and significant effect on sustainable growth. It can be seen from the path coefficient of the board of directors variable, which is 0.68 positive with P < 0.001, that hypothesis 1 (H1) is accepted. The board of directors positively affects sustainable growth. This significant effect can be explained by the fact that the board of directors has a crucial role in enhancing sustainability. The important role of the board of directors in the company's strategy can determine the long-term sustainability of the company. The innovation efficiency will determine the sustainability of the company, as can be seen in Figure 1, where the interaction of innovation efficiency with the board of directors (IE*DIRECTOR) score is 0.19 and significant with P = 0.017 < 0.05. Thus, hypothesis 2 (H2) is accepted. Innovation efficiency strengthens the positive effect of corporate governance proxied by the board of directors on sustainable growth.

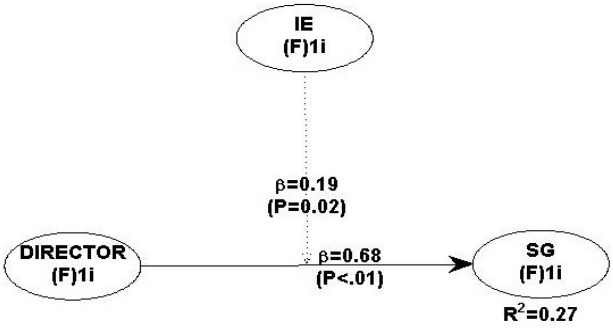

Figure 1 Path diagram

Efficiency in the company is needed to ensure the implementation of strategic plans [32]. Furthermore, the company should include the aspect of innovation at all decision-making levels. It can be highlighted that optimal innovation efficiency can improve the company's ability to maintain sustainable growth. The input and output formulation in this study assesses the efficiency of human resources, which is covered by the number of employees and the company's allocation to research and development. When these factors are efficiently managed, which contributes to the company's revenue, the company maintains its sustainability. The more efficient a company's management of its resources, including its number of employees and research and development allocation, the greater its ability to maintain its sustainability. This aspect can be part of the management of the flow of the company's business activities.

This study demonstrates the importance of the role of the board of directors and innovation efficiency in terms of sustainable growth and implies theories and practices. From the point of view of theory implication, this research contributes to a stakeholder theory study that focuses on

how the company continues to maintain its business activities. In practice, company management should optimize the role of the board of directors in their function of business strategy. Companies should also maintain awareness about the importance of innovation efficiency in their business operations to increase their sustainability. Innovations that can be implemented include improvements in the manufacturing process. The company should also produce more varied products. The board of directors, which has an important role in strategic planning, determines the company's sustainability. It is important to consider the efficiency of human resource management and aspects of research and development to support the company in achieving optimal revenue. This study indicates that if the board size is larger, it can increase the company's ability to maintain sustainability. The role of innovation efficiency strengthens this relationship. This means that the larger the board, supported by innovation efficiency, the greater the company's ability to maintain its sustainability.

The limitation of this study is that the year of observation only consisted of 5 years from the 2017-2021 period, so further research can expand the number of years of observations. This research topic is particularly interesting and opens a direction for future research with regard to the ongoing debate of sustainable growth. The efficiency approach in this study only uses SFA; future research can consider the use of data envelopment analysis (DEA) and explore the input-output formulation based on firm characteristics in various industries.

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Physical internet - where are we at? A systematic literature review

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Keywords: physical internet, sustainability, Industry 4.0, collaboration models.
Abstract: The Physical Internet (PI) concept represents a paradigm shift in how logistics and supply chain management can be conceptualised and implemented. Through a meticulous literature review, this study maps the current state of PI research, spotlighting the necessity for a deeper dive into unexplored areas. The analysis reveals significant opportunities for enhancing logistic efficiency and sustainability, providing a foundation for future research and practical applications. This work invites scholars and industry practitioners to explore the transformative potential of PI. In the face of the dynamically evolving discussion on the Physical Internet, this article offers an in-depth analysis of the literature on this concept, shedding light on current research trends in this new face of logistics, challenges, and unexplored areas. The focus is on optimization models, collaboration, and system architecture, identifying knowledge gaps in areas of human impact on the management of the future logistics system and flows, legal aspects, financial management, economic feasibility, social and environmental effects, readiness for cooperation, security, and cultural differences. The literature review emphasizes the importance of PI for sustainable development and the goals of Industry 4.0, pointing to its potential role in transforming global logistic processes. By examining challenges, proposing solutions, and highlighting the potential of PI principles in improving logistic processes, this work constitutes a valuable resource for researchers, practitioners, and policymakers aiming to understand and implement the concept of the Physical Internet.

1 Introduction

The term Physical Internet (PI) refers to a concept that aims to apply principles of information flow and coordination from the digital world to the physical movement of goods. It involves interconnected logistics networks, collaborative shipping, and the use of smart technologies to improve efficiency in freight transportation. The concept of the Physical Internet remains relatively unknown to many, yet the need for resource conservation and addressing the impact of human activities on climate change necessitates solutions that maximize the utilization of existing resources, promote resource sharing, and minimize the need for new infrastructure and fleet development that further exploit resources. In logistics, the Physical Internet serves as a viable approach to achieve these objectives.

Since the inception of this concept, numerous research efforts have emerged, and as this field develops and collaboration among stakeholders in the transport and logistics industry strengthens, new unexplored possibilities arise. Therefore, the aim of this article is to investigate the trends in the literature and identify research gaps. These gaps are crucial because entities already operating within networks that can be classified as the Physical Internet encounter practical challenges that have not been thoroughly explored by theorists. Defining and understanding these challenges can facilitate the identification of potential solutions.

Physical Internet emphasizes logistics and supply chain optimization, therefore the Author identified articles that contribute to understanding the flow of information and goods within the PI. The Physical Internet offers a holistic approach in managing all element of logistics – not only goods and information flows and management, but also financial flow optimization.

From the analysis of the presentations on the latest 9th Physical Internet conference in Athens, it becomes evident that the mindset remains a barrier to the advancement of the Physical Internet. However, research often neglects this topic, partly due to the intangible nature of mindset, which makes it challenging to measure. Unfortunately, if something cannot be measured, it cannot be improved. Nonetheless, openness to sharing is a key factor in the development of the Physical Internet since sharing and collaboration are the foundational principles of this concept, while logistics serves as the invisible backdrop of our daily lives. If societies are not prepared for degrowth concepts, which would enable resource conservation and sustainable utilization, the answer lies within the Physical Internet.

2 Methodology

The literature review methodology followed a systematic approach to identify relevant articles on the topic of the "physical internet." The search was conducted in the Scopus database using a specific search query. The search string employed was: TITLE-ABS-KEY ("physical internet") AND (LIMIT-TO (OA, "all")) AND (LIMIT-TO (EXACTKEYWORD, "Physical Internet")). This query aimed to retrieve articles that had the exact keyword match for "physical internet" and were also available as open access publications.

Upon retrieving the articles, a comprehensive evaluation was undertaken. All selected articles underwent

a thorough reading to assess their relevance and quality. A total of 74 articles were deemed suitable for further analysis.

To gain insights into the thematic structure and research trends within the selected articles, a clustering technique was employed. The articles were categorized into thematic clusters based on their content, allowing for a systematic exploration of the topics and identification of research gaps within the field of the physical internet.

In addition to thematic analysis, an investigation of author affiliations was conducted to provide an understanding of the geographical distribution of contributors in this research domain. A map was created to visually represent the countries from which the authors' affiliations originated, shedding light on the global engagement in physical internet research.

To further delve into the interconnections between topics and keywords within the selected articles, the VosViewer tool was utilized. By employing network analysis techniques, the relationships and associations between different themes and keywords were explored, allowing for a comprehensive understanding of the conceptual landscape and knowledge interdependencies in the field of the physical internet.

Furthermore, to identify the key concepts and emphasize the recurring themes across the selected articles, a word cloud representation was generated. This visualization technique showcased the frequency and prominence of different keywords extracted from the articles, providing a concise summary of the main focus areas in the literature.

By employing this rigorous methodology encompassing search query construction, article selection, thematic analysis, author affiliation mapping, network analysis, and word cloud visualization, a comprehensive and scholarly examination of the literature on the physical internet was conducted, enabling a systematic understanding of the existing knowledge landscape, research trends, and research gaps in this domain.

3 Analysis and results

Since the inception of the Physical Internet concept, several papers have been published, with limited progress. However, during the pandemic period, a significant surge in research activity within this field has been observed. This phenomenon can be attributed to the heightened awareness that reliance on long and complex supply chains may not be sustainable, particularly in the face of disruptions. Additionally, the recognition of the detrimental consequences of independence and lack of collaboration has further underscored the need for reevaluation. Figure 1 shows the number of papers over the years.

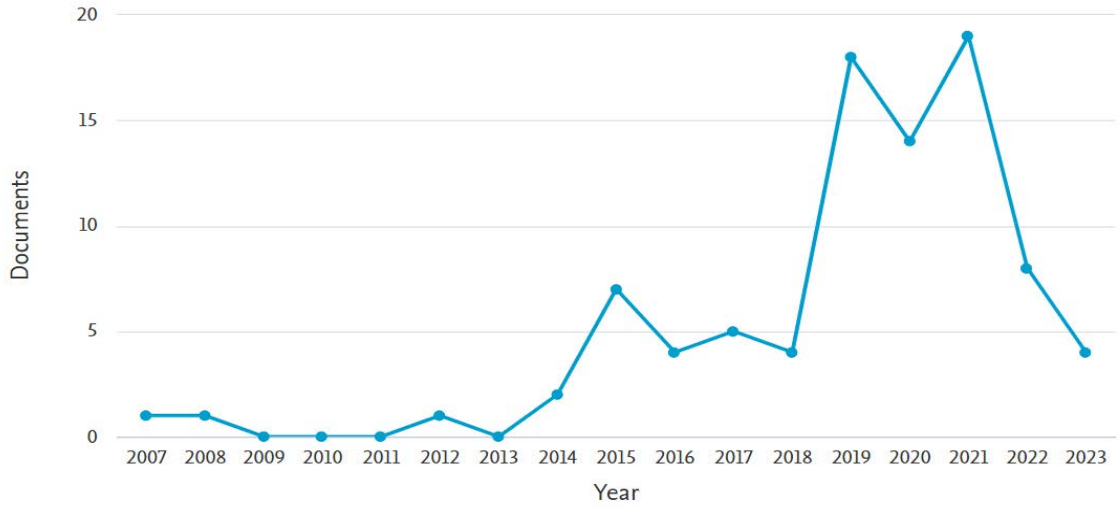

Figure 1 Documents by year
Source: Scopus database

Physical Internet is not limited to a few specific countries but involves a diverse international community, reflecting global interest and collaborative efforts in advancing the understanding and application of the Physical Internet concept (Figure 2).

Based on the number of authors and their affiliating countries in the field of Physical Internet, several conclusions it can be noticed that France has the highest number of authors with affiliations in the field of Physical Internet, indicating a strong presence and contribution from the French academic and research community. The United States follows closely behind France, suggesting significant engagement and research output from American scholars in the area of Physical Internet. The United Kingdom, China, and Canada also demonstrate a notable presence, with a considerable number of authors contributing to the literature on the Physical Internet. Germany, Belgium, Hungary, Morocco, and the

Netherlands exhibit moderate involvement, indicating active participation in research related to the Physical Internet. Other countries, including Austria, Hong Kong, Poland, Portugal, South Korea, and Vietnam, contribute with a smaller number of authors but still have a noteworthy presence in the field.

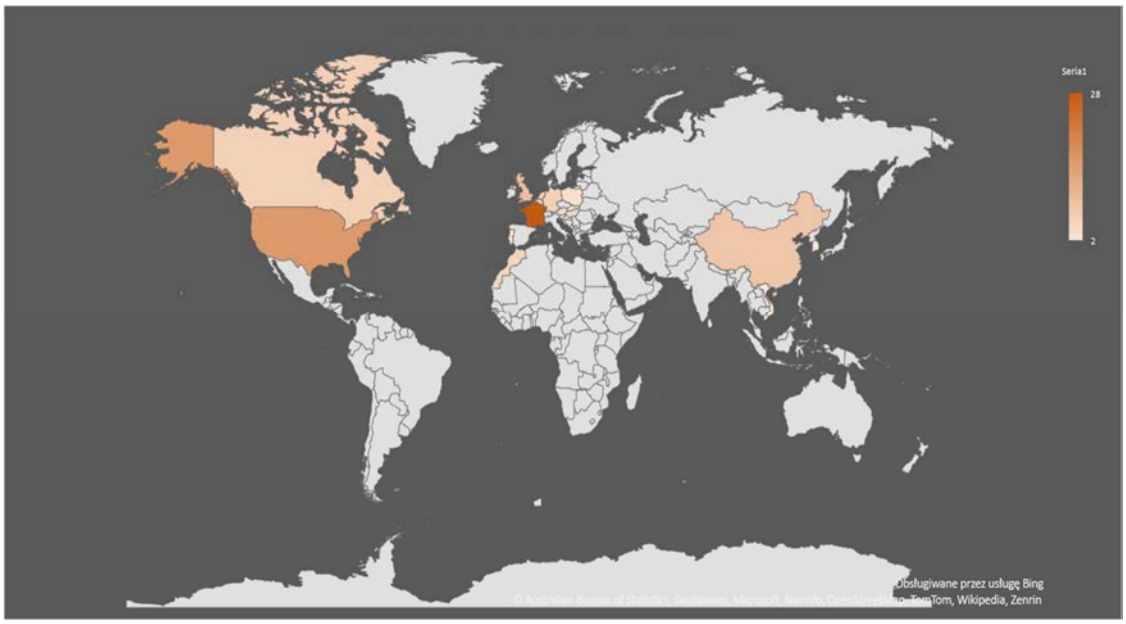

Figure 2 Countries of authors' affiliating institutions
Source: Own elaboration

As for possible reasons possible reasons for France having a high number of authors in the field of Physical Internet it can be indicated that France possesses a robust academic and research system, including renowned scientific institutions and universities, including Physical Internet Chair in MINES ParisTech, PSL Research University. Another possible reason are numerous research projects, contributing to the increase in the number of authors in the field of Physical Internet. All this makes France having a high level of awareness and interest in the topic of Physical Internet among its scientists and researchers. Research institutions and universities in the country may actively promote and support studies related to this area.

This interdisciplinary approach is crucial for developing comprehensive solutions and understanding the broader implications of implementing the Physical Internet concept. Figure 3 shows the subjects areas of analyzed papers.

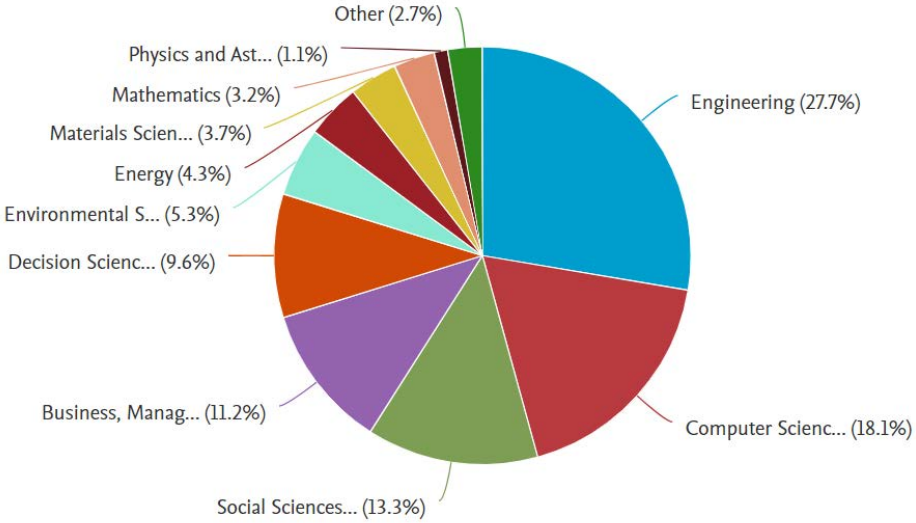

Figure 3 Documents by subject area
Source: Scopus database

Based on the distribution of documents by subject area in the field of Physical Internet, several conclusions can be drawn.

Engineering has the highest representation among the subject areas, accounting for 27.7% of the documents. This suggests that a significant portion of research in the field of Physical Internet focuses on engineering aspects, such as infrastructure design, transportation systems, and logistics optimization. Computer sciences follow closely behind, comprising 18.1% of the documents. This highlights the importance of computational methods, data analysis, and information systems in advancing the understanding and implementation of the Physical Internet concept. Social sciences have a significant presence, representing 13.3% of the documents. This indicates the recognition of the societal impact and implications of the Physical Internet, including its influence on supply chain management, collaboration, and sustainable development. Business and management contribute to 11.2% of the documents, showcasing the recognition of the economic and managerial aspects of implementing the Physical Internet in organizations and supply chains. Decision sciences and environmental sciences have moderate representation, with 9.6% and 5.3% of the documents, respectively. This highlights the focus on decision-making frameworks and the consideration of environmental sustainability in the context of the Physical Internet. Energy, materials sciences, mathematics, and physics have relatively lower representation, ranging from 4.3% to 1.1%. These findings indicate the multidisciplinary nature of research on the Physical Internet, with contributions from engineering, computer sciences, social sciences, and various other fields.

