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Application of The Analytic Hierarchy Process (AHP) in Strategic Factory Selection for Putra Madura Sejati Cigarette Company in Pamekasan

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Abstract - **The tobacco industry in Indonesia is developing rapidly. Indonesia is the fifth-largest tobacco-producing country. Cigarettes are one of the sectors that contribute the most to excise and foreign exchange revenues for the country. With the rapid growth of the cigarette industry, producers must devise effective strategies to continue competing and developing in this market, one of which is finding a strategic factory location that ensures consumer satisfaction. The purpose of this study is to find the best location for the PR Putra Madura Sejati cigarette factory based on the criteria of accessibility, environment, workforce, market, and traffic. And the alternative locations that will be selected in this research are located in the Pamekasan district, namely on Blumbungan Street, Bangunran Street, Larangan Street, and Pademawu Street. The method used this time is the Analytical Hierarchy Process (AHP). Based on the results of the pairwise comparison between the criteria, this time it shows that the accessibility criterion has a value of 0.09, the environment has a value of 0.23, the workforce has a value of 0.47, the market has a value of 0.05, and traffic has a value of 0.16. then the results of the pairwise comparison between the accessibility criteria with all alternatives obtained the nyalaran road alternative has the highest value with 0.59, environmental criteria with the alternative namely nyalaran road highest with 0.53, workforce criteria with the alternative namely blumbungan road highest with 0.49, market criteria with the alternative namely pademawu road with 0.49, and traffic criteria with the alternative namely nyalaran road with 0.52. The final result of the pairwise comparison between all alternatives and all criteria shows that Jalan Nyalaran is the best location to be selected, with a value of 41.6. The author advises PR Putra Madura Sejati to continue implementing strategies by getting closer to the market and selecting skilled workers so that the quality of the cigarettes created will be better and can provide satisfaction to consumers.**

Index Terms: About; AHP, Customer Satisfaction, cigarette factory, location selection

I. INTRODUCTION

The cigarette industry is one of the fastest-growing industries in Indonesia and globally. Currently, the cigarette business is gaining popularity among entrepreneurs due to its high demand. Indonesia is the fifth-largest tobacco producer in the world, with total production in 2011 reaching 256 million cigarettes [Salsabila et al, 2022]. Along with the high demand, innovation among cigarette businesses is increasing. In addition to the clove cigarettes that are the hallmark of Indonesian cigarettes, filtered cigarettes are now being developed, even with various flavors and menthol, which are in high demand among young people. With the growing and booming cigarette industry, this business has become a pillar of the regional and national economy. The tobacco industry is one of the sectors that contributes the majority of state revenue through tobacco excise revenue and contributes significantly to foreign exchange earnings through cigarette and cigar exports [Prayoga dan Kusuma, 2020].

Cigarettes are one of the tobacco industries that have developed rapidly in Indonesia from the 19th century to the present day. There are several types of cigarettes consumed by the Indonesian people, ranging from hand-rolled kretek cigarettes, machine-rolled kretek cigarettes, and machine-rolled white cigarettes with a variety of flavors. Cigarettes have become a daily necessity and a necessity for those who smoke because they contain addictive substances that make users addicted to them. The chemical in cigarettes is nicotine, which is dangerous because it is addictive. Smokers who try to quit will find it difficult due to nicotine withdrawal symptoms. [Kodir dan Anggarawati, 2022]. With such rapid demand and proximity to the source of raw materials, namely tobacco, many businesses have

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begun to emerge in Pamekasan, East Java, operating in the cigarette industry. Tobacco cigarette factories in Indonesia are one of the many industries contributing to the government's taxation sector. The increase in excise revenue since 2009 has played a significant role in this revenue, *Anggaran Pendapatan dan Belanja Negara* (APBN) [Samuel, 2022]. PR Putra Madura Sejati is one of the cigarette companies that exists in Pamekasan Regency, producing hand-rolled kretek cigarettes. PR Putra Madura Sejati is passionate about preserving the tobacco industry and providing employment opportunities for the surrounding community, thereby helping to support the regional and national economy. PR Putra Madura Sejati is currently located in Cenlecen Village, Pakong District, Pamekasan Regency. Over time, with the premises not too large and demand continuing to increase significantly, PR Putra Madura Sejati wants to establish a second factory as a form of commitment to meet consumer needs with various criteria that will later become a reference in selecting a location such as accessibility, the environment around the factory, the availability of labor in the area, proximity to markets, and adequate traffic. Location is a company's decision to determine the place of business, carry out business activities or operational activities, and distribute goods or services that are part of its business activities to consumers. [Harani et al, 2022].