When analyzing the keywords of the reviewed papers (Figure 4) we can observe the most frequently mentioned issues. The keywords mention various mechanisms such as auction-based mechanisms, hybrid modeling, and peer-to-peer mechanisms. These mechanisms are likely related to economic models, logistics systems, and decision-making processes. Also, keywords often mention multi-objective optimization, sensitivity analysis, and Pareto principle. These concepts are often used in the context of finding the best solutions or trade-offs in complex systems, such as freight transportation, supply chain management, and logistics networks. Urban planning and transportation are keywords that indicate research on urban planning, urban transportation, and logistics in urban areas. This suggests a focus on understanding and optimizing the movement of goods and services within cities, taking into account factors such as sustainability, efficiency, and decision-making processes. There are also keywords related to maritime ports, port selection, and port performance evaluation. These keywords indicate a focus on optimizing port operations, analyzing port-related factors, and improving efficiency in maritime logistics. Ports and other terminals, serve as critical nodes in the PI, facilitating the flow of goods, information, and financial resources and PI promises enhancing port efficiency and integration. Some keywords mention blockchain technology, smart contracts, and supply chain management. This suggests an interest in exploring the potential applications of blockchain for improving transparency, traceability, and security in supply chain operations. We can also observe the “digital twin” phrase, which refers to a digital representation or simulation of a physical object, system, or process. This concept involves creating a virtual model that mirrors real-world entities, enabling simulation, analysis, and control. The keywords mention digital twins in the context of supply chain management, logistics systems, and real-time evaluation. There are also keywords related to sustainability, sustainable development, carbon footprint, and energy efficiency. These keywords indicate a focus on incorporating environmental considerations and reducing the impact of logistics and transportation activities. Finally, the keywords mention various decision-making approaches, such as multi-criteria decision analysis, Markov decision processes, and heuristic algorithms. These techniques are often used to support decision-making processes and optimize complex systems.

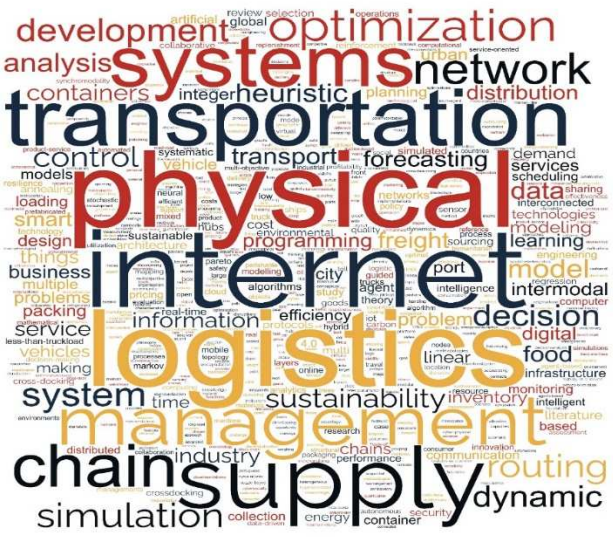

Figure 4 Keywords used in analyzed papers
Source: Own work using Wordclouds.com

Figure 5 and Figure 6 show how authors most commonly combine selected topics.

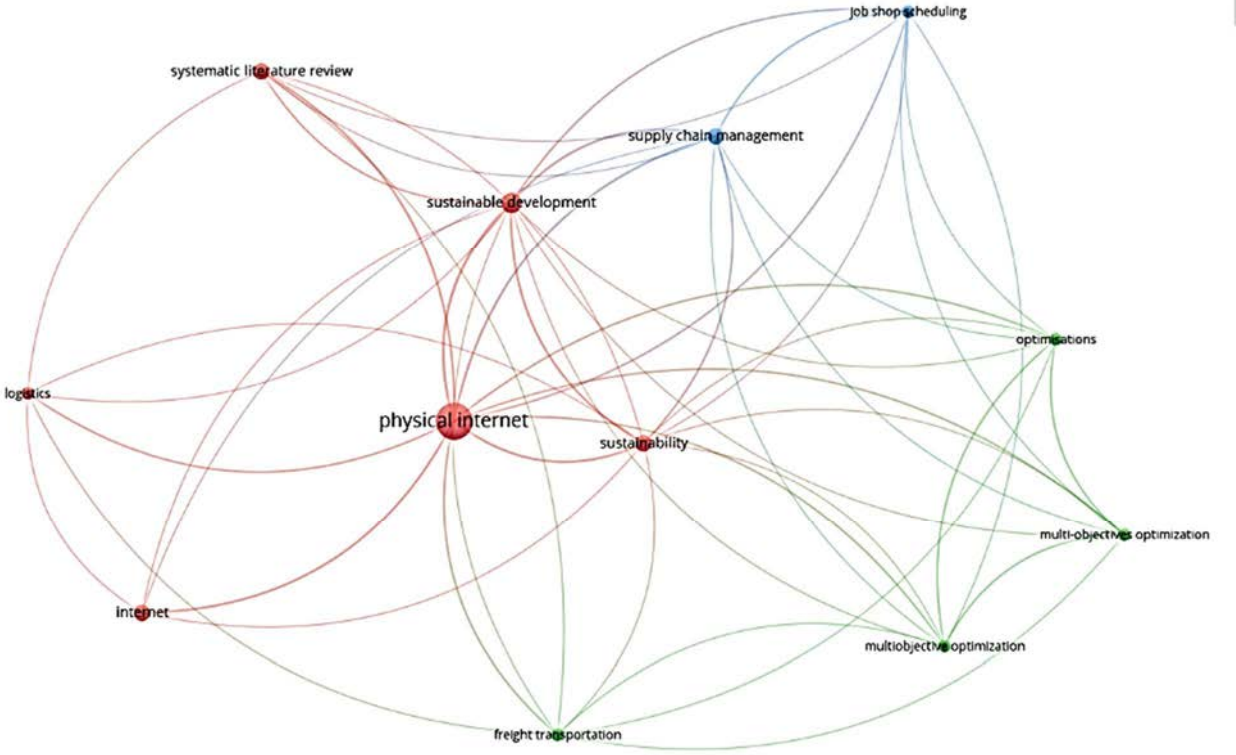

Figure 5 Phrases most often connected in the reviewed literature

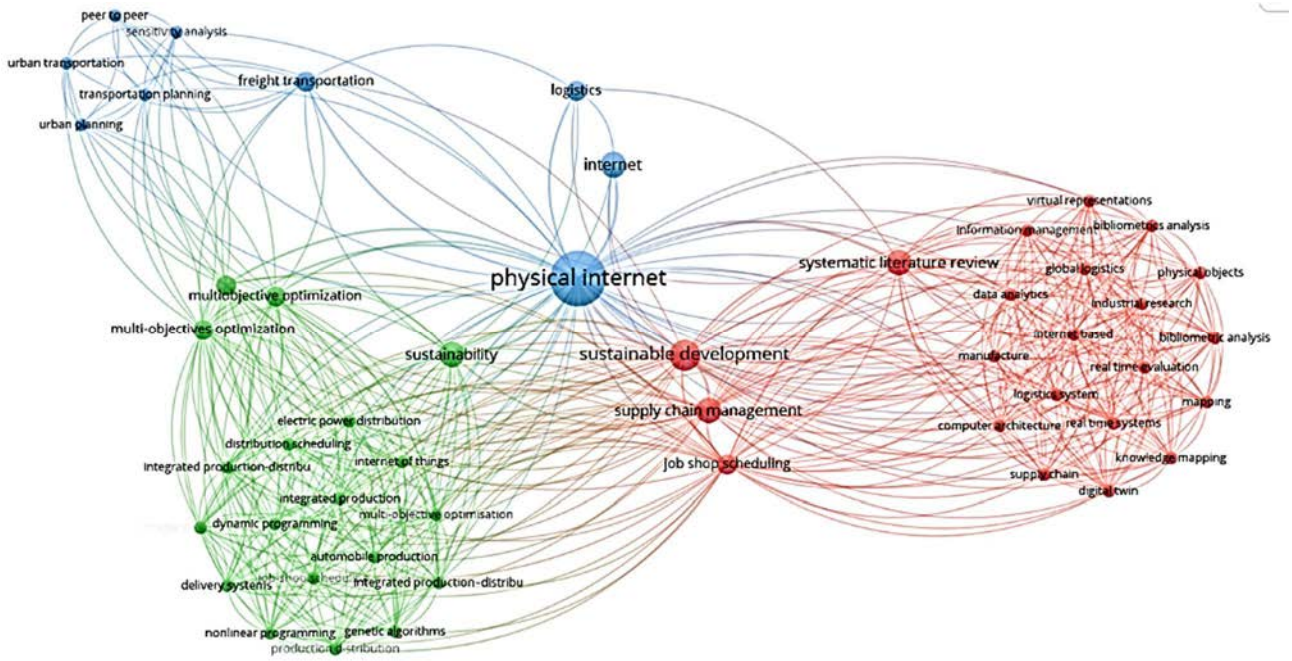

Figure 6. Clusters of phrases most often connected in the reviewed literature

Figure 7 - Figure 10 depict individual clusters of concepts and their associated connotations in the examined articles.

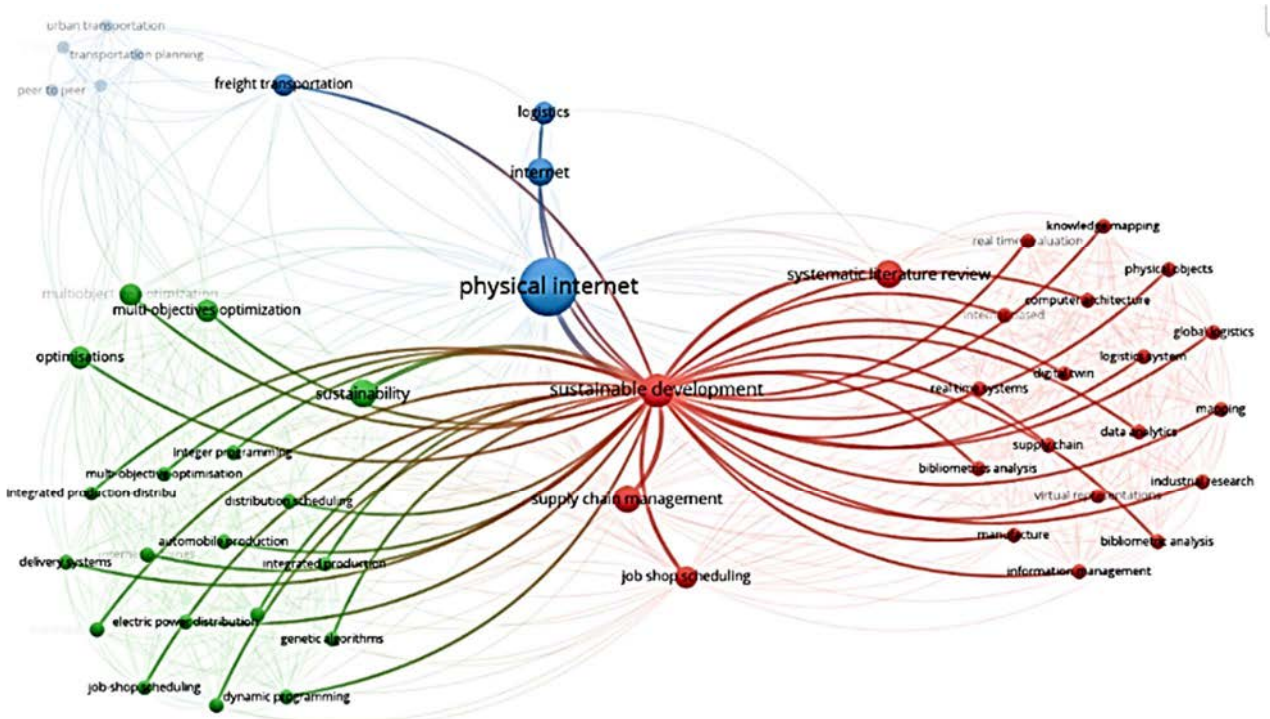

Figure 7 The cluster of phrases most often connected with the phrase 'sustainable development' reviewed literature

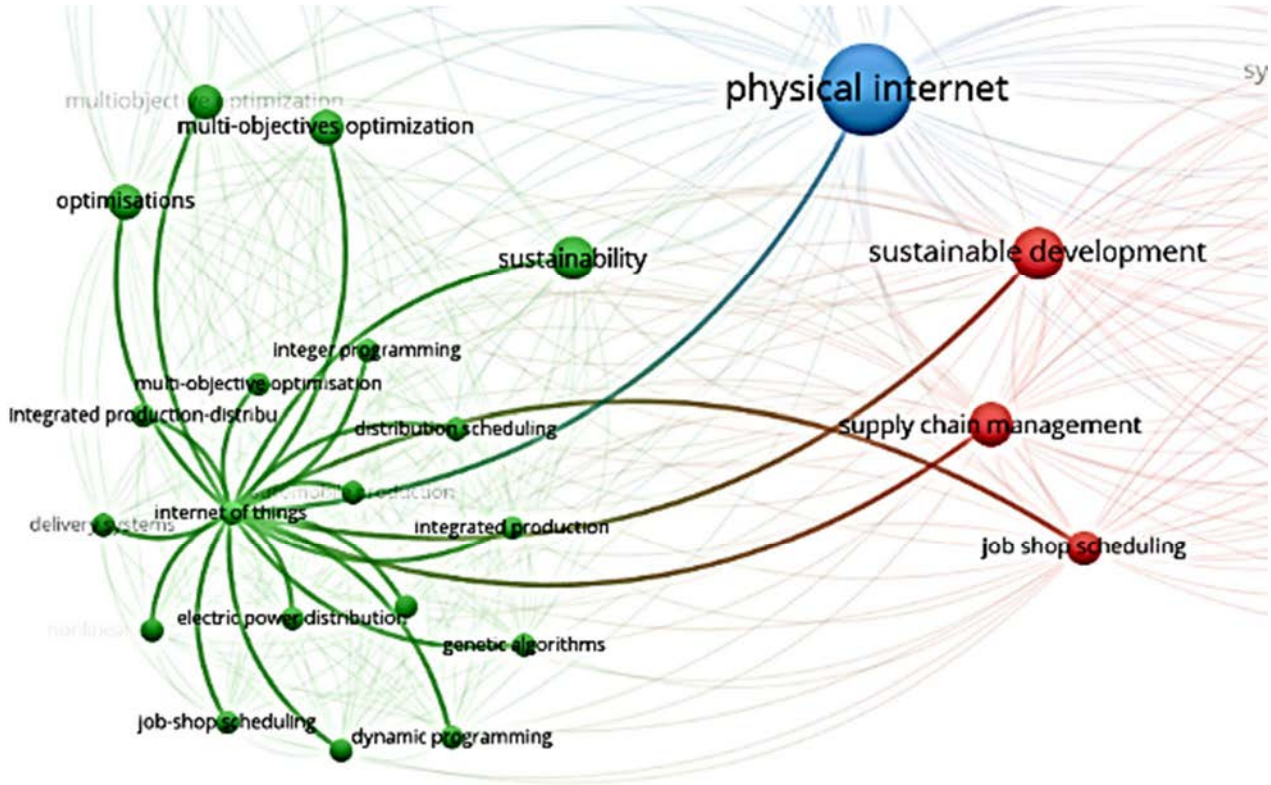

Figure 8 The clusters of phrases connected with the phrase 'internet of things' in the reviewed literature