This study uses the Analytical Hierarchy Process (AHP) method as a method for selecting alternative solutions based on criteria, so that it becomes a decision-making method used to determine the location of the PR PMS factory. This method can make effective decisions on complex issues by simplifying and accelerating the decision-making process [Capryani et al, 2016]. Basically, the Analytical Hierarchy Process (AHP) is a method for solving a complex and unstructured problem into groups, arranging the groups into a hierarchy, entering numerical values as a substitute for human perception, making relative comparisons, and finally, with a synthesis, determining which element has the highest priority. The Analytical Hierarchy Process (AHP) is an appropriate method for solving the problem of selecting a business location because it is able to accommodate various criteria with different importance weights in a hierarchical framework [Aritonang dan Rizky, 2025]. AHP is an analysis method that has advantages and disadvantages. The advantages of the AHP method are its hierarchical structure, as a consequence of the selected criteria, down to the deepest sub-criteria. In addition, it takes into account validity up to the tolerance limit of inconsistency as the criteria and alternatives chosen by the decision maker, and takes into account the durability of the output of the decision-making sensitivity analysis [Permatasari, 2020].

Several previous studies related to location selection using the AHP method were conducted by [Capryani et al, 2016] at the office in Surakarta, at the restaurant location [Habibruhman dan HAmali, 2023], general business location [Sudasmoro dan Wendhasmoro, 2025]Home industry business locations in Pringsewu Regency [Susilowati, 2019]. This study used different criterion variables and alternative locations. The differences between this study and previous studies lie in the research object and data variables. This study sought to identify the best location for a cigarette factory based on accessibility, environment, workforce, market, and traffic. The authors are trying to determine the best location for the PR Putra Madura Sejati cigarette factory so that the company can increase its production capacity, improve its competitiveness, and be better known in the market to provide greater revenue.

I. RESEARCH METHODOLOGY

In this research methodology, we will discuss the stages of identifying problems and determining the objectives and methods that will be used to process the data that has been obtained in accordance with the objectives that have been set. First, the problem identification stage, the initial stage of this research, involves clearly defining the problem and the case study to be used. In this study, the problem raised is the location selection for the PR Putra Madura Sejati factory. Next, the objectives to be achieved from this research are determined, providing guidelines and reminders for researchers to focus on the predetermined objectives and avoid deviations from the objectives in this study. Furthermore, a literature review is used to provide researchers with further insight, sourced from previous research or journals, and to ensure that this research has never been conducted before. The respondents, as experts in this study, are the owners or directors of PR RMS who have

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conducted observations for these criteria and alternatives.

Data collection was carried out by gathering the necessary data, including primary data, which is data generated through observations and interviews with business owners regarding the business's strategy or business plan. Secondary data, which is existing data that does not require further observation by the researcher.

The data processing stage of the study discusses the factors or criteria that influence decision-making in determining the location of the PR Putra Madura Sejati factory. The researchers selected four alternative locations in Pamekasan Regency, East Java: Jalan Blumbungan, Jalan Nyalaran, Jalan Larangan, and Jalan Pademawu. The researchers focused on these four locations as alternatives in solving the problem of selecting the location of the PR Putra Madura Sejati factory.

Data processing was performed using the Analytical Hierarchy Process (AHP) approach. AHP also evaluates the consistency of decision-making by examining the consistency of the pairwise comparison matrix. This is essential to ensure that decisions are based on consistent and accountable comparisons. [1Sudarsono dan Wendhasmoro, 2025]. AHP is a method that aims to create a priority ranking for a decision and choose the best decision by considering existing criteria and by developing a numerical value as a ranking for each decision alternative [Habibruohman dan Hamali, 2023]. Based on the processing stages using the Analytical Hierarchy Process (AHP) method approach, namely:

a) Define the problem and determine the desired solution
b) Create a hierarchical structure that starts with the main objective
c) Create a pairwise comparison matrix that describes the relative contribution or influence of each element on the objectives or criteria at the same level as it
d) Define pairwise comparisons so that the number of assessments obtained is n X [(n-1) / 2], where n is the number of elements being compared
e) Calculate eigenvalues and test their consistency
f) Repeat steps 3,4 and 5 for all hierarchical levels
g) Calculate the eigenvectors of each pairwise comparison matrix
h) Checking the consistency of the hierarchy

II. RESULT AND DISCUSSION

These results and discussion contain data that the author has collected and processed to find the best decision in determining the appropriate location for the PR Putra Madura Sejati factory. The data used includes the criteria for selecting a business location and the alternatives provided.