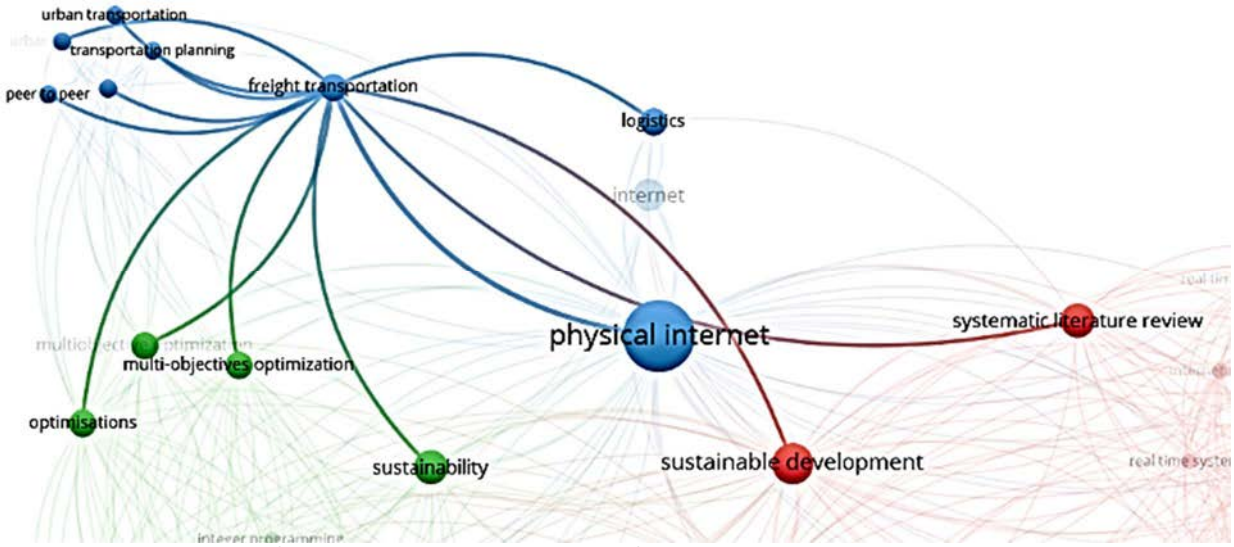

Figure 9 Clusters of phrases connected with the phrase 'freight transportation' in the reviewed literature

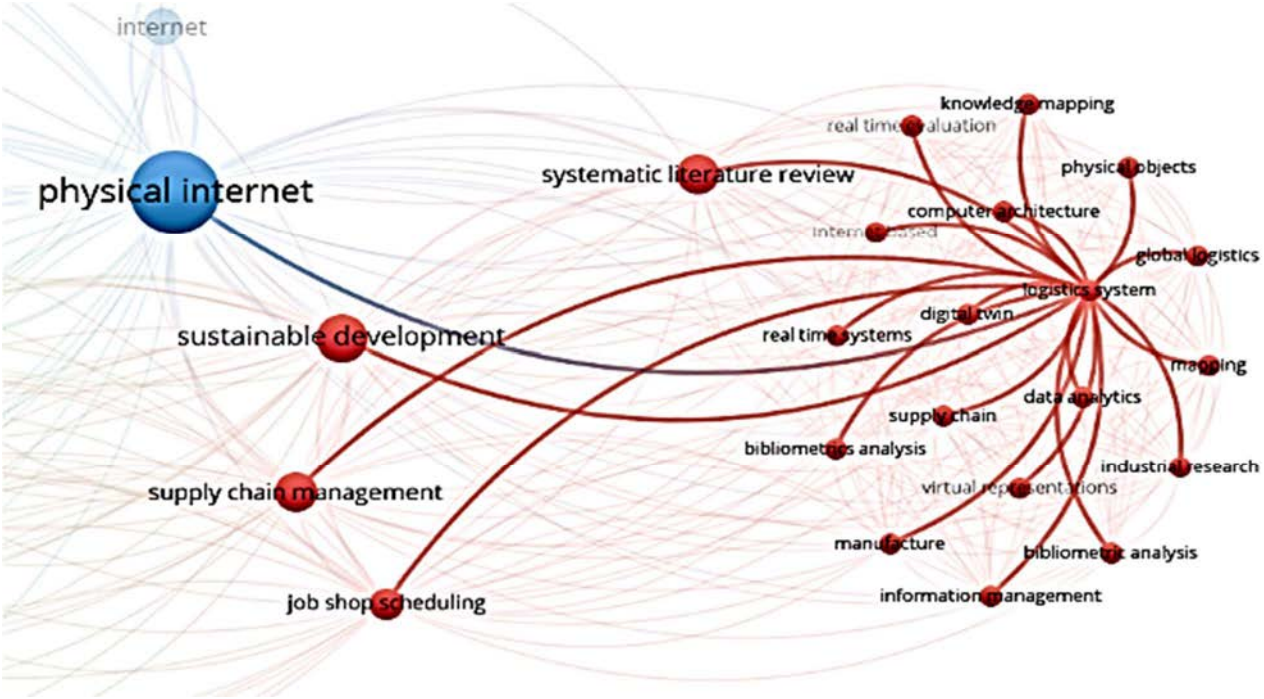

Figure 10 Clusters of phrases connected with the phrase 'logistics system' in the reviewed literature

Table 1 (in general) and Table 2 (in detail) describe the trends, thematic groups, and specific topics addressed by the authors of the analyzed texts.

Table 1 Areas discussed in the reviewed papers

The most frequently discussed aspects of the Physical Internet	**Examples**
Efficiency and sustainability: The Physical Internet is seen as a solution to improve the economic, environmental, and social efficiency of global logistics systems.	• Global logistics sustainability and efficiency • Conceptual framework and network models for PI • Application and verification of PI principles in economic practice
Logistics transformation: The Physical Internet aims to redefine supply chain configurations, business models, and value-creation patterns by introducing an open global logistics system.	• Open logistics interconnection reference model for PI

Industry 4.0: The Physical Internet is considered a practical solution to support the requirements of Industry 4.0, which involves addressing the challenges of incorporating new technologies, information systems, and physical facilities.	• Logistics Web and Industry 4.0 • Digital transformation and its implications for PI • Blockchain and smart contracts in hyperconnected logistics • Lean thinking and value stream mapping for the transition to PI
Interoperability and modularity: The concept of the Physical Internet emphasizes the need for interoperability between different logistics systems and the modular design of logistics services.	• Design and characteristics of PI containers
Smart product-service systems: The integration of smart product-service systems within the Physical Internet is explored as a way to tackle complex logistics systems and improve efficiency.	• Smart product-service systems in interoperable logistics • Order bundling and transparent user networks
Collaboration and networking: The Physical Internet envisions collaborative networks and information exchange among logistics stakeholders as a means to achieve sustainable logistics practices.	• Motives and success factors for collaboration in PI networks

Table 2 The examined articles are sorted by thematic groups

Subject area	**Literature summary**
Physical Internet Concept and Framework these summaries demonstrate the focus on developing an efficient and sustainable logistics web, incorporating modular units, real-time planning, information exchange, communication infrastructure, and IoT-enabled services. The Physical Internet aims to address the challenges of the evolving manufacturing industry and urban logistics while requiring further research and innovation for its successful implementation	Physical Internet aims to enable an efficient and sustainable Logistics Web - Logistics Response to the Industry 4.0 [1]. The evolving manufacturing industry necessitates the development of suitable information systems, physical infrastructure, and technologies to meet future economic needs, with the Physical Internet being a proposed solution that requires further in-depth research [2]. The NOLI model is compared and contrasted with the OSI and TCP/IP models of the Internet, and it is also integrated with Montreuil's OLI model for the Physical Internet. Contrasts between the NOLI model presented here and the aforementioned models primarily manifest in the way physical object definitions are structured across various layers, extending beyond the lowest layer [3]. The idea of implementing Physical Internet principles in logistics operations underscores the significance of modular transport components, dynamic planning, data sharing, and communication infrastructure. It also encourages future exploration into comprehensive solutions for all facets of the Physical Internet [4]. Exploring the connections and collaborative dynamics between these elements leads to the concept of Hyperconnected City Logistics systems, encompassing nine core principles that provide a robust framework for creating effective and eco-friendly urban logistics and transportation systems. The chapter closes with a set of research and innovation hurdles to address [5]. Information framework and service-oriented architecture for the Internet of Things (IoT) applied in logistics operations, highlighting the potential benefits of IoT-enabled logistics services in the Physical Internet [6].
Logistics and Supply Chain Optimization (include optimization models for carrier revenue, inventory management, container flows, lean paradigms, introducing additional service points, collaboration within Physical Internet networks, supply chain modeling, data clustering, vehicle technology innovations, last mile delivery, cross-docking, synchromodality, dynamic pricing for carriers, and the integration of the Physical Internet with Industry 4.0 practices.	A model for optimizing carrier revenue within the context of the Physical Internet is created by integrating Dynamic Programming and Integer Programming techniques. In this model, carriers submit bids for incoming Less-Than-Truckload (LTL) requests of varying volumes and destinations, with the aim of maximizing their profits [7]. Inventory management in the Physical Internet, where interconnected hubs enable multiple source selection options and transshipments, leading to cost reduction and improved customer service levels compared to current centralized inventory control policies [8]. The correlation between Lean principles and the Physical Internet is examined, with a particular focus on the role of value stream mapping as a tool to facilitate the attainment of goals outlined in Alliance for Logistics Innovation through Collaboration roadmap for logistics innovation. Additionally, it aids in aligning the Physical Internet principles with the predefined timelines [9]. The study investigates the consequences of integrating extra service points into pre-established dedicated freight routes in a service-oriented company, as part of the broader Physical Internet vision. This vision seeks to reshape conventional logistics networks into transparent open systems that can be accessed by a diverse range of users [10]. The study delves into the motivations behind and key drivers for collaboration within a Physical Internet (PI) network. It employs an interpretive case-based research methodology involving shippers and logistics service providers. This research offers valuable insights into why organizations become part of a PI network and the essential prerequisites for ongoing cooperation. Notably, this represents a pioneering study in a multi-industry setting [11]. Existing supply chain models review and proposal of enhanced approach for modeling the digital supply chain [12]. The introduction of a refined metaheuristic algorithm, named ISCA, focuses on data clustering to augment PI-SCN decisions. This algorithm is designed to offer decision-making support for

	business owners. Its robustness is verified through comparisons with five other metaheuristics, using established benchmark datasets [13]. In a PI-SCN within case study in Morocco, utilizing a hybrid method that combines artificial neural networks with an enhanced slime mould algorithm metaheuristic has been examined for its effectiveness in reducing costs and shortening lead times. [14]. Hubs and online design in dynamic hubs at the tactical [15]. The potential of a collaborative and interconnected logistics system, inspired by the Physical Internet concept, to improve last mile delivery and vehicle dispatching, with a focus on reducing empty vehicle movements and carbon dioxide emissions for a more sustainable green freight transport [16]. Flexible model to consider the different needs of the companies [17]. Synchromodality, a flexible and dynamic approach to transportation, utilizes multiple modes of transport to promote environmentally friendly options like rail and inland waterways, while maintaining responsiveness and service quality, with a proposed decision rule that integrates parallel usage and real-time switching of transport modes to induce a modal shift towards low carbon options [18]. The rise of e-commerce and the Physical Internet has transformed the role of showcasing in the supply chain, allowing for fast and reliable delivery of goods from connected sources, leading to the need for a decision support system to optimize showcasing value, as demonstrated through a model focusing on recreational vehicle dealerships [19]. An evolving pricing challenge for less-than-truckload carriers arises across multiple auction cycles in the context of the Physical Internet. This challenge takes into account the forecasting of peak demand. The Physical Internet is characterized by the interconnection of logistics networks through accessible PI-hubs, featuring a multitude of transportation requests. Carriers engage in a series of auction rounds to bid for these requests [20]. Exploring the interaction between resilience and sustainability within Physical Internet (PI)-enabled supply chains, this study suggests a novel hybrid approach. This approach melds a method for scoring performance based on resilience and sustainability with mixed-possibilistic programming. It aims to optimize cost, sustainability, and resilience levels. The results demonstrate the superior sustainability and resilience performance of PI-enabled supply chains when coping with disruptions, as compared to traditional supply chains [21].
Technology and Digital Transformation in the Physical Internet (these papers shed light on the role of emerging technologies and digital transformations in optimizing logistics operations, improving visibility, enhancing collaboration, and achieving efficiency and sustainability within the Physical Internet framework.). Technology such as blockchain, IoT devices and smart contracts are crucial to ensure transparency, security, and efficiency within the PI logistics networks, to manage information and financial flows.	The integration of blockchain, IoT devices, and smart contracts provides heightened transparency and safeguards against fraud in the olive oil supply chain, granting a distinct competitive advantage. The widespread adoption of blockchain technology in all food supply chains with quality verification enhances visibility and delivers a competitive edge to industry participants [22]. The potential for reconfiguring platoons within the Physical Internet system through the establishment of a virtual transfer point [23]. Embracing Digital Transformation (DT) within the context of the Physical Internet (PI) fosters increased connectivity and compatibility through intermodal hubs, collaborative protocols, and standardized containers. This presents both challenges and opportunities for future research in the pursuit of an efficient and sustainable global logistics system [24]. The potential of smart Product-Service Systems (PSS) in service-oriented, intelligent interoperable logistics, highlighting their promising potential in the Physical Internet (PI) and suggesting the need for further research to advance the field and usher in a new era of intelligent interoperable logistics [25]. Demonstrating a concrete implementation, this explores how blockchain and smart contracts hold promise for integration into hyperconnected logistics [26]. Proposing a conceptual framework for examining the Physical Internet (PI) with inspiration drawn from the well-established Digital Internet (DI). This framework emphasizes the necessity of tackling both the reachability problem and optimization issues within the PI network. It includes the incorporation of logistics-related metrics such as cost, emissions, and delivery time [27]. Deep reinforcement learning is emerging as a promising avenue for addressing sequential decision-making challenges, particularly when the optimal policy structure is not well-understood. When applied within supply chain control towers, it has the potential to streamline and enable collaborative shipping in the context of the Physical Internet [28]. A decentralized system, known as the Cyber-Physical Internet of Things System (CPIoTS), supported by blockchain technology. This system is designed to reduce latency, guarantee secure consensus, and ensure dependable resource coordination within edge-cloud computing. These objectives are accomplished through the implementation of an efficient resource allocation algorithm that leverages policy-based Deep Reinforcement Learning (DRL) techniques [29]. The FreightShare Lab Platform is dedicated to fostering horizontal collaboration in freight logistics. It achieves this by implementing collaborative operational plans and decision support

	algorithms. This approach empowers logistics service providers and freight operators to maintain their profit margins while also sharing the benefits of improved efficiency, as showcased in a case study involving a UK freight operator [30]. An agent-based simulation is utilized to replicate interactions between mobile resource units and the physical infrastructure within a rail-road transport network. This simulation illustrates the advantages of the Physical Internet, particularly in diminishing the occurrence of empty truck journeys. Additionally, it highlights the role of the Physical Internet in facilitating digital transformation within urban rail transit systems for both distribution and passenger transport [31]. Analyzing the incorporation of Industry 4.0 practices reveals that, although previous suggestions have led to only minor adjustments, there is an increasing focus on Industry 4.0 principles, with a notable emphasis on physical internet hubs [32].
Port Operations and Physical Internet (these papers emphasize the significance of ports in the Physical Internet and provide insights into the areas where ports can contribute, the information architecture required, the role of autonomous decision-makers, and the evolution of Port Community Systems to enhance supply chain performance and efficiency within the Physical Internet framework.):	The scheduling and routing problem in a Rail-Road PI-Hub terminal, aiming to minimize energy consumption and cost through the use of PI-containers, and presents optimal solutions using a Multi-Objective Mixed-Integer Programming model and meta-heuristics [33]. Strategic approaches for ports to support the Physical Internet's growth and deployment encompass enhancing transport infrastructure, promoting standardization, developing advanced terminal areas, upgrading ICT hardware, improving information systems and platforms, and focusing on sustainability management. [34]. The proposed information architecture in the Physical Internet (PI) ports integrates real-time decision-making and dynamic cargo bundling, facilitated by an open interface platform and the use of PI containers, which requires reevaluating existing information systems and understanding future requirements for satisfying their needs [35]. The functioning of maritime ports in the context of the PI is still underexplored [36]. Two autonomous decision-makers, intelligent containers and ships, for evaluating port performance and selection in the Physical Internet (PI). It identifies future evaluation criteria and their importance based on expert surveys [37]. The evolution guidelines of Port Community Systems (PCS) and the business factors that improve supply chain performance. It highlights the transition from isolated supply chains to open supply chains and the improvement of supply chain efficiency [38].
Urban Logistics and City Systems (these papers provide insights into the potential applications and benefits of the Physical Internet in logistics and urban areas. They explore collaborative planning, facility location, shared networks, and optimization models, highlighting the need for efficient and sustainable transportation systems within the context of the Physical Internet.). City logistics does not only mean urban freight distribution, it is important to highlight the significance of managing human flows and information flows in urban logistics systems, supported by the PI concept, to promote sustainable and efficient city systems.	The potential for collaborative planning within an urban logistics system supporting the Physical Internet, functioning as a central hub for freight transportation with multiple e-commerce warehouses [39]. The Internet of Perishable Logistics (IoPL) introduces a layered architecture model based on the cyber Internet for distributing perishable goods. It explores the synergies between IoPL and the cyber Internet, shedding light on research opportunities emerging from these synergies [40]. In the innovative domain of the Physical Internet, the development of efficient PI-cross-docking hubs that enable rapid, efficient, and adaptable container transfers is a fundamental aspect [41]. An optimization model is devised for the collaborative coordination of deliveries within a multi-tier hyperconnected urban logistics system. This model specifically concentrates on tactical planning within the initial tier, where a consortium of carriers and logistic operators pool resources and information flows to provide more efficient and sustainable delivery services [42]. The potential of shared networks within urban areas to mitigate congestion and transportation costs is explored. This is achieved by analyzing and modeling a system where high-capacity freight vehicles operate between Key Freight Areas, addressing the inefficiencies of general freight transport within large metropolitan regions [43]. The perspectives of transport service providers in Austria concerning horizontal collaborations and the Physical Internet are examined, emphasizing the significance of awareness and information sharing during the implementation process [44]. Bridging the gap by introducing a framework that integrates multi-layer decision-making and the Physical Internet methodology, with a focus on the functional aspects of operational challenges in City Logistics systems and optimization. The aim is to enhance integration, cooperation, and the utilization of logistic infrastructure [45]. Facility location within a Physical Internet environment is considered [46]. Dynamic Multiple Depots Vehicle Routing explores feasible solutions for routing transportation between PI-hubs and retailers within the same cluster [47]. The potential of mobile access hub deployments for urban parcel logistics is investigated. It identifies the impact of design parameters on economic and environmental performance, with results highlighting design flexibility and pronounced advantages in highly variable environments [48]. UCC as a realization of the Physical Internet concept within cities are discussed [49].
Artificial Intelligence and Optimization Algorithms (these papers contribute to the	The asynchronous multimodal process approach is presented as a valuable addition to existing Physical Internet concepts, where modeling, analysis, and optimization of a supply chain are discussed. [50].

understanding and advancement of modeling, optimization, and analysis within the Physical Internet framework. They explore approaches for improving supply chain efficiency, addressing information communication issues, optimizing vehicle exchange, and forecasting container flows.):	An innovative approach to cost reduction and lead time enhancement within a physical internet supply chain network is explored. This approach employs a hybrid framework that combines artificial neural networks with an improved slime mold algorithm. The study underscores the effectiveness of this approach in comparison to other metaheuristics, particularly for training feed-forward neural networks [51]. The PI-BIMS (Physical Internet-based Business Information Management System) facilitates real-time data collection, communication, and visualization across various stages of production, transportation, and on-site assembly [52]. A virtual hub facilitates the swapping of vehicles among platoons. The study introduces a reinforcement learning-based model aimed at enhancing efficiency in situations with high volumes of incoming vehicles and short dispatch intervals. However, it notes that heuristic models tend to outperform in environments characterized by fewer vehicles [53]. A framework for forecasting inbound container volumes encompasses three distinct phases: data preprocessing, training through convolutional neural networks and recurrent neural networks, and evaluation based on accuracy metrics such as mean absolute error [54]. The Physical Internet-enabled hyperconnected order-to-delivery system incorporates IoT-enabled machines for communication. Additionally, a multi-objective genetic algorithm is utilized to optimize sustainable production-distribution scheduling within the Physical Internet-enabled hyperconnected manufacturing system [55].
Collaboration and Collaboration Models (these papers contribute to various aspects of freight transport and the implementation of the Physical Internet, including organizational approaches, applications of technology and optimization methods, UCC development, and potential benefits in different contexts.):	Gamification methodology to investigate the centralization and decentralization of the market. A freight transport game was developed for simulation [56]. The application of heuristic and reinforcement learning (RL) models to enable collaborative logistics and innovation in vehicle technology, specifically focusing on multiple platoon collaboration, and evaluates their efficiency based on transportation cost, highlighting the advantages of RL for high vehicle numbers and low dispatch interval, and heuristics for low vehicle numbers [57]. The potential benefits of adopting the Physical Internet paradigm in developing countries, considering the challenges they face in managing supply chain and logistics networks, and proposes options for assessment and research methodology design [58]. The performance characteristics for each PI-hub and for the whole PI-hub network [59]. The study explores how imbalances within the logistics network can lead to either a shortage or excess of supplies at various network points. It investigates solutions to address these challenges. [60]. A multi-agent reinforcement learning algorithm is utilized to simulate the strategic bidding behavior of carriers and shippers in the freight transportation market. This research incorporates a game-theoretical approach and numerical analysis, focusing on extracting insights into their behaviors [61].
Sustainability and Environmental Impact (he papers discuss different aspects of supply chain management, logistics operations, sustainability, and the application of technology in transportation. They highlight the potential benefits and challenges associated with adopting new approaches, such as the Physical Internet, artificial intelligence, and data analytics, in the logistics and transportation industry).	The application of Physical Internet (PI) principles within humanitarian organizations is examined as a means to amplify their operational efficiency and effectiveness in supply chain and logistics endeavors. This entails considering the integration of PI principles in transportation, storage allocation, and inventory management, despite the associated expenses and the necessity for comprehensive logistical and legal reconfiguration [62]. Theoretical perspectives related to sustainable industrial systems within the transportation sector are explored, with specific attention directed towards the On-board Unit in Electronic Toll systems. This exploration delves into the utilization of artificial intelligence and Industry 4.0, employing kernel density analysis. It underscores the significance of regulatory frameworks and protective measures for technological advancements in artificial intelligence and robotics [63]. Anonymized microdata obtained from the European Road Freight Transport Survey is harnessed to identify recurring patterns in logistics operations across EU and EFTA countries. This analysis underscores the value of data analytics in enhancing the efficiency of logistics operations and addressing sustainability imperatives [64]. Innovative methods for tracking parcels within the network are introduced [65].
Smart containers (he papers cover topics such as the learning capabilities of smart containers, information sharing challenges, logistics system architectures, modular box development, design of PI-containers, optimization models for PI-hubs, and strategies for truck loading	In a self-organizing logistics environment, smart containers collectively acquire bidding policies through information sharing, despite their limited lifespan, utilizing a reinforcement learning algorithm. Nevertheless, carriers may exhibit disincentives to share information, emphasizing the necessity for further exploration into the interplay between smart containers and transport services [66]. An investigation into how recent global standards and technologies are applied in a multi-companies open network, particularly concerning the management of reusable pallets [67]. The methodical development process leading to the creation of modular box prototypes incorporates a holistic approach that encompasses all the requirements of the shipping network [68].

and container grouping in the Physical Internet context)	Emphasis is placed on the design of such containers, with particular attention to their associated activeness. After outlining the physical and informational prerequisites linked to PI-containers, the concept of activeness is delineated, and the primary research challenges in this domain are presented [69]. A multi-objective mathematical model is introduced to optimize operations within Road-Road PI-hubs, with a focus on minimizing truck delays and reducing energy consumption during the transfer of PI-containers. This model serves as a foundation for prospective research in the context of the Physical Internet concept [70]. Strategies are developed to optimize truck loading by leveraging the use of active containers, focusing on the scheduling of both incoming and outgoing trucks, as well as organizing PI-containers in train wagons and outgoing trucks for efficient transport [71]. An exploration into how the design and characteristics of PI-containers will influence the flow of containers within a domestic network context [72].
Passenger transport The Physical Internet primarily focuses on optimizing the flow of goods and information in supply chains by applying principles such as standardization, modularization, and collaboration. While the concept of the Physical Internet may inspire ideas for optimizing passenger transport, such as shared mobility or interconnected transportation systems, it is important to note that the application of the Physical Internet concept to passenger transport would require significant adaptation and research. The requirements and dynamics of passenger transportation, including safety, comfort, and individual preferences, differ significantly from those of goods transportation.	The proposal suggests deploying the concept of the Physical Internet for passenger air transport to increase resource efficiency and reduce emissions, with potential benefits for airlines, and calculates that implementation in the EU could reduce emissions by 9.3 Mt (13.5%) compared to 2019 levels [73].

Source: Own elaboration based on the reviewed papers

4 Discussion

Based on the analysis, we can identify the following popular topics and trends in Physical Internet research.

Many studies focus on developing mathematical optimization models and strategies to enhance the efficiency and effectiveness of operations within the Physical Internet. These models often aim to minimize energy consumption, costs, delays, and improve resource allocation.

Given the complexity and open nature of the Physical Internet, researchers are exploring the application of information systems, data analytics, and technologies like artificial intelligence and Industry 4.0 to facilitate real-time data collection, communication, visualization, and decision-making. These efforts aim to improve the monitoring, management, and coordination of parcels and resources within the network.

Collaborative logistics and coordination among various stakeholders, including carriers, shippers, and logistics service providers, are important areas of research. Studies investigate the potential benefits of collaborative planning, information sharing, and decision-making to enhance the efficiency and sustainability of supply chains within the Physical Internet context.

Researchers recognize the need for innovative system architectures that can support the requirements of new and shared logistics models. Efforts are being made to integrate technologies, such as global standards, to enable interoperability and traceability in the management of resources like reusable pallets.

There is significant research interest in designing modular, reusable, and smart containers (PI-containers) that encapsulate goods within the Physical Internet. Researchers are exploring the physical and informational requirements associated with these containers and investigating their activeness. The role of smart containers in enhancing the technical elements of logistics by

facilitating efficient flow management of materials through advanced tracking and optimized loading strategies.

There are still areas the seem to be neglected in the research on PI. While there is some research on bidding policies and decision-making by carriers and shippers, more studies could focus on understanding the behavior and motivations of various actors within the Physical Internet system. Investigating incentives, disincentives, and behavioral insights can provide valuable insights for system design and optimization. The texts do not extensively discuss the legal and regulatory aspects of implementing the Physical Internet. Further research is needed to understand the legal implications, potential barriers, and necessary legal restructuring required for the adoption of Physical Internet principles and practices. While efficiency and sustainability are emphasized, there is a need for research that addresses the economic viability and cost-benefit analysis of implementing the Physical Internet. Evaluating the financial implications, return on investment, and cost-effectiveness of adopting Physical Internet concepts can help decision-makers assess its feasibility and potential benefits.

The texts touch on sustainability, but there is limited exploration of the broader social and environmental impacts of the Physical Internet. Research could delve into the social equity implications, carbon footprint reduction, and the overall societal benefits and challenges associated with implementing the Physical Internet. To achieve the sustainability goals and reduce environmental impact, logistics operations mut be optimized and PI helps managing material and information flows.

The willingness of stakeholders to collaborate and cooperate is crucial for the successful implementation of the Physical Internet. While some studies touch on collaboration and information sharing among carriers, there is a need for further research to understand the factors influencing stakeholders' willingness to cooperate within the Physical Internet framework. This includes examining incentives, trust-building mechanisms, and the identification of barriers and challenges that may hinder collaboration.

Ensuring the security of goods, data, and operations is a critical aspect of the Physical Internet. As the system relies on interconnected networks and information sharing, there is a need for robust security measures to protect against cyber threats, data breaches, and unauthorized access. Further research should focus on developing security frameworks, protocols, and technologies to address these concerns and maintain the integrity and confidentiality of Physical Internet operations.

While research specifically focusing on cultural aspects in the context of the Physical Internet is limited, it is essential to consider cultural factors when designing and implementing logistics systems. Cultural differences can influence the level of trust and willingness to collaborate among stakeholders. Cultures that prioritize individualism may have a different approach to cooperation compared to cultures that emphasize collectivism. Understanding cultural preferences and norms regarding collaboration can help in designing appropriate incentives and strategies to promote cooperation within the Physical Internet framework. Cultural variations in communication styles, decision-making processes, and power dynamics can impact information sharing and decision-making within the Physical Internet. Different cultures may have distinct preferences for hierarchical or consensus-based decision-making, which can influence the effectiveness of collaborative efforts and information flow. Cultural variations may lead to differences in regulatory and legal frameworks related to logistics and data sharing. Cultural norms and values can shape the development of policies and regulations that affect the implementation and operation of the Physical Internet. Understanding these differences is crucial for addressing legal and compliance issues across different cultural contexts. Cultural attitudes towards technology adoption and innovation can influence the acceptance and implementation of technological solutions in the Physical Internet. Cultural predispositions towards risk-taking, openness to change, and technological literacy can impact the adoption of new technologies and processes within logistics systems. Considering cultural differences and predispositions is important to ensure that the design and implementation of the Physical Internet align with the cultural context of the regions or countries involved. This may involve tailoring strategies, communication approaches, and regulatory frameworks to accommodate cultural nuances and promote successful adoption and collaboration. Further research is needed to explore the specific cultural factors and their implications for the Physical Internet. By addressing these research gaps, researchers can further advance the understanding, implementation, and impact of the Physical Internet concept.

5 Conclusions

Based on the summary provided, it is evident that the discourse surrounding the Physical Internet revolves around several key points. Firstly, there is a strong emphasis on enhancing efficiency and promoting sustainable development in the realm of logistics. The Physical Internet is perceived as a solution aimed at enhancing economic, environmental, and societal efficiency in the worldwide transportation, warehousing, and distribution of tangible goods. Furthermore, the advent of digital transformation in the logistics industry is a crucial aspect of the Physical Internet. This transformation brings about significant implications for the development and implementation of an efficient and sustainable logistics system on a global scale.

Collaboration and the sharing of information constitute essential foundations of the Physical Internet concept. The concept entails the sharing of logistical resources and the exchange of information within an open network. It is believed that the introduction of the Physical Internet can

greatly contribute to the development of sustainable logistics. Important elements of the implementation process include raising awareness and facilitating the exchange of information among stakeholders.

In addition, researchers have focused on exploring the utilization of technologies such as blockchain and smart contracts to optimize logistical processes within the Physical Internet framework. These technologies hold promise in streamlining operations and improving efficiency.

Nevertheless, it is noteworthy that the summary also underscores certain underexplored or omitted areas within the context of the Physical Internet. These encompass a detailed examination of the Physical Internet's influence on various industries and economic sectors, the feasibility of its large-scale adoption, the resolution of obstacles such as legal and administrative complexities to stimulate cooperation among logistics firms, and research concentrated on the real-world applications of the Physical Internet within the corporate sphere. These areas warrant further investigation to gain a comprehensive understanding of the full potential and practical implications of the Physical Internet concept.

Furthermore, it appears that contrary to the initial assumptions, the Physical Internet has the potential to expand into passenger transportation, and this area represents the largest research gap and, thus far, an overlooked gap in knowledge. Some authors mention the possibility of sharing infrastructure and even fleets within cities, but it seems that we can go further and begin managing human flows in accordance with the principles of the PI.

The literature review presented in the provided text explores various aspects of the Physical Internet (PI) concept and its potential implications. It highlights the foundational ideas behind the PI, with the goal of transforming the global transportation and storage of physical goods, with an emphasis on enhancing economic, environmental, and societal efficiency and sustainability. The review underscores the importance of the Physical Internet (PI) in tackling the challenges of 17 Sustainable Development Goals and advancing the objectives of Industry 4.0. It highlights the necessity for well-suited information systems, physical infrastructure, and technologies to align with the evolving demands of the economy. The review acknowledges the need for further research on the proposed logistics paradigm and identifies the challenges associated with implementing the PI as a practical solution. It highlights the potential of blockchain, smart contracts, lean thinking, and value stream mapping in enhancing PI practices and fostering the transition from traditional logistics.

Additionally, the literature review touches upon the verification of PI principles in economic practice, showcasing the possibilities of applying PI solutions to optimize logistics processes and enhance communication infrastructure.

Overall, the literature review provides a comprehensive overview of the key concepts, challenges, and potential opportunities associated with the Physical Internet, offering insights into its potentially transformative impact on global logistics systems.

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The logistics and sustainability in the European Union
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The logistics and sustainability in the European Union

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Keywords: business logistics, sustainability, correlation analysis, cluster analysis, geographic analysis.
Abstract: The paper is focused on the issue of business logistics performance and sustainability of countries in the EU due to their constantly growing importance in the social, economic and environmental field. We assume a significant dependence between the mentioned quantities. To research the relationship between business logistics performance and sustainability, we used the data of the business logistics performance index and the sustainability index across each EU countries. The importance of the selected indices lies in the ability to identify possible opportunities and challenges of business logistics as a benchmarking tool to increase its performance. To assess the relationship of these researched parameters, we applied the correlation coefficient, cluster and geographic analysis to identify relatively homogeneous groups - EU countries - clusters with the greatest possible difference within the clusters. The results proved a statistically significant dependence between the performance of business logistics and sustainability in EU member states. From a geographic analysis perspective, we have identified a tendency to create geographically close groupings of EU countries within the examined parameters.

1 Introduction

Sustainability and logistics have been gaining more and more attention in recent years [1]. Logistics as such and activities related to it have several positive socio-economic effects, as it meets the requirements for accessibility and mobility, creation of infrastructure, jobs, reduction of poverty, hunger, etc., thereby enriching society as a nation and satisfying people's demands. Companies began to take global market demand into account in their strategic planning. This has caused the expansion of trade liberalization and globalization. Globalization and the associated potential growth of competitive advantages in the market and development began to require continuous business processes and their innovations to maintain competitiveness. Business logistics began to be considered the most crucial area that requires innovation, because it constituted a successful method of streamlining performance [2-7]. However, recent logistics create multiple negative impacts on the surrounding environment. First, logistics is still heavily dependent on fossil fuels and non-renewable natural resources, which is harmful to an individual's health and safety of the population, causes air, soil, water pollution, noise and other negative externalities negatively affecting the environment [8,9] and societies. Sustainable development is an inspiring element for sustainable logistics to create activities to reduce the negative impacts of logistics [8] and even increase favourable effects of this sector on the environment and society. The problems lie in the creation of negative externalities, which come from daily operation to long-distance distribution [10] including emissions, congestion, visual disturbance, infrastructure failure, etc. In addition, these disadvantages of logistics further lead to a decline in the performance of the logistics chain at the company level and at the regional level, which, since the need for logistics increases, creates an exponential growth of negative impacts on the economy and the entire ecosystem [11].