A. Define the problem and determine the solution

At this stage, we will define the problem clearly so that the solution we choose is appropriate and appropriate to the problem. The following are the alternatives that will be tested based on the definition of each criterion.

a. Blumbungan

Blumbungan Road is easily accessible by public transportation. Located north of Pamekasan, it serves as the main road leading to the north coast of Java, particularly to tobacco-producing areas. This densely populated area is very close to markets. There is still land available, ready for use in cigarette factories. Traffic access is unimpeded, making it easy to conduct business.

b. Nyalaran

Nyalaran Road is easily accessible, has good road infrastructure, and is located north of Pamekasan City, providing access to tobacco-producing areas. This densely populated area still has plenty of vacant land ready for cigarette factories. This competitive strategy is highly effective, as Nyalaran is home to numerous tobacco warehouses and the emergence of local cigarette factories. Traffic access is adequate and unobstructed, ensuring smooth operations.

c. Larangan

This Larangan Road is easily accessible, being the main access road to Sumenep Regency. This area is densely populated, but there is still land available for building factories. Located east of Pamekasan City, this area is also home to a growing number of local cigarette factories.

d. Pademawu

The Pademawu area is still largely empty and not densely populated. Located east of Pamekasan City, it provides access to the Pamekasan coastal area. Accessibility is easy, and road infrastructure is adequate, although some roads are still in poor

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condition. There are no operating cigarette factories in the area.

B. Hierarchical Structure

After defining the objectives, criteria, and alternatives to be taken for the decision-making process of selecting the location of the PR Putra Madura Sejati factory, a hierarchical structure was created with the main objective at the top level being the selection of the cigarette factory location. The second level was comprised of five decision-making criteria: accessibility, environment, labor, market, and traffic. The third or lowest level consisted of alternatives, namely Blumbungan Street, Nyalaran Street, Larangan Street, and Pademawu Street.

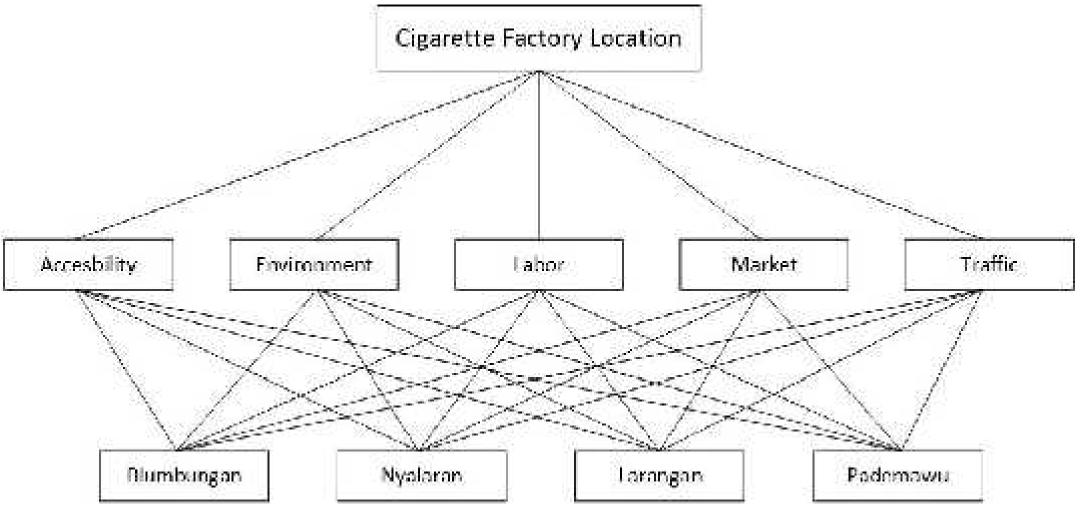

Figure 1. Hierarchical Structure

C. Calculation of the pairwise comparison matrix of alternatives and criteria

a. Pairwise Comparison Matrix of Criteria

From the results of the weighting and calculations that can be seen in Table 1 for each of the criteria for selecting the location to be chosen, the workforce criteria has the largest value, then the second is the environmental criteria, then the traffic, fourth is accessibility, and last is the market. In this calculation, the data is considered consistent because it has a consistency ratio value of <0.1 or has a value of 0.