The sustainable development of logistics requires activities that result in societal and economic benefits along with reducing adverse effects on the environment. In the long term, however, these activities are not easy at all and represent great challenges associated with various dilemmas and barriers. Developed countries including the European Union emphasize trends, such as mobility, urbanization, aging, but also migration, which pose challenges for their social and economic development. The main environmental challenges are global warming and growing shortage of fossil fuels. All these issues as well as potential future challenges, play an essential role in the management of sustainability. The challenges of environmental sustainability and logistics are elaborated from a supply chain perspective by Abbasi and Nilsson

[12], classifying them into costs, complexity, mindset changes, operationalization, cultures, and uncertainties. Paradoxes in the field of green logistics elucidated Rodrigue et al. [13] as a result of cost, reliability, time/speed, storage and e-commerce [8,14]. Aspects of many solutions that can lead to effective systems supporting sustainable development play a key role in recent approaches to sustainability. As part of the aspects of sustainability, other approaches and ideas based on and supporting the circular economy are therefore being developed simultaneously. The concept of a circular economy centers on and is predicated on the recycling and use of waste and existing resources. From this point of view, transformation is based on the reuse of existing infrastructures and the facilitation of processes within new infrastructures [15]. Developed countries with regard to demography, social and economic conditions are preparing cities for the inevitable transformation with regard to the circular economy and sustainable development, because the achievement of sustainability goals can support the use of circular economy concepts [16,17]. Sharing and recycling solutions in transport and regeneration of energy resources, waste management, digital transformation and transport systems in various industrial sectors form complementary policies in the framework of sustainable development and improvement of mobility systems. Most studies focus on challenges from the perspective of sustainability in logistics, but do not focus on measuring their mutual relationship [8,14]. Therefore, the aim of this paper is to determine the relationship between business logistics performance and sustainability in EU countries. Based on the mentioned literature, we set the research question: "We assume a statistically significant dependence between the logistics and sustainability performance in the EU."

2 Methodology

For the statistical investigation of the reserch question, we used data the Logistics Performance Index (LPI) [18] and the Sustainability Development Index (formerly SDG Index & Dashboards) [19].

To determine company logistics possibilities and challenges, the Logistics Performance Index, as an interactive benchmarking tool to increase logistics performance, was used. The Logistics Performance Index evaluates 160 countries to identify business experience in the global logistics-business environment. It represents a benchmarking tool not only for comparing these qualitative-quantitative indicators, but also for sharing experiences in this area. The logistics components of each country are captured by the Logistics Performance Index from the perspective of six different elements, see figure 1.

The logistics components	Customs
	Infrastructure
	International shipments
	Logistics quality and competence
	Tracking and tracing
	Timeliness

Figure 1 Basic elements of the Logistics Performance Index

The Sustainable Development Report (the term "SDG index" is used for the purpose of this study) assesses the progress of all 193 UN Member States on the SDGs: In 2023, Finland, Sweden and Denmark top the rankings. The SDG Index is a worldwide evaluation that assigns equal weight to each of the 17 SDGs and assesses how well a country has performed overall. The number represents the country's position between the goal (score of 100) and the worst-case scenario (score of 0). The figure 2 shows the short titles of the 17 SDGs.

The short titles of 17 SDGs	SDG 1 - No poverty
	SDG 2 - Zero hunger
	SDG 3 - Good health and well-being
	SDG 4 - Quality education
	SDG 5 - Gender equality
	SDG 6 - Clean water and sanitation
	SDG 7 - Affordable and clean energy
	SDG 8 - Decent work and economic growth
	SDG 9 - Industry, innovation, and infrastructure
	SDG 10 - Reduced inequalities
	SDG 11 - Sustainable cities and communities
	SDG 12 - Responsible consumption and production
	SDG 13 - Climate action
	SDG 14 - Life below water
	SDG 15 - Life on land
	SDG 16 - Peace, justice, and strong institutions
	SDG 17 - Partnerships for the goals

Figure 2 The short titles of the 17 SDGs

The SDGs emphasize the interconnected environmental, social and economic aspects of sustainable development by putting sustainability at their center [7,20,21].

The secondary data provided are the basic inputs of this study. Collected secondary data were for 27 countries of the European Union. The obtained secondary data were processed using Microsoft Excel and Statistic software. Correlation, cluster and geographic analysis was used for the analysis of the obtained secondary data. Correlation analysis, which identifies how strongly the research variables are related to one another, was used to determine the relationship between sustainability and the performance of corporate logistics in EU countries within the research wuestion. The resarch question was transformed into a hypothesis:

H1 “Between the Logistics Performance index and the Sustainability Development Index there is a statistical significant dependence”. The strength of the relationship identified through the correlation coefficient within the performed correlation analysis is interpreted as follows:

- especially strong, when the variables are highly dependent on one another - the range of values for the correlation coefficient is 0.8 to 1, respectively -0.8 to -1,
- moderately strong - when there is a moderately strong interdependence between the variables - the range of values for the correlation coefficient is 0.4 to 0.8, respectively from -0.4 to -0.8,
- weak, when there is a weak interdependence between the variables - the range of values for the correlation coefficient is 0 to 0.4, respectively from -0.4 to 0.

Correlation coefficient values represent the dependence between the variables under study, so that if one variable changes, it affects the other variable. For further analysis of the relationship between the studied variables, we used cluster and geographic analysis to identify the EU countries with the most significant possible similarity among the group of countries (clusters), and at the same time with the greatest possible difference between the groups [22,23]. Through the method of induction and deduction, we drew up conclusions of our research.

3 Result and discussion

By processing secondary data, evaluating them through correlational, cluster and geographical analysis, we reached the following conclusions. Table 1 displays the components of the logistics performance index, the SDG Index, and correlation indicator data.

Table 1 Sustainability and business logistics performance in the EU – primary data [18,19]

Country	Logistics Performance Index 2023							SDG index
	Total	Customs	Infrastructure	International shipments	Logistics quality and competence	Tracking and tracing	Timeliness	
Germany	4.20	4.09	4.37	3.86	4.31	4.24	4.39	83.40
Sweden	4.05	4.05	4.24	3.92	3.98	3.88	4.28	86.00
Belgium	4.04	3.66	3.98	3.99	4.13	4.05	4.41	79.50
Austria	4.03	3.71	4.18	3.88	4.08	4.09	4.25	82.30
Netherlands	4.02	3.92	4.21	3.68	4.09	4.02	4.25	79.40
Denmark	3.99	3.92	3.96	3.53	4.01	4.18	4.41	85.70
Finland	3.97	3.82	4.00	3.56	3.89	4.32	4.28	86.80
France	3.84	3.59	4.00	3.55	3.84	4.00	4.15	82.00
Spain	3.83	3.62	3.84	3.83	3.80	3.83	4.06	80.40
Italy	3.74	3.47	3.85	3.51	3.66	3.85	4.13	78.80
Czech Republic	3.68	3.29	3.46	3.75	3.72	3.70	4.13	81.90
Portugal	3.64	3.17	3.25	3.83	3.71	3.72	4.13	80.00
Luxembourg	3.63	3.53	3.63	3.37	3.76	3.61	3.90	77.70
Poland	3.54	3.25	3.21	3.68	3.58	3.51	3.95	81.70
Ireland	3.51	3.36	3.29	3.42	3.60	3.62	3.76	80.20
Hungary	3.42	3.35	3.27	3.22	3.21	3.67	3.79	79.40
Slovenia	3.31	3.42	3.26	3.19	3.05	3.27	3.70	81.00
Estonia	3.31	3.32	3.10	3.26	3.15	3.21	3.80	81.70
Greece	3.20	2.84	3.17	3.30	3.06	3.18	3.66	78.40
Romania	3.12	2.58	2.91	3.18	3.07	3.26	3.68	77.50
Croatia	3.10	2.98	3.01	2.93	3.10	3.01	3.59	81.50
Bulgaria	3.03	2.94	2.76	3.23	2.88	3.02	3.31	74.60
Slovakia	3.03	2.79	3.00	3.10	3.14	2.99	3.14	79.10
Lithuania	3.02	2.85	2.73	2.79	2.96	3.12	3.65	76.80
Malta	2.81	2.70	2.90	2.70	2.80	2.80	3.01	75.50
Latvia	2.81	2.80	2.98	2.74	2.69	2.79	2.88	80.70
Cyprus	3.15	3.05	2.89	3.15	3.00	3.15	3.62	72.50
Correlation index	0.63	0.66	0.65	0.50	0.60	0.62	0.58	1.00

As the correlation coefficient values of the individual variables show, the relationship between logistics performance and sustainability has a moderately strong dependence between the researched variables – Customs (0.66), Infrastructure (0.65), Tracking and tracing (0.62), Logistics quality and competence (0.60), Timeliness (0.58), and International shipments (0.50). Based on the mentioned results, we can conclude that the dependence between innovaitons and the logistics performance in the EU is statistically significant and hypothesis H1 is accepted.

In order to separate the EU countries into groups (clusters) with the greatest similarity in terms of business logistics performance and sustainability, while also having the greatest differences between individual clusters - groups, a cluster analysis was another processed analysis of the investigated issue (see Figure 3).

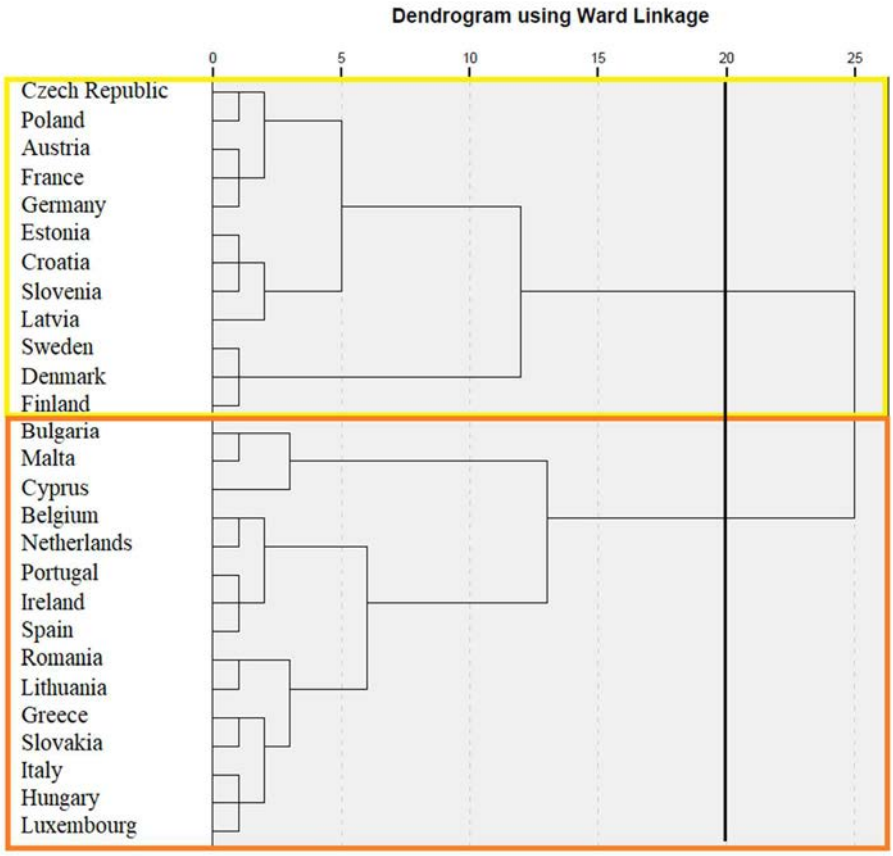

Figure 3 The sustainability and logistics in the EU – cluster analysis

At the Eudlicean distance of 20, we identified the largest distance between groups (clusters) of EU countries. In terms of the research relationship between business logistics performance and sustainability, this distance indicates the greatest difference between the analyzed groups - clusters and the highest similarity within the groups - clusters of the examined EU countries. Based on the above, we identified two clusters:

The *first cluster* consists of countries with an average higher index of business logistics performance and sustainability: Sweden, Finland, Denmark, Germany, France, Austria, Czech Republic, Poland, Estonia, Slovenia, Latvia, and Croatia.

The *second cluster* consists of countries with an average lower index of business logistics performance and sustainability: Bulgaria, Malta, Cyprus, Belgium, Netherlands, Spain, Italy, Portugal, Luxembourg, Ireland, Hungary, Greece, Romania, Slovakia, Lithuania.

Subsequently, a geographical analysis was carried out. Through geographic analysis, we plotted the average values of business logistics performance and sustainability of individual EU countries on the map, see Figure 2. The figure shows the level of business logistics performance and sustainability according to the intensity of the color. The more saturated the color, the higher the average value of the indices of business performance and sustainability. The weaker the color, the lower the average value of the business logistics performance and sustainability indices.

Figure 4 Geographical analysis of the relationship between logistics and sustainability

Drawing from the conducted analyses, we may conclude that countries with a higher value of the sustainability index (SDG index) tend to have a higher performance of business logistics, which confirms the moderate statistical dependence of their relationship

(0.63). Simultaneously, the geographical analysis of the relationship between sustainability and logistics allows us to conclude that the countries with the best performance in business logistics and sustainability tend to form geographically close groups or the well-reformed Nordic countries have a greater implementation of sustainability in practice - the performance of business logistics and sustainability declines with increasing geographical distance from the more efficient countries in the researched area, this finding confirmed the previous studies of Loučanová, Europe Sustainable Development Report [23,24].

The results confirm the facts of the dependence of sustainability and logistics [8], as the identified dependence between the monitored variables is positive (the correlation coefficient of the dependence of the researched variables of logistics and sustainability has a positive value). We assume that logistics has a positive influence especially on the economic-social goals of sustainability, which prevail over the environmental goals of sustainability [4-6]. Business logistics began to be considered the most crucial area that requires innovation, because they represented an effective means of streamlining performance and thus also reducing negative impacts on the environment. Organizations might potentially grow and gain competitive advantages in the market by implementing innovative business processes within logistics and at the same time try to eliminate the negatives associated with logistics. As stated by studies [25,26], the innovations increase performance, economic growth and sustainability by their impact.

4 Conclusions

The study demonstrates a causal relationship between EU member states' sustainability and trade logistics performance. The findings of the analyses that were conducted indicate that:

- countries with a higher value of the sustainability index tend to achieve higher business logistics performance within the medium statistical dependence of their relationship,
- countries that perform best in sustainability and business logistics typically cluster together in close geographical areas.,
- the performance associated with business logistics and sustainability decreases with growing geographical distance from the more efficient countries in the studied area.

Based on the evaluation of the hypotheses and the confirmation of the positive relationship between the selected variables, we can subsequently point to the significant influence of logistics on the successful achievement of the set goals, both economic and social. It is important to respect the need for sustainability, which is also required in the field of business logistics when fulfilling the stated goals. Through innovative solutions in the field of logistics, which will lead to the elimination of negative impacts on the environment, we can expect positive results that will be reflected not only in the growing performance of the company itself but also in its competitiveness on the global market.

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Reliability analysis of marine diesel engines vs. industrial diesel engines: a comparative approach
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Reliability analysis of marine diesel engines vs. industrial diesel engines: a comparative approach

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Keywords: reliability analysis, operational conditions, maintenance practices, heat exchanger.
Abstract: The study presents a comparative analysis of the reliability of marine and industrial diesel engines, emphasizing the role of heat exchangers. Diesel engines in marine vessels and industrial applications face distinct challenges, influencing their reliability. This paper examines these differences, focusing on operational conditions, load profiles, redundancy, safety measures, and maintenance practices. Three types of heat exchangers (Fin fan, Plate, and Shell & Tube) are analyzed which are used in these engines. The assessment covers failure rates, Mean Time to Failure (*MTTF*), and the impact of independent and dependent failures on reliability. The study identifies unique failure modes like insufficient heat transfer, external leakage, parameter deviation, and structural deficiencies and their differing impacts in marine and industrial contexts. The research highlights the sensitivity of marine engine heat exchangers to seawater-induced corrosion and fouling, affecting heat transfer efficiency. In contrast, industrial engines display varying failure characteristics due to system controls and operational parameters. A significant finding is the decrease in reliability over time for all heat exchanger types, underscoring the importance of maintenance and monitoring. Our results show slight shifts in failure rates due to equipment inefficiencies markedly affecting heat exchangers' operational lifecycles. The study concludes with a necessity for tailored maintenance strategies and design considerations for marine and industrial diesel engine heat exchangers. This focused approach offers insights into optimizing diesel engine reliability, particularly by understanding the main role of heat exchangers.