Table 1. Pairwise Comparison Matrix of Criteria

Criteria	Accesbility	Environment	Labor	Market	Traffic	CI	IR	CR
Accesbility	1.00	0.33	0.20	2	0.50	0.09	1.11	0.08
Environment	3	1.00	0.25	6	2			
Labor	5	4	1.00	5	5			
Market	0.5	0.17	0.20	1.00	0.33			
Traffic	2	0.5	0.20	3	1.00			
Total	11.50	6.00	1.85	17.00	8.83			

a. Alternative pairwise comparison matrix in accessibility criteria

The weighting and calculations carried out between accessibility and all alternative locations to be selected can be seen in Table 2, where Nyalaran has the highest value, then second is Blumbungan, third is Larangan, and last is Pademawu. In this calculation, the data is considered consistent because it has a consistency ratio value of <0.1 or has a value of 0.09

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Table 2. Alternative pairwise comparison matrix with accessibility

Accesbility	Blumbungan	Nyalaran	Larangan	Pademawu	CI	IR	CR
Blumbungan	1.00	0.50	3	4	0.08	0.9	0.09
Nyalaran	2	1.00	4	5			
Larangan	0.33	0.25	1.00	4			
Pademawu	0.25	0.20	0.25	1.00			
Total	3.58	1.95	8.25	14.00			

Pairwise comparison matrix of alternatives in environmental criteria

The weighting and calculations carried out between the environment and all alternative locations to be selected can be seen in Table 3, where Nyalaran has the highest value, then second is Larangan, third is Blumbungan, and lastly is Pademawu. In this calculation, the data is considered consistent because it has a consistency ratio value of <0.1 or has a value of 0.08.

Table 3. Alternative pairwise comparison matrix with environment

Environment	Blumbungan	Nyalaran	Larangan	Pademawu	CI	IR	CR
Blumbungan	1.00	0.20	0.50	3	0.07	0.90	0.08
Nyalaran	5	1.00	2	4			
Larangan	2	0.50	1.00	5			
Pademawu	0.33	0.25	0.20	1.00			
Total	8.33	1.95	3.70	13.00			

c. Alternative pairwise comparison matrix in the Labor criteria

The weighting and calculations carried out between the workforce and all alternative locations to be selected can be seen in Table 4, where Blumbungan has the highest value, then second is Nyalaran, third is Larangan, and lastly is Pademawu. In this calculation, the data is considered consistent because it has a consistency ratio value of <0.1 or has a value of 0.0.

Table 4. Alternative pairwise comparison matrix with Labor

Labor	Blumbungan	Nyalaran	Larangan	Pademawu	CI	IR	CR
Blumbungan	1.00	3	5	6	0.07	0.90	0.08
Nyalaran	0.33	1.00	3	3			
Larangan	0.20	0.33	1.00	3			
Pademawu	0.17	0.33	0.33	1.00			
Total	1.70	4.67	9.33	13.00			

b. Pairwise comparison matrix of alternatives in market criteria

The weighting and calculations carried out between the market and all alternative locations to be selected can be seen in Table 5, where Pademawu has the highest value, then second is Larangan, third is Nyalaran, and lastly is Pademawu. In this calculation, the data is considered consistent because it has a consistency ratio value of <0.1 or has a value of 0.08.

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Table 5. Alternative pairwise comparison matrix in market criteria

Market	Blumbungan	Nyalaran	Larangan	Pademawu	CI	IR	CR
Blumbungan	1.00	0.33	0.33	0.17	0.07	0.90	0.08
Nyalaran	3	1.00	0.33	0.20			
Larangan	3	3	1.00	0.33			
Pademawu	6	5	3	1.00			
Total	13.00	9.33	4.67	1.70			

c. Pairwise comparison matrix of alternatives in traffic criteria

The weighting and calculations carried out between traffic and all alternative locations to be selected can be seen in Table 6, where Nyalaran has the highest value, then second is Blumbungan, third is Larangan, and lastly is Pademawu. In this calculation, the data is considered consistent because it has a consistency ratio value of <0.1 or has a value of 0.08.

Table 6. Alternative pairwise comparison matrix with traffic

Traffic	Blumbungan	Nyalaran	Larangan	Pademawu	CI	IR	CR
Blumbungan	1.00	0.25	2	3	0.07	0.90	0.08
Nyalaran	4	1.00	4	5			
Larangan	0.50	0.25	1.00	3			
Pademawu	0.33	0.20	0.33	1.00			
Total	5.83	1.70	7.33	12.00			

e. Results of the pairwise comparison matrix of alternatives and criteria

Table 7. Pairwise comparison matrix of alternatives and criteria

Election	accesbility	environment	labor	Market	Traffic	
Criteria	0.09	0.23	0.47	0.05	0.16	
Blumbungan	0.21	0.13	0.49	0.07	0.26	23.2
Nyalaran	0.59	0.53	0.28	0.16	0.52	41.6
Larangan	0.14	0.27	0.15	0.29	0.16	20.2
Pademawu	0.07	0.07	0.08	0.49	0.07	15.6

Based on the table of results of the pairwise comparison matrix of alternatives and criteria in Table 7 above, the first choice is Jalan Sayalaran with a value of 41.6, the second is Jalan Blumbungan with a value of 23.2, the third is Jalan Larangan with a value of 20.2, and the fourth is Jalan Pademawu with a value of 15.6.

d. Hierarchical structure of AHP Calculation Result

From the calculation results above, it can be seen in Figure 2 that the values obtained by each criterion and alternative become the final value, which is used as a reference in making decisions in choosing a cigarette factory location.