1 Introduction

The reliability of diesel engines plays a vital role in marine (ships' main engine) and industrial sectors (standby power generators for hospitals or data centers, construction equipment, etc.), where these powerhouses serve critical roles in various applications. By exploring key factors influencing reliability, such as environmental conditions, load profiles, redundancy, safety measures, and maintenance practices, this paper aims to illustrate the different distinct challenges and considerations between marine diesel engines and industrial diesel engines.

There is a lot of diversity in the literature addressing the reliability of different engine components within different environmental conditions and operation specifications. In their study, Jing et al. indicated that the material properties of engine components are not the main cause of failures. The study focused on the reliability of diesel engine cylinder heads through fatigue failure analysis and the influence of working loads; gas force amplitude was the main factor, and thermal loads were the secondary factors affecting the component's reliability. The applied method through the study was the finite element simulation [1]. Dolas et al. presented a reliability analysis of the cooling system of diesel engines used for compressor application, depending on Mean Time to Failure (*MTTF*) data, Weibull distribution analytical least square method, and Minitab 16.1R Software. The obtained failure rate value was lower than the empirical values, and the values calculated were based on the Weibull distribution [2]. Anantharaman et al. present an integration of the Markov model (for constant failure components) and the Weibull failure model (for wearing out components) to provide a realistic and practical analysis of the marine diesel engine with a case study of turbocharger effects on the overall engine reliability and safety [3].

Dionysiou et al. investigated the safety improvements of the lubricating oil system of marine diesel engines by applying safety, reliability, availability, and diagnosability analyses. Reliability Block Diagrams were used to estimate the reliability and availability metrics at different design modifications. The analysis also included a combination of Failure Modes, Effects and Criticality Analysis, and the Functional Fault Tree Analysis methods. The results show that the most critical components in the lubricating oil system are the suction strainer (Reliability Importance 57.2%) and the lubricating oil pump (Reliability Importance 32.27%). Seven additional sensors were introduced to enhance the system design, and the investigated alternative designs exhibit significantly lower probabilities of failure and higher availability values [4]. Kirolivanos et al. investigated the reliability of marine dual-fuel engines compared to conventional diesel engines. The research results were 8.48% for diesel engine reliability mean value and 8.84% for dual-fuel engines,

which means dual-fuel engines are more reliable than diesel engines. The results also offer insights into the relationship between the system's reliability and the planned maintenance strategies [5]. Other studies focused on improving the reliability of marine diesel engine subsystems by analyzing the reliability metrics at different conditions and designs. These studies analyze key performance indicators such as the Mean Time to Repair, Failure Rate, and Mean Time Between Failures [6,7]. Issa et al. focused on analyzing the impacts of low engine load (below 30%) and environmental conditions such as temperature, humidity, abrasive dust, and corrosive environments on the operation of modern diesel generators. Their findings reveal that prolonged operation of diesel engines at low loads can result in deterioration, which means that running these engines for extended periods at low loads might cause irreversible damage. Additionally, there's a noticeable decrease in engine performance when these engines exceed specific environmental limits [8]. Eriksen et al. examine the limitation on reliability improvement through redundancy on ship components and how the length of the ship course will affect it. The study also addressed the effects of independent and dependent failures on reliability [9]. Some research studied the possibilities of increasing ship operational reliability by implementing a new maintenance strategy. The study calculations identified the system's critical components while advising more practical maintenance activities [10,11].

By incorporating these studies, we can build upon their methodologies and findings to comprehensively compare marine and industrial diesel engine reliability changes. Drawing from their insights, we aim to enrich the understanding of how environmental conditions, load profiles, redundancy, safety measures, and maintenance practices collectively contribute to the reliability and performance of these engines.

The paper is organized as follows: first, a demonstration of distinct environmental conditions and load profiles in both marine and industrial diesel engines are presented in Section 2. After that, the critical role of redundancy and safety measures in ensuring reliability is evaluated in Section 3. Then, the maintenance practices and strategies and their influences on reliability are explained in Section 4. The methods and equations used in the reliability and maintainability engineering field are shown in Section 5. The final part addresses the paper's reliability results and discusses the possible solutions to enhance reliability in Section 6.

The paper's main added value is the holistic examination of reliability factors combined with practical insights and real case studies. The study offers a novel comparative analysis of heat exchanger reliability in marine and industrial diesel engines, highlighting specific failure modes, the impact of environmental conditions, and the importance of tailored maintenance and design strategies for enhanced efficiency and longevity.

2 Environmental conditions and load profiles for marine and industrial diesel engines

The wide range of environmental conditions and load demands significantly affects the performance of both marine and industrial diesel engines. However, marine diesel engines face more significant challenges due to the dynamic load demands and harsh environmental conditions. Marine diesel engines must withstand frequent load fluctuations and saltwater exposure while incorporating features to manage vibrations, rolling, and pitching. On the other hand, stationary or industrial diesel engines benefit from more controllable environments and generally more predictable load profiles, leading to a potentially longer lifecycle and optimized operational efficiency.

2.1 Environmental conditions

Diesel engine performance requires operation within certain limits for environmental conditions such as temperature, humidity, abrasive dust, and corrosive environments. When an engine exceeds these limitations, a noticeable decrease in performance will appear [8]. On the other hand, marine diesel engines are designed to operate efficiently and effectively while considering various environmental factors. Marine diesel engines are designed with a combination of advanced technologies, emission control systems, and operational considerations to navigate through changing environmental conditions while following international and regional emission regulations such as the International Maritime Organization's (IMO) and MARPOL ANNEX VI regulations [12]. Table 1 demonstrates the different environmental conditions encountered by diesel engines during the operation.

The comparative analysis of marine and industrial diesel engines investigates their unique challenges and operational conditions, providing the background for future research and technological improvements. It offers practical insights for industry experts to improve efficiency, safety, and environmental compliance, serving academic and practical needs in engine management.

Table 1 Comparison of environmental conditions for marine and industrial engines

Marine Diesel Engines	Industrial Diesel Engines
• Operate in highly corrosive and humid marine environments with exposure to saltwater.	• Operate in a controlled indoor environment, typically less exposed to corrosive elements.
• High humidity and saltwater can accelerate corrosion and impact electrical systems.	• Temperature and humidity control can be easier to manage, reducing the impact on components and electrical systems.
• Vibration and rolling from wave-induced motion can affect engine components.	• Vibration and rolling factors are generally lower but might still be relevant depending on the application.
• Introduce more safety challenges due to marine environments' corrosive and dynamic nature.	• Offer a safer working atmosphere for operators, with reduced risks associated with these factors.
• Designed for continuous operation during long sea trips.	• Have more varied applications and usage patterns.
• Components are designed to be robust, but maintenance is still necessary to prevent unexpected failures and ensure reliability. • Maintaining different components can be difficult due to the limited and tight spaces on vessels	• The frequency and approach to maintenance vary based on the specific applications and requirements. • Have more accessible components.

2.2 Load profiles and operation demands for marine and industrial diesel engines

The load profile of an engine describes the relationship between the power output and the engine's speed. It depends on the application, design, and operation of the engine. Table 2 demonstrates the load spectrum based on the percentage of continuous maximum rating for a better understanding of engine load differences and demands.

Table 2 Diesel engine load scenarios and operation demands

Applied Load	Description	Marine Diesel Engine	Industrial Diesel Engines
0-25%	Extreme low load	Standby mode: The ship is docked in a port and needs to maintain basic operations (lighting and onboard systems)	Only during minimal power demand
25-40%	Low load	Slow cruising Calm waters	Slight increase in power demand
40-80%	Regular operation load	Moderate sea conditions	Normal working hours
80-90%	High load	Rough seas Tight schedule	Substantial demand for power
90-100%	Extreme high load	Rapid acceleration Rough seas	Peak power demand

Marine diesel engines are used for propulsion and onboard power generation of ships and offshore platforms. Depending on the vessel's speed, sea conditions, and maneuverings, these engines must operate in various unpredictable load conditions, from low to extremely high. Marine diesel engines must also comply with strict emission regulations for marine environments [12]. Industrial diesel engines are used for power generation and mechanical drive of industrial equipment, such as pumps, compressors, etc. These engines must operate in steady or variable load conditions, depending on the demand and the system stability, and must meet different emission standards for different regions and applications. In the case of marine diesel engines, dynamic transient loads occur during the engine's operation, such as acceleration, deceleration, change of propeller pitch, etc. These changes add additional complexity and affect the friction, wear, lubrication, and vibration of the engine components, such as the piston, cylinders, and crankshaft. These effects can influence the performance and lifecycle of the engine components, as well as fuel consumption and emissions [8]. In contrast, industrial diesel engines typically encounter more progressive and predictable load changes. Industrial applications often involve steady or slowly varying loads. Unlike the rapid and frequent load shifts of marine engines, industrial engines have more stable operational profiles. This allows for better load management, reduced wear and tear on components, and optimized fuel consumption [8].

Understanding these load profiles and their implications is vital for designing, operating, and effectively maintaining marine and industrial diesel engines. It enables engineers to optimize engine performance, enhance reliability, and mitigate environmental impacts, all while ensuring compliance with relevant regulations.

In conclusion, the varying load demands of marine and industrial diesel engines reflect the complexity of their respective operational environments. The dynamic and unpredictable load shifts encountered by marine engines emphasize the need for flexible designs and effective maintenance. In contrast, industrial engines' steadier and more predictable load transitions enable strategic optimization and prolonged reliability. Considering these

differences is fundamental for the practical engineering, operation, and maintenance of these critical engines, ensuring that they meet the demands of their applications with precision and durability.

3 The role of redundancy and safety measures in increasing diesel engines' reliability

Redundancy involves incorporating standby or backup components, systems, or processes within a system. This step provides an alternative pathway in case of failure in the primary component. In marine and industrial diesel engines, redundancy can contribute significantly to reliability. Downtime can lead to severe consequences in critical applications like marine vessels and power plants. Redundancy reduces the risk of complete system failure, protecting against potential hazards and economic losses. In addition, it enhances the system's ability to tolerate faults, especially in environments where component failures due to extreme conditions or wear are more likely, such as corrosive marine environments. Redundancy is vital in marine diesel engines due to the often-challenging operating environments. Ships must be able to navigate safely, even during engine failures. As a result, marine engines typically incorporate higher levels of parallel redundancy, such as multiple main engines, generators for various onboard systems, and propulsion systems, such as propellers or thrusters. This ensures that a single point of failure does not jeopardize the ship's safety or ability to reach port. In critical cases, maritime regulations often mandate redundancy to prevent accidents and environmental disasters. However, there are limitations to the reliability level that can be reached through redundancy in real applications [9,13]. While redundancy is also important in industrial applications, the degree of redundancy might vary depending on the criticality of the operation. Some industrial operations may prioritize redundancy, where downtime can lead to significant financial losses or safety hazards. However, not all industrial applications require the same level of redundancy as marine engines. Industrial setups may have backup power systems and safety measures to mitigate disruptions but may not always reach the extensive redundancy seen in marine vessels [14].

Safety measurements include various practices and technologies designed to prevent accidents and reduce risks, and it is also designed to protect crews, the environment, and machines [15,16]. In diesel engines, safety measurements contribute significantly to overall reliability. These safety measurements include the measurement of the emergency shutdown systems, alarms, and protective barriers. In addition, prioritizing the safety of operators working with or around diesel engines enhances the operation's overall reliability by minimizing the potential for accidents and injuries. Other safety measurements include measurements that address emissions, spills, and leaks and contribute to the reliability of these engines by ensuring compliance with environmental regulations [17,18]. Safety measurements also focus on preventive maintenance and regular inspections, which reduce the possibility of unexpected failures and disruptions. Marine diesel engines operate in complex and often unpredictable environments, including open seas, with potential hazards like storms and collisions. As a result, safety measurements include comprehensive navigation systems, life-saving equipment, and emergency response protocols. These measurements are designed to ensure the safety of passengers, crew, and the marine environment. Safety measurements for industrial diesel engines are specific to the industrial environment and associated risks. However, the scope and extent of safety measurements may not be as extensive as those required for marine engines, such as the immediate risks and environmental consequences, which may differ.

In summary, both marine and industrial diesel engines prioritize reliability, redundancy, and safety measurements, adjusting their emphasis based on the specific operating environment and associated risks. Marine engines, due to dealing with challenging and regulated maritime conditions, often incorporate higher levels of redundancy and more comprehensive safety measurements to ensure the safety of lives and the environment. Industrial engines adapt their redundancy and safety measurements based on the level of criticality of their operation and the potential consequences of failure.

4 The role of maintenance in increasing diesel engines' reliability

Maintenance practices refer to the specific tasks, activities, and routines that are carried out to ensure the proper functioning, reliability, and longevity of equipment, machinery, and systems. On the other hand, maintenance strategies are wider and more strategic approaches to managing maintenance activities. These strategies involve deciding when and how to perform maintenance based on equipment criticality, cost considerations, operational requirements, and risk management. Maintenance practices and strategies are selected to ensure that engines operate reliably, avoid costly downtime, maintain safety standards, and achieve their intended operational lifecycle [18]. By combining well-defined maintenance practices with strategic decision-making, marine and industrial diesel engines can meet reliability requirements and contribute to efficient and smooth operations [11]. In the last few years, the shipping industry has adjusted to the international standards and recommendations of the International Maritime Organisation (IMO) and other maritime regulations [10].

Strategic maintenance and practices, more specifically preventive and predictive maintenance play a vital role in improving the reliability of both marine and industrial diesel engines. These practices are designed to proactively address potential issues, minimize unplanned downtime, and extend the operational life of the engines. Preventive maintenance involves scheduled routine inspections,

servicing, and component replacements based on manufacturer recommendations and industry best practices. These maintenance activities address wear and tear before they escalate into more severe problems. Predictive maintenance involves using data-driven insights and real-time monitoring to predict when maintenance is needed. By analyzing performance data and trends, operators can take corrective actions before failures occur. Scheduled inspections, component replacements, and proactive interventions collectively prevent excessive wear and deterioration of engine components. Strategic maintenance practices extend the operational lifecycle of marine and industrial diesel engines by addressing minor issues before they develop, reducing the frequency of major overhauls, and maintaining engine performance at stable levels.

Marine vessels and industrial applications heavily rely on the consistent availability of engines. By minimizing the downtime caused by different breakdowns, these practices directly enhance the reliability of both engine types.

In marine applications, accessibility to different components for regular maintenance can be challenging due to the compact and confined spaces on vessels. While industrial engines may offer more accessible components, regular maintenance is crucial to prevent unexpected failures and maintain optimal performance.

5 Methodology of the reliability calculations

In this study, we will rely on the data from the OREDA (Offshore REliability DAta) handbook [19], which is the most comprehensive resource of reliability data in the maritime domain for reliability engineering and risk assessment. The data in the OREDA handbook is collected from various sources, including data from offshore installations, and is used by engineers and researchers to assess the reliability of equipment and systems used in offshore operations [9]. The OREDA handbook includes data on failure rates, repair rates, and other reliability-related parameters for various offshore equipment, such as pumps, valves, electrical systems, control systems, and more [19]. The handbook includes reliability data from offshore drilling and production. Unfortunately, obtaining such data for ship installations has proven to be exceedingly challenging. Consequently, the only possible solution for many reliability studies is to use a data set from OREDA. However, in our research, offshore installations expose equipment to conditions mutually relevant to both marine and industrial engines. The OREDA data presents a valuable opportunity to perform reliability analysis of both marine and industrial engines.

OREDA does not differentiate between independent and dependent failures; Independent failures in diesel engine systems occur without any direct influence from other failures. These failures are random and unrelated to the functioning or failure of other components, while dependent failures are those where the failure of one component influences or causes the failure of another component. Moreover, no alternative source of failure rate data for dependent failures has been identified. Jones [20] suggests that around 10% of failures are dependent, although the method of determining this percentage remains unclear. In order to explore the impact of even minor numbers of dependent failures on reliability, we assume in our reliability calculations that 10% of the failures considered in these scenarios are dependent. We also assumed the failure rates are exponentially distributed during the useful life phase, which means our calculation focuses on the constant part of the bath-tube curve. In addition, all the data from the OREDA handbook are measured per 10^6 hours of aggregated time in service [19].

5.1 Important metrics used for the reliability calculations

Reliability calculation for individual diesel engine components involves determining the probability that each component will perform its intended function without failure over a specified period. The specific reliability calculation method will depend on the type of component and the available data. Various mathematical models and equations could be used to calculate the reliability function depending on the component type and the available data [1]. The following two concepts are integral in the reliability analysis of diesel engine components:

1. Mean Time to Failure (*MTTF*)

MTTF is the average time expected until the first failure of a piece of equipment or a system. It's a statistical measure typically used for non-repairable systems or where repair is not economically feasible. *MTTF* (1) is often used in systems with redundant components, where it helps determine the overall system reliability.

$$MTTF = 1 / \lambda \qquad [h] \qquad (1)$$

where: λ is the failure rate of the component.

2. Exponential Distribution

The exponential distribution is commonly used to model the failure rate behavior of components or systems that exhibit a constant failure rate over time. It assumes that failures occur randomly and are unrelated to previous failures. The failure rate (λ) represents the rate at which failures occur and remains constant throughout the component's life. The reliability function (2) for components following an exponential distribution can be calculated using the following equation:

$$R(t) = exp(-\lambda t) \qquad (2)$$

where: $R(t)$ is the reliability at time t;
λ is the failure rate parameter.

The failure rate parameter can be estimated using historical failure data or testing and analysis. The exponential distribution assumes independence between

failures, which may not be valid when failures depend on previous events or conditions. Therefore, it's crucial to evaluate the appropriateness of the exponential distribution and consider alternative distributions or models if necessary.

6 Case studies for different heat exchanger models at offshore installations

Diesel engine heat exchangers are selected as the equipment unit for analysis in this study because they are one of the distinguishing units between marine diesel engines and industrial diesel engines. Heat exchangers are a vital component that transfers heat from the engine coolant to a separate cooling fluid; marine engines usually use seawater. It helps regulate the temperature of the coolant by dissipating excess heat. Industrial diesel engines also commonly use heat exchangers to maintain optimal operating temperatures.

There are several types of heat exchangers used for both marine diesel engines and industrial diesel engines. The specific type of heat exchanger utilized can vary based on engine design, cooling system requirements, and space limitations. A few common types are Fin fan heat exchangers, Plate heat exchangers, and Shell & Tube heat exchangers. The failure rate characteristics of heat exchangers can vary depending on design, material quality, maintenance practices, operating conditions, and the engine's environment. When properly maintained, heat exchangers generally have a relatively constant failure rate throughout their operational life.

The following results demonstrate the failure rates at critical failure modes for marine and industrial engines, in the case of different heat exchanger models, Mean Time to Failure values, and reliability function, in addition to the possible applications in marine diesel engines and industrial diesel engines. Also, the following results show the influence of dependent and independent failures on the reliability function by assuming 10% of the failures caused by dependent reasons and comparing these results to the 100% independent failures. In the context of heat exchangers in diesel engines, understanding whether a failure is independent, or dependent is crucial for designing robust systems. Independent failures may be addressed through regular maintenance and monitoring of individual components. On the other hand, dependent failures might require additional safeguards, such as redundant components or backup systems, to prevent failures that could compromise the overall reliability and performance of the diesel engine.

The possible independent and dependent failure in the case of the heat exchangers can be the following:

1. Independent failures in heat exchangers: For example, the degradation of a heat exchanger's fin due to corrosion over time. This is an independent failure as it occurs without being directly influenced by the state of other components. It may lead to reduced heat transfer efficiency but does not cause failures in other parts of the system.

2. Dependent failures in heat exchangers: For example, the failure of a coolant pump in the engine cooling system leads to insufficient coolant flow through the heat exchanger. This dependent failure can result in increased temperatures in the engine, potentially causing other components, such as gaskets or seals, to fail due to overheating.

6.1 First case study: Fin fan heat exchangers

Fin fan heat exchangers, also known as air-cooled or finned-tube heat exchangers, are widely used in various industries, including marine and industrial applications. These heat exchangers are crucial in dissipating heat from process fluid to the surrounding air through finned tubes and fans. They are commonly used when water sources are rare or when processed fluids need to be cooled without direct contact with cooling water.

In Table 3, we used failure rate (λ_i) values at different failure modes, which have been collected in the OREDRA handbook from empirical observations on offshore platforms. These failure rate modes are Insufficient heat transfer, Minor in-service problems, and Parameter deviation. The term "parameter deviation" refers to a situation where one or more critical parameters deviate from their expected or designed values, leading to a potential failure or degradation in the performance of the heat exchanger. These parameters could include factors such as temperature, pressure, flow rates, or other operational conditions. These failure rate values are used to calculate *MTTF* by applying equation (1), and this analysis is conducted in two cases: a) all failures are evolved due to independent factors; b) only 90% of failures are evolved due to independent factors and 10% are evolved due to dependent factors. This comparison allows us to evaluate the impact of sustaining the optimal performance of all equipment within the system.

Table 3 Failure rate and MTTF results for Fin fan heat exchanger [19]

Critical Failure modes	a) λ_i [h^{-1}]	***MTTF*** [h]		b) ***90%*** λ_i [h^{-1}]	***MTTF*** [h]
1. Insufficient heat transfer	$\lambda_1 = 6.84 \cdot 10^{-6}$	$146.198 \cdot 10^{+3}$		$6.156 \cdot 10^{-6}$	$162.443 \cdot 10^{+3}$
2. Minor in-service problems	$\lambda_2 = 3.42 \cdot 10^{-6}$	$292.397 \cdot 10^{+3}$		$3.078 \cdot 10^{-6}$	$324.886 \cdot 10^{+3}$
3. Parameter deviation	$\lambda_3 = 3.42 \cdot 10^{-6}$	$292.397 \cdot 10^{+3}$		$3.078 \cdot 10^{-6}$	$324.886 \cdot 10^{+3}$
4. Other*	$\lambda_4 = 3.42 \cdot 10^{-6}$	$292.397 \cdot 10^{+3}$		$3.078 \cdot 10^{-6}$	$324.886 \cdot 10^{+3}$

**Other includes (Abnormal instrument reading, Internal leakage, Plugged/Choked, and Structural deficiency).*

The results in Table 3 illustrate how even a small impact, such as 10% from other equipment inefficiencies, affects the failure rate. This influence manifests as a reduction in the service time of the heat exchanger, ranging

from a minimum of (*MTTF* = 16,245 hours) to a maximum of (*MTTF* = 32,489 hours); (these numbers represent the difference in *MTTF* values before and after removing 10% of the failure rate λ_i), highlighting the potential variability in the operational lifecycle due to this impact. Table 4 shows reliability calculation in the cases of 4 scenarios: 1.) Insufficient heat transfer (mainly related to marine applications); 2.) Parameter deviation (mainly related to industrial applications); and Cumulative failure rates in both cases; 3.) 90% of failures are evolved due to independent factors, and 4.) all failures are developed due to independent factors. The reliability values in these four scenarios are calculated by equation (2). These results provide the reliability of the heat exchanger at different calendar times (t_I = 2500 [h], t_{II} = 5000 [h], t_{III} = 7500 [h], and t_{IV} = 10000 [h]).

Table 4 Reliability calculation at different calendar times t_i

Fin fan heat exchanger	**Reliability of the heat exchanger**			
	t_I **= 2500** [h]	t_{II} **= 5000** [h]	t_{III} **= 7500** [h]	t_{IV} **= 10000** [h]
Insufficient heat transfer	98.3	96.63	94.99	93.38
Parameter deviation	99.14	98.30	97.46	96.63
$\Sigma\,\lambda_i$ [h^{-1}]	95.81	91.80	87.96	84.28
Σ 90% λ_i [h^{-1}]	96.22	92.59	89.09	85.73

The results in Table 4 illustrate the importance of understanding different failure rates and their impact on the reliability of fin fan heat exchangers in various applications, including marine and industrial diesel engines. The differential failure modes experienced by marine and industrial diesel engines can be attributed to several critical factors, including the distinct operating environments, cooling fluids, and operational requirements. As time passes, the reliability of the heat exchanger decreases. This is noticeable from the decreasing values in the "Reliability of the heat exchanger" columns. Figure 1 shows the fin fan heat exchangers' reliability function at different failure modes, demonstrating the relation between reliability function *R(t)* and time.

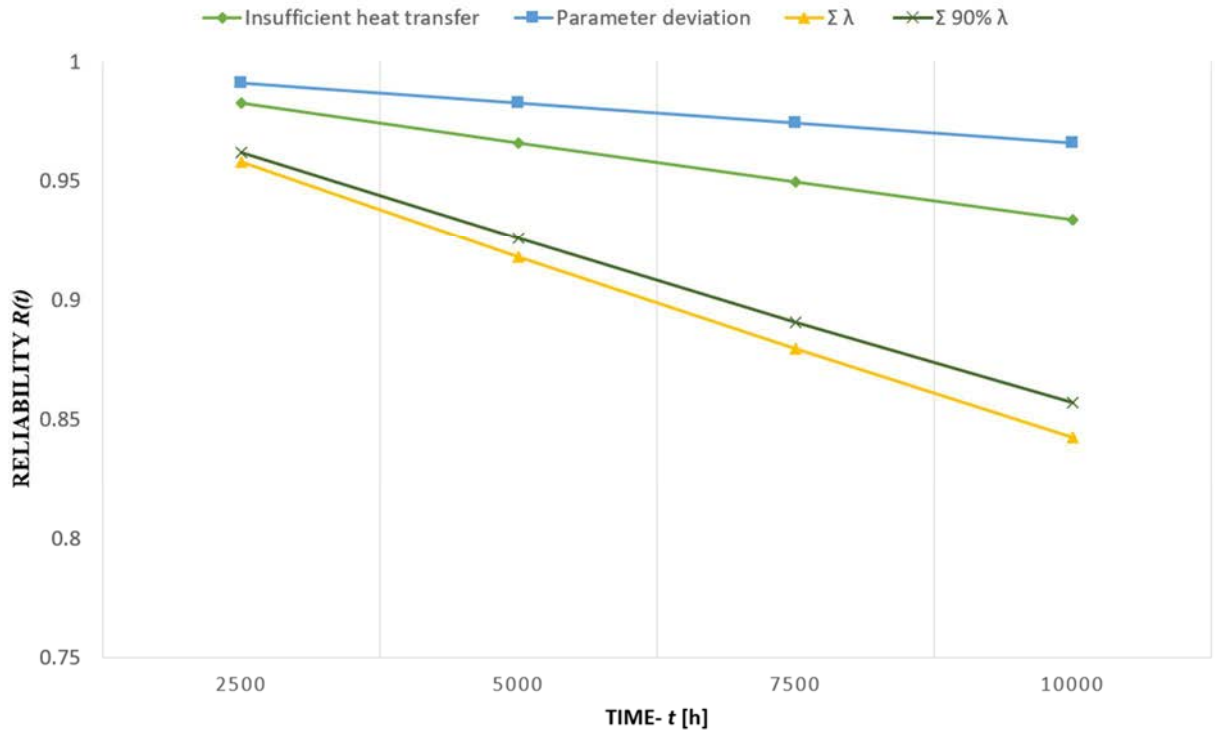

Figure 1 Reliability function at different failure modes (Fin fan heat exchangers)

Cumulative failure rates ($\Sigma\,\lambda i$) represent the combined failure rates of all identified failure modes (yellow line in Figure 1). It provides a measure of the overall reliability (*R(t)*) of the heat exchanger. As time progresses, the cumulative failure rate increases, which increases the probability of failure. Tables 3-4, and Figure 1 show how even a small change in the failure rate can significantly affect both the cumulative failure rate and *MTTF*. For instance, if the failure rate for "Insufficient heat transfer" were slightly higher or lower, it would have a notable

impact on the overall reliability and *MTTF* of the heat exchanger. Insufficient heat transfer (green line in Figure 1) in marine diesel engines is often related to fouling and corrosion caused by a corrosive nature like seawater, which links this type of failure rate primarily to marine applications.

Industrial diesel engines typically operate in controlled environments with less exposure to corrosive elements. Therefore, the corrosion resistance challenge is less severe in industrial applications. Industrial engines typically have complex control systems to maintain temperature and flow rate parameters. Errors or malfunctions in these systems can lead to parameter deviation (blue line in Figure 1), affecting heat exchanger performance.

Heat exchangers' failure modes and rates can vary between marine and industrial applications. The specific failure modes and their frequencies can be influenced by factors such as the type of fluids being cooled, the operating conditions, and the maintenance practices. For example, marine engines may be more susceptible to structural deficiencies due to the harsh environment. In contrast, industrial engines might face more minor in-service problems related to processing fluids. Marine heat exchangers must be highly resistant to corrosion caused by saltwater. This necessitates using specialized materials and coatings to protect the fine tubes and other components from deterioration. While industrial engines may not face the same level of corrosion as marine engines, they still require corrosion-resistant materials, especially when dealing with chemically aggressive fluids.

6.2 Second case study: Plated heat exchangers

Plated heat exchangers are valuable marine and industrial diesel engine components. These heat exchangers are vital in managing heat and maintaining efficient engine operation, whether for cooling systems, heat recovery, or other applications. The plates are typically made of materials such as stainless steel or titanium to ensure efficient heat transfer and corrosion resistance.

In Table 5, we used failure rate values at different failure modes, which have been collected in the OREDRA handbook [20] from empirical observations on offshore platforms. The critical failure modes are external leakage - Process medium, external leakage - Utility medium, and parameter deviation. The failure rate values are used to calculate *MTTF* by applying equation (1), and this analysis is conducted in two cases: a.) all failures are evolved due to internal factors; b.) only 90% of failures are developed due to internal factors, and 10% are developed due to external factors.

Table 5 Failure rate and MTTF results for Plated heat exchanger [19]

Critical failure modes	**a)** λ_i [h^{-1}]	***MTTF*** [h]		**b)** ***90%*** λ_i [h^{-1}]	***MTTF*** [h]
External leakage - Process medium	$\lambda_1 = 9.49 \cdot 10^{-6}$	$105.374 \cdot 10^{+3}$		$8.541 \cdot 10^{-6}$	$117.082 \cdot 10^{+3}$
External leakage - Utility medium	$\lambda_2 = 4.34 \cdot 10^{-6}$	$230.414 \cdot 10^{+3}$		$3.906 \cdot 10^{-6}$	$256.016 \cdot 10^{+3}$
Parameter deviation	$\lambda_3 = 4.34 \cdot 10^{-6}$	$230.414 \cdot 10^{+3}$		$3.906 \cdot 10^{-6}$	$256.016 \cdot 10^{+3}$

The results in Table 5 illustrate how even a small impact, such as 10% from other equipment inefficiencies, affects the failure rate. This influence manifests as a reduction in the service time of the heat exchanger, ranging from a minimum of (*MTTF* = 11,708 hours) to a maximum of *MTTF* = 25,602 hours); (These numbers represent the difference in *MTTF* values before and after removing 10% of the failure rate λ_i), highlighting the potential variability in the operational lifecycle due to this impact. Table 6 shows reliability calculation in the case of 4 scenarios, which are the following: 1.) External leakage - Process medium; 2.) External leakage - Utility medium; Cumulative failure rates in two cases: 3.) 90% of failures are evolved due to independent factors; furthermore, 4.) Cumulative failure rates in case of all the failures are evolved due to independent factors. The reliability values in these four scenarios are calculated by equation (2). These results provide the reliability of the heat exchanger at different calendar times (t_I = 2500 [h], t_{II} = 5000 [h], t_{III} = 7500 [h], and t_{IV} = 10000 [h]).

Table 6 Reliability calculation at different calendar times t_i

Plate heat exchangers	**Reliability of the heat exchanger**			
	t_I **= 2500** [h]	t_{II} **= 5000** [h]	t_{III} **= 7500** [h]	t_{IV} **= 10000** [h]
External leakage - Process medium	97.65	95.36	93.12	90.94
External leakage - Utility medium	98.92	97.85	96.79	95.75
$\Sigma\, \lambda_i$ [h^{-1}]	95.55	91.31	87.26	83.38
$\Sigma\, 90\%\, \lambda_i$ [h^{-1}]	95.99	92.14	88.45	84.91

The results in Table 6 illustrate the importance of understanding different failure rates and their impact on the reliability of plated heat exchangers in various applications. The differential failure modes experienced by marine and industrial diesel engines can be attributed to several critical factors, including the distinct operating environments, cooling fluids, and operational requirements. As time passes, the reliability of the heat exchanger decreases. Figure 2 shows the reliability function of plated heat exchangers at different failure modes, demonstrating the relation between reliability function *R(t)* and time.