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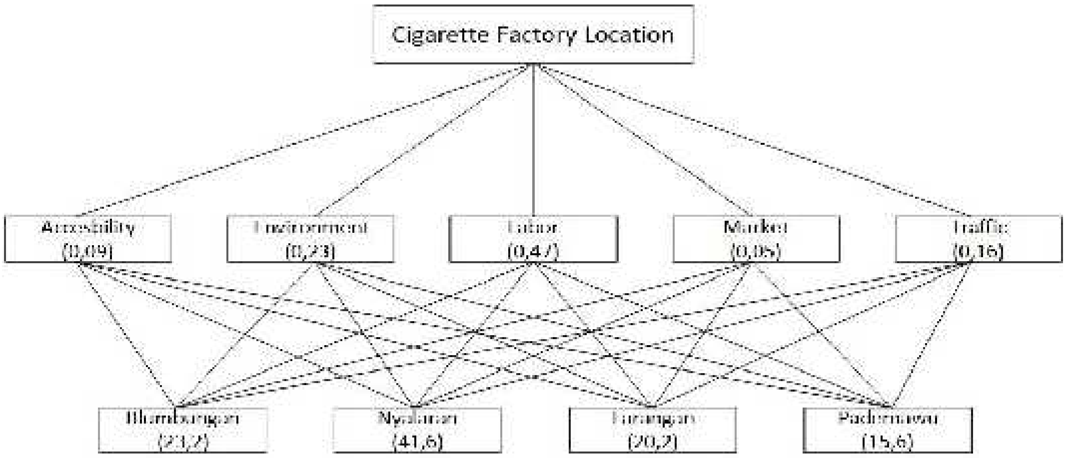

Figure 2. Hierarchical Structure with AHP Scores

C. CONCLUSION

Based on the results of the AHP calculation above, with a case study of selecting the location of the PR PMS factory with the criteria of accessibility, environment, workforce, market, and traffic, Nyalaran Street became the location chosen for the new factory location with a value of 41.6.

Based on the data analysis and calculations above, the author advises PR PMS to prioritize the selection of competent workers with good personal responsibility to help advance the company. Furthermore, PR PMS must examine the environmental conditions surrounding the new factory location, which will ultimately affect production waste and environmental pollution in surrounding settlements, to ensure the production process is not disrupted. Furthermore, the author recommends that previous research provide more comprehensive criteria variables and more objective weighting values to provide better results.

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Minimization of Defects in the Loading and Unloading Process of Gallon Water Using a Lean Manufacturing and Value Stream Mapping Approach

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***Abstract*— Logistics processes, particularly in the loading and unloading area, pose a critical challenge for the Bottled Drinking Water (AMDK) industry, as they have the potential to reduce profitability due to waste. This study aims to eliminate non-productive activities in the distribution line of PT XYZ using a Lean Manufacturing approach. By integrating Value Stream Mapping (VSM) into map process flows and the Waste Assessment Model (WAM) to weight operational issues, this study examines the company's operational problems. The identification results indicate that defect is the most dominant form of waste, contributing 24.37% of the total waste variability, which significantly hampers distribution flow. Root Cause Analysis (RCA) highlights employee discipline and operational work instructions as the primary factors causing these defects. As a mitigation strategy, this study formulates improvement recommendations based on restructuring work instructions and strengthening employee discipline standards to reduce defect rates and accelerate service lead time.**

Index: Defect; Lean Manufacturing; Loading-Unloading; Value Stream Mapping

I. INTRODUCTION

The Bottled Drinking Water (AMDK) industry in Indonesia is facing increasingly intense competitive pressure, in which supply chain efficiency has become a key determinant of corporate competitiveness. Operating in a highly dynamic market environment with thin profit margins, supply chain efficiency serves as a critical factor in sustaining competitive advantage. While many companies focus on improving efficiency in filling and packaging production lines, downstream logistics activities, particularly the loading and unloading processes, are often overlooked. In fact, inefficiencies at this stage increase delivery led time to customers and elevate the risk of damage to finished products that are ready for sale. In AMDK distribution, the smooth flow of products from warehouses to transportation fleets plays a crucial role in determining customer service lead time. [Nurhayati, 2021] However, logistics activities, especially during the loading and unloading stages, frequently become significant bottlenecks. Disorganization in these processes not only leads to delivery delays but also increases the risk of product damage and unnecessary operational costs. [Mapping et al,2000]. Therefore, mapping non-value-added activities is essential for companies seeking to maintain profitability.

PT XYZ, as a growing AMDK producer, faces serious challenges in its distribution operations. Based on preliminary observations in the finished goods warehouse area, the transfer of gallon products to distribution fleets is still carried out manually and semi-automatically, making it highly susceptible to waste. This waste is reflected in the high frequency of defective products during loading and the fluctuating waiting time of transportation fleets. Company data indicate that a significant number of defects, in the form of cracked or broken gallons, occur during the loading process rather than during production. These damages force operators to perform rework or product replacement, which directly interrupts the distribution flow and causes waiting time for truck fleets. This condition creates a domino effect, including disrupted delivery schedules, increased operational costs due to overtime and product replacement, and potential complaints from distributors as a result of delays. If this waste is not promptly eliminated, the company risks losing market growth momentum due to internal inefficiencies. This situation indicates that the company's value stream is not operating optimally and, if left unaddressed, will continuously erode

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productivity and customer satisfaction. [Tiara&Siagian,2024].

To address these issues, the Lean Manufacturing approach offers a systematic framework for identifying and reducing waste. One of the most effective Lean tools for mapping material and information flows is Value Stream Mapping (VSM) [woofuru_enyeke, 2019]. Although VSM is highly effective for visualization purposes, this method has limitations in quantitatively measuring the weighted interrelationships among different types of waste. Therefore, integrating VSM with the Waste Assessment Model (WAM) is necessary to provide a more precise understanding of the root causes. [Pwagung et al, 2024]. WAM complements VSM by simplifying the relationships among different types of waste, thereby allowing improvement priorities to be determined objectively.

Previous studies have extensively discussed the implementation of Lean in manufacturing production lines; however, studies that specifically integrate Value Stream Mapping (VSM) and the Waste Assessment Model (WAM) in the loading and unloading area of AMDK products remain limited [cerezo et al, 2019]. This study aims to address this gap by conducting an in-depth analysis of the distribution process flow at PT XYZ. The primary focus of this research is to identify the most influential waste, analyse its main causal factors using Root Cause Analysis, and formulate improvement strategies to minimize defects and accelerate the loading and unloading process. The results of this study are expected to provide practical contributions to improving the company's logistics system and serve as an academic reference for the application of Lean in the AMDK distribution sector.

II. RESEARCH METHOD

This study maps the loading and unloading process to identify waste using a Lean Manufacturing approach. The primary method employed is Value Stream Mapping, which consists of the following stages:

1. Current State Mapping
   Current State Mapping is used to observe all activities in the loading and unloading process by mapping all physical and information flows and calculating the time required for each activity (cycle time). Based on the cycle time analysis, activities are classified into Value-Added (VA) activities and Non-Value-Added (NVA) activities. [Lu & Aidil, 2024]
2. Waste Assessment Model (WAM)
   To measure the severity level of each type of waste, including overproduction, defect, motion, transportation, waiting, inventory, and overprocessing, weights are assigned using the WAM factor scale by ranking the waste from the highest to the lowest priority.
3. Waste Relationship Matrix (WRM)
   The Waste Relationship Matrix is used to analyze cause-and-effect relationships among different types of waste by assessing the level of influence between wastes on a scale of 1 to 4 [Kurangi et al, 2024]. This assessment generates the symbols A, E, I, O, and U, which are then used to determine the driving waste that exerts the greatest influence. As a result, the waste that constitutes the root cause of the problem can be identified.
4. Waste Assessment Questionnaire (WAQ)
   The Waste Assessment Questionnaire is administered to evaluate the frequency of waste occurrences and to validate the results of observations and the Waste Assessment Model. WAQ results are calculated using weighted scores, where 1 represents Yes, 0.5 represents Moderate, and 0 represents No. Consequently, each type of waste is assigned a quantitative value.
5. Root Cause Analysis (RCA)
   After the most significant waste has been identified, Root Cause Analysis is conducted using a Fishbone Diagram and the 5 Whys Analysis to determine the root causes and to formulate improvement recommendations.
6. Future State Mapping (FSM)
   Future State Mapping is developed based on the results of the Root Cause Analysis through the following stages:
   - Designing a more efficient process
   - Eliminating Non-Value-Added (NVA) activities
   - Reducing cycle time in Value-Added (VA) activities
   - Developing a new value stream map with minimal waste.