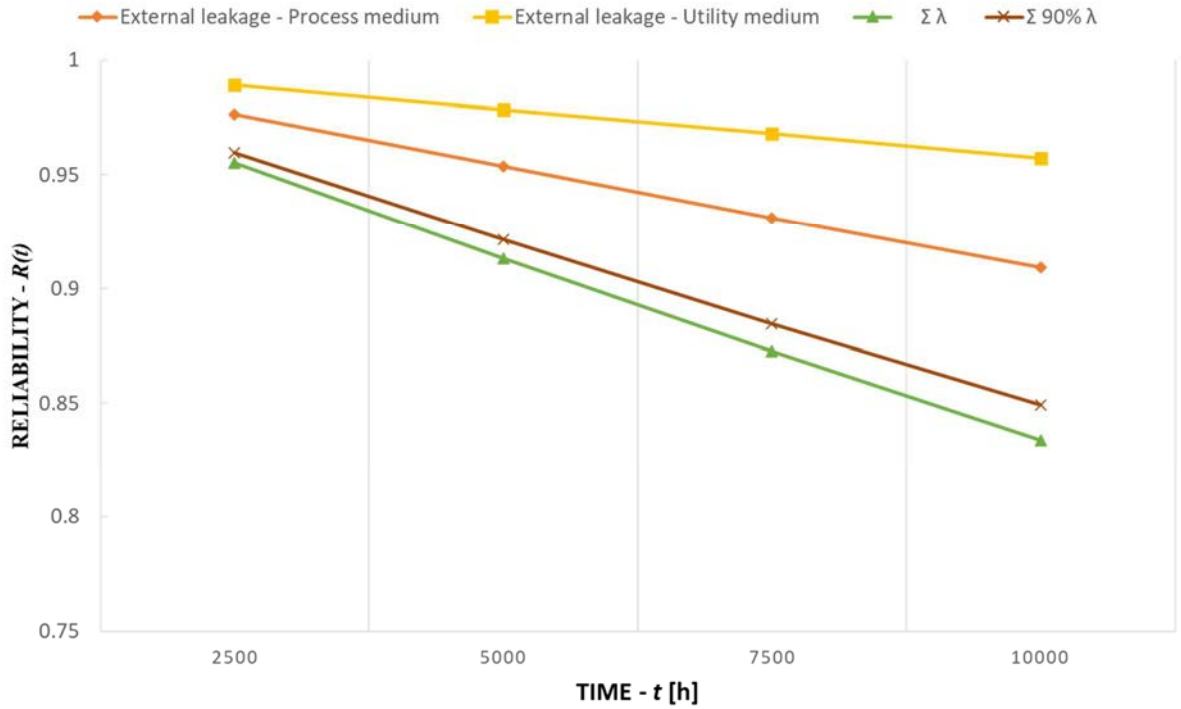

Figure 2 Reliability function at different failure modes (Plate heat exchangers)

The failure modes demonstrated in Figure 2, Table 5, and Table 6 include "External leakage - Process medium; (orange line in Figure 2)" and "External leakage - Utility medium; (yellow line in Figure 2)" are critical for both marine and industrial applications in a different perspective. Leakage can lead to the mixing of fluids, efficiency loss, and potential damage. "Parameter deviation" is another failure mode listed, which indicates that deviations in operating parameters (e.g., temperature, pressure) can impact heat exchanger performance. This is a common challenge in both marine and industrial applications. It also demonstrates that the reliability of plated heat exchangers decreases over time. This indicates that as the heat exchanger operates for longer durations, its reliability decreases, and the probability of experiencing a failure increases, which requires proactive maintenance to extend *MTTF*. Cumulative failure rates ($\Sigma \lambda_i$) represent the combined failure rates of all identified failure modes (green line in Figure 2). It provides a measure of the overall reliability ($R(t)$) of the heat exchanger. As time progresses, the cumulative failure rate increases, which increases the probability of failure.

In marine applications, accessibility to heat exchangers for maintenance can be challenging due to the limited space on vessels. Industrial engines may offer more accessible heat exchangers, making maintenance easier. However, Industrial engines may deal with a broader range of fluid properties, including chemicals and contaminants, which can affect the performance and longevity of plated heat exchangers. Monitoring and maintenance strategies must be adapted accordingly.

6.3 Third case study: Shell & Tube heat exchangers

Shell & Tube heat exchangers are another type commonly used in marine and industrial diesel engines to facilitate heat transfer between fluids. These heat exchangers help regulate the temperature of the engine coolant by transferring heat from the coolant to a separate cooling medium, such as seawater, which prevents engine overheating and ensures efficient operation. Shell and tube heat exchangers are durable and can withstand harsh operating environments, making them suitable for marine and industrial applications. In addition, this type of heat exchanger is designed for easy inspection and cleaning, with removable tubes that facilitate maintenance activities.

In Table 7, we used failure rate values at different failure modes, which have been collected in the OREDRA handbook from empirical observations on offshore platforms. The critical failure modes are 1.) Abnormal instrument reading, 2.) External leakage-process medium, 3.) Parameter deviation, and 4.) Structural deficiency. These failure rate values are used to calculate *MTTF* by applying equation (1), and this analysis is conducted in two cases: a.) All failures are evolved due to internal factors. b.) Only 90% of failures are developed due to internal factors, and 10% are developed due to external factors. This comparison allows us to evaluate the impact of sustaining the optimal performance of all equipment within the system.

Table 7 Failure rate and MTTF results for Shell & tube heat exchanger [19]

Critical failure modes	**a)** λ_i [h^{-1}]	***MTTF*** [h]		**b)** ***90%*** λ_i [h^{-1}]	***MTTF*** [h]
Abnormal instrument reading	$\lambda_1 = 17.39 \cdot 10^{-6}$	$57.504 \cdot 10^{+3}$		$15.651 \cdot 10^{-6}$	$63.893 \cdot 10^{+3}$
External leakage – Process medium	$\lambda_2 = 7.67 \cdot 10^{-6}$	$130.378 \cdot 10^{+3}$		$6.903 \cdot 10^{-6}$	$144.864 \cdot 10^{+3}$
Parameter deviation	$\lambda_3 = 4.49 \cdot 10^{-6}$	$222.717 \cdot 10^{+3}$		$4.041 \cdot 10^{-6}$	$247.463 \cdot 10^{+3}$
Structural deficiency	$\lambda_4 = 8.07 \cdot 10^{-6}$	$123.915 \cdot 10^{+3}$		$7.263 \cdot 10^{-6}$	$137.684 \cdot 10^{+3}$

The results in Table 7 illustrate how even a small impact, such as 10% from other equipment inefficiencies, affects the failure rate. This influence manifests as a reduction in the service time of the heat exchanger, ranging from a minimum of (*MTTF* = 6,389 hours) to a maximum of (*MTTF* = 13,769 hours); (These numbers represent the difference in *MTTF* values before and after removing 10% of the failure rate λ_i), highlighting the potential variability in the operational lifecycle due to this impact. Table 8 shows reliability calculation in the case of 6 scenarios: 1.) Abnormal instrument reading; 2.) External leakage - Process medium; 3.) Parameter deviation; 4.) Structural deficiency; 5.) Cumulative failure rates in the case of 90% of failures developed due to independent factors; furthermore, 6.) Cumulative failure rates in case of all failures are developed due to independent factors. The reliability values in these six scenarios are calculated by equation (2). These results provide the reliability of the heat exchanger at different calendar times (t_I = 2500 [h], t_{II} = 5000 [h], t_{III} = 7500 [h], and t_{IV} = 10000 [h]).

Table 8 Reliability calculation at different calendar times t_i

Shell & Tube heat exchanger	**Reliability of the heat exchanger**			
	t_I **= 2500** [h]	t_{II} **= 5000** [h]	t_{III} **= 7500** [h]	t_{IV} **= 10000** [h]
Abnormal instrument reading	95.74	91.67	87.77	84.03
External leakage - Process medium	98.10	96.23	94.40	92.61
Parameter deviation	98.88	97.78	96.68	95.60
Structural deficiency	98.00	96.04	94.12	92.24
$\Sigma\, \lambda i$ [h^{-1}]	97.85	95.75	93.70	91.69
$\Sigma\, 90\%\ \lambda i$ [h^{-1}]	98.06	96.17	94.31	92.49

The results in Table 8 illustrate the importance of understanding different failure rates and their impact on the reliability of shell and tube heat exchangers in various applications, including marine and industrial diesel engines. The differential failure modes experienced by marine and industrial diesel engines can be attributed to several critical factors, including the distinct operating environments, cooling fluids, and operational requirements. As time passes, the reliability of the heat exchanger decreases. This is noticeable from the decreasing values in the "Reliability of the heat exchanger" columns. Figure 3 shows the reliability function of Shell & Tube heat exchangers at different failure modes, demonstrating the relation between reliability function *R(t)* and time.

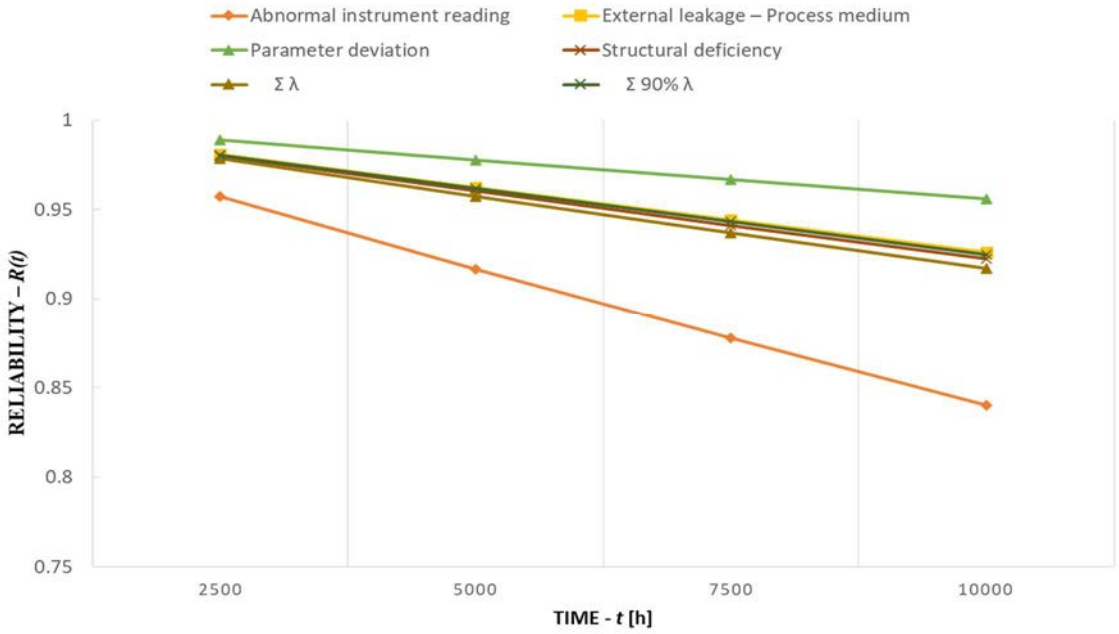

Figure 3 Reliability function at different failure modes (Shell & Tube heat exchangers)

The provided data in Figure 3, Tables 7-8 shows several critical failure modes and their associated failure rates (λ). "External leakage – Process medium" and "Parameter deviation" are listed as failure modes, similar to the challenges faced by plate and fine tube heat exchangers. In addition, "Structural deficiency" is another failure mode, indicating potential structural issues in the heat exchanger. This can be a concern, especially in marine applications where the equipment may be subjected to vibrations and extreme conditions. Table 8 shows the reliability of the shell and tube heat exchanger at different calendar times. Like the other heat exchanger types, shell and tube heat exchangers experience decreased reliability over time. Proper maintenance practices are essential to extend the Mean Time Between Failures (*MTTF*) and ensure efficient operation. Cumulative failure rates ($\Sigma\ \lambda_i$) represent the combined failure rates of all identified failure modes (brown line in Figure 3). It provides a measure of the overall reliability (*R(t)*) of the heat exchanger. As time progresses, the cumulative failure rate increases, which increases the probability of failure. The following chart demonstrates a Comparison of *MTTF* and Reliability in the case of the three heat exchanger types.

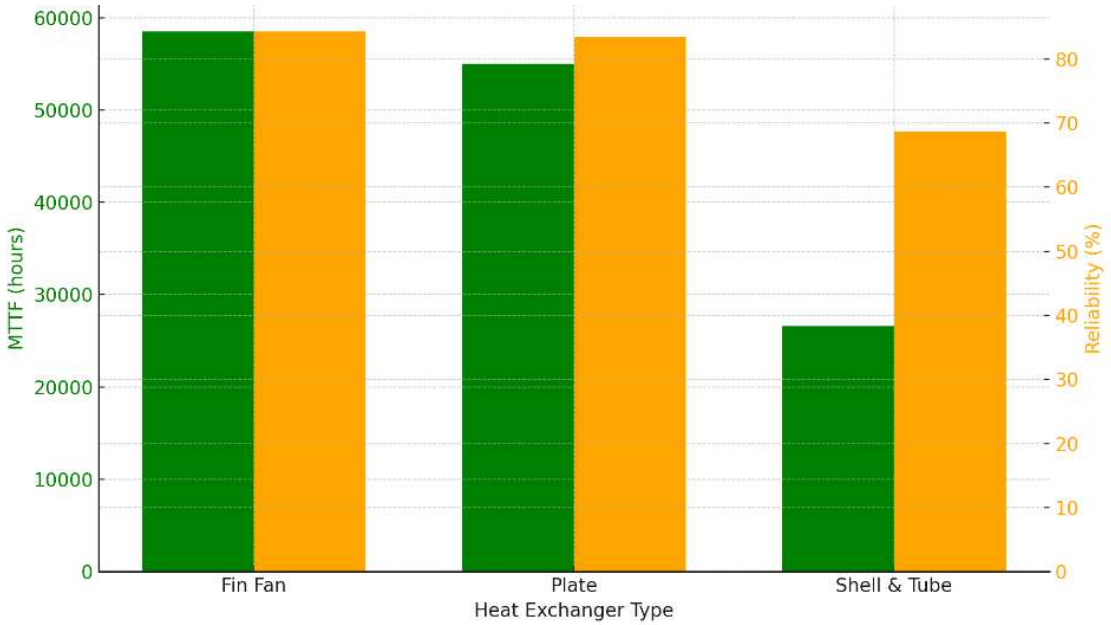

Figure 4 Comparison of MTTF and Reliability in the case of the three heat exchanger types

In Figure 4, two key parameters, *MTTF* and Reliability, are compared for the three types of heat exchangers (Fin Fan, Plate, and Shell & Tube).

1. *MTTF* is represented in hours. This parameter indicates the average operational time before a failure is expected. The higher the *MTTF*, the longer the component is expected to function without failure. In this Figure, it is shown on the left *Y*-axis in green.

2. Reliability is expressed as a percentage. This reflects the probability of a heat exchanger operating without failure for a specific duration (in this context at t_{IV} = 10000 hours). Higher reliability percentages indicate a greater likelihood of the component functioning correctly over time. It is displayed on the right *Y*-axis in orange.

By comparing these two parameters, we can see how each type of heat exchanger performs in terms of both longevity (*MTTF*) and consistent performance (*Reliability*) over time. This comparative analysis aids in understanding the strengths and weaknesses of each heat exchanger type in practical applications.

In summary, while these heat exchangers are used in marine and industrial diesel engines to manage temperature and heat transfer, the specific challenges and operating conditions can lead to differences in the choice of materials, maintenance practices, and strategies for addressing failure modes. Our research contributes to a deeper understanding of diesel engine reliability in marine and industrial contexts. We demonstrated that while both engine types share some common reliability challenges, each also faces unique conditions that require specific strategies and solutions. The study offers valuable insights into three types of heat exchangers, enhancing our understanding of diesel engine components. It provides a foundation for further research and development, aiming to improve the performance and safety of these critical engines in their respective sectors.

7 Conclusions

This paper has explored the reliability requirements for both marine and industrial diesel engines, emphasizing their main roles in marine vessels and various industrial applications. The comparative analysis conducted throughout this study has shed light on several vital factors

that distinctly influence the reliability of each engine type, thereby offering valuable insights into their unique challenges and considerations. Our comprehensive study on the reliability of different heat exchanger models used in marine and industrial diesel engines focused on Fin fan heat exchangers, Plate heat exchangers, and Shell & Tube heat exchangers, assessing their failure rates, *MTTF*, and the impact of independent and dependent failures on their reliability.

The study reveals distinct failure modes in heat exchangers, including insufficient heat transfer, external leakage, parameter deviation, and structural deficiencies, which affect marine and industrial diesel engines differently. In marine engines, which frequently use seawater in heat exchangers, the challenges of corrosion and fouling are prominent. Conversely, industrial engines primarily face issues related to system controls and parameters, typically operating in less corrosive environments. A significant result is a 10% alteration in failure rates, attributable to equipment inefficiencies, impacting the Mean Time to Failure (*MTTF*), pointing to the necessity for robust design and diligent maintenance strategies. Effective management of independent failures such as corrosion can be achieved through routine maintenance, whereas dependent failures, leading to conditions such as overheating, require more sophisticated solutions, including the incorporation of redundancy and backup systems to maintain overall engine reliability. The selection of materials and the design of heat exchangers are especially crucial in marine applications where corrosion resistance is a key consideration. Furthermore, the study underscores the importance of maintenance and monitoring, especially in industrial settings, where proactive maintenance strategies are fundamental to enhancing reliability and prolonging *MTTF*.

In summary, this study offers a comprehensive analysis of heat exchanger reliability in marine and industrial diesel engines. It highlights the need to consider a spectrum of factors, from environmental conditions to specific failure modes, maintenance practices, and material selections. These insights are vital for improving the operational efficiency and longevity of heat exchangers, providing valuable guidance for the design and operation of diesel engines across varied industrial and marine applications.

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