The following is the flow diagram of this study:

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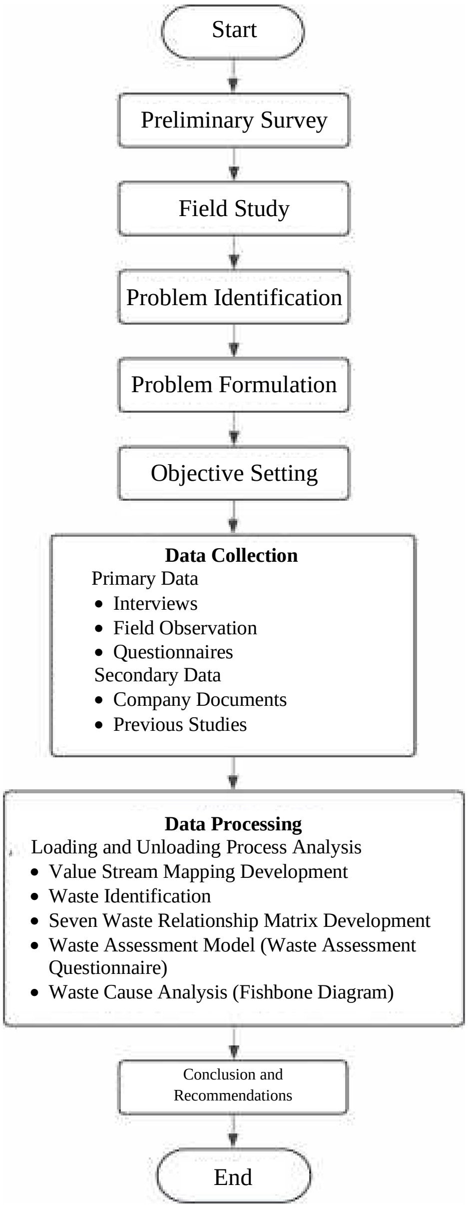

Figure 1. Research flowchart

Based on the diagram above, the development of Value Stream Mapping facilitates a more comprehensive identification of the seven types of waste, namely overproduction, waiting, transportation, overprocessing, inventory, motion, and defect. Each type of waste is represented by specific indicators and measurement criteria, allowing waste to be identified more effectively. [Lubis et al, 2025]

III. RESULTS AND DISCUSSION

The initial step of this study was to map the physical and information flows of the loading and unloading process at PT XYZ using Current State Mapping (CSM). Based on field observations, the distribution process begins with order receipt, followed by product retrieval from the finished goods warehouse, and concludes with loading onto transportation fleets.

The CSM analysis in Figure 2 reveals a significant presence of Non-Value-Added (NVA) activities along the distribution flow. The total cycle time of the loading process exhibits high variability, primarily caused by frequent line stoppages due to material accumulation and errors in manual handling. The proportion of Value-Added (VA) activities is currently recorded at 63%, while the remaining time is dominated by Necessary but Non-Value-Added (NNVA) activities and pure Non-Value-Added (NVA) activities. This condition indicates inefficiencies in the logistics flow that require immediate reduction.

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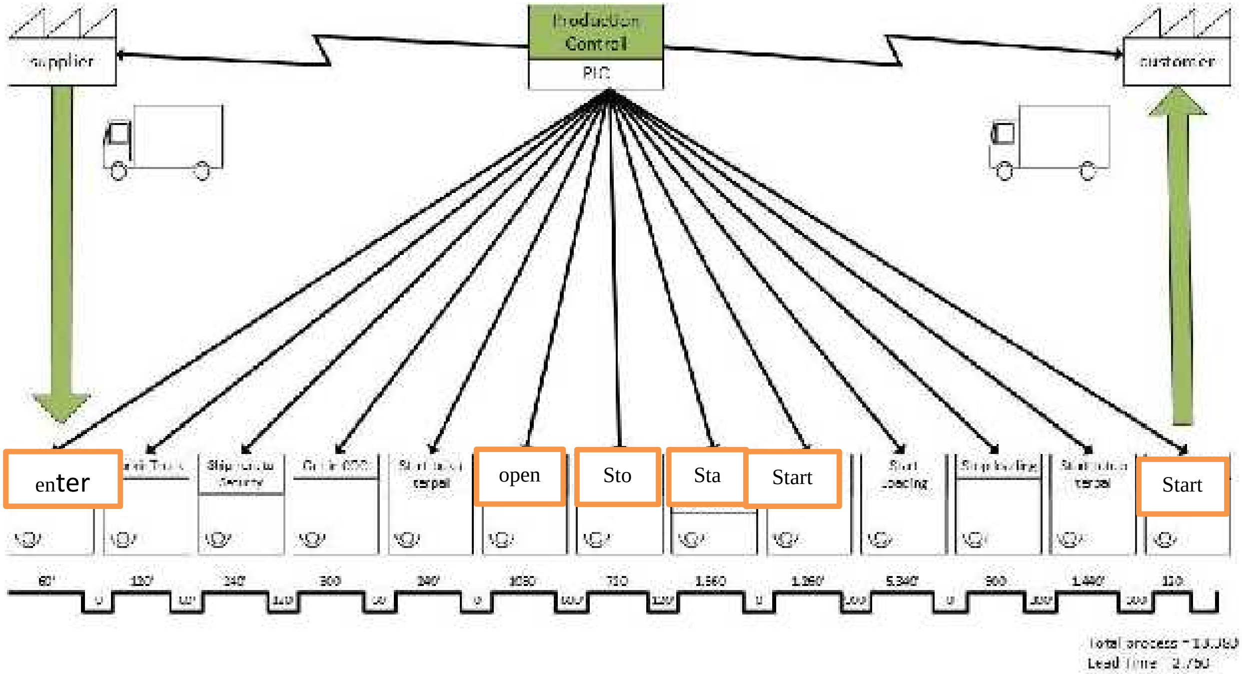

FIGURE 2. CURRENT STATE MAPPING

After establishing the Current State Mapping condition, waste identification can be conducted through the following steps:

1. Identification of Critical Waste Using the Waste Assessment Model (WAM)
   This stage aims to determine improvement priorities in the most objective manner. As shown in Table 1, the waste that most significantly triggers the emergence of other waste is defect, with a contribution of 8.13%. Meanwhile, the waste most heavily affected by other wastes is waiting, with a contribution of 9.57%

Table 1. Waste *Assessment* Model

	Overproduction	Inventory	Defect	Motion	Transportation	Process	Waiting	Score	%
Overproduction	10	4	4	4	4	0	4	30	7.18
Inventory	4	10	2	6	4	0	0	26	6.70
Defect	2	4	10	6	6	0	6	34	8.13
Motion	0	2	4	10	0	8	4	30	6.70
Transportation	2	4	6	4	10	0	8	34	8.18
Process	2	2	4	8	0	10	8	34	8.18
Waiting	4	2	6	0	0	0	10	22	5.26
Score	24	28	36	38	24	18	40	418	
%	6.22	6.70	8.61	9.09	5.57	4.31	9.57		

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The recapitulation of the final WAM scores indicates that defect is the most dominant type of waste, with a contribution of 24.37%. This high defect rate primarily occurs during the transfer of gallon products from the conveyor to the truck, where the gallons frequently experience collisions, cracking, or breakage. The second most dominant waste consists of unnecessary activities, namely waste of motion and waiting, which contribute approximately 8% to the total inefficiency. These findings confirm that the primary focus of improvement efforts should be directed toward reducing product damage in order to enhance overall efficiency.

2. **Process Activity Mapping**
   To further examine the structure of inefficiencies identified in the Current State Mapping, a more detailed analysis was conducted using Process Activity Mapping (PAM). PAM decomposes each work step in the loading and unloading process into five activity elements, namely Operation, Transportation, Inspection, Delay, and Storage. Based on Table 2, which presents the mapping results of all activities occurring on the shop floor, the following activity composition was identified:

Table 2. Process Activity Mapping

Activity	Frequency	Time
Operation	13	**136**
Transportation	6	**27**
Inspection	3	**4**
Storage	1	**15**
Delay	8	**60**
VA	8	**153**
NNVA	18	**70**
NVA	5	**19**
TOTAL TIME(minutes)	**242**	
%VA	**63%**	
%NNVA	**29%**	
%NVA	**8%**	

- *Value Added* – VA: VA activities account for 63% of the total process time. These activities include core operations such as retrieving gallon products from pallets and arranging them inside the truck. Although VA activities dominate the process, this proportion indicates that nearly 40% of operators' working time is still consumed by non-productive activities.
- *Non-Value Added* – NVA: NVA activities are identified as relatively significant, primarily dominated by transportation and delay elements. The transportation waste arises from the relatively long manual handling distance between the end of the conveyor and the truck bed, which forces operators to perform excessive and unnecessary walking movements.
- *Necessary but Non-Value Added* – NNVA: NNVA activities include brief visual inspections and the rearrangement of misaligned gallons. These activities do not add value to the product from the customer's perspective; however, they are unavoidable due to limitations in the current work system.

This Process Activity Mapping confirms the findings of the previous Waste Assessment Model (WAM) analysis. The high proportion of Non-Value-Added (NVA) activities,

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particularly transportation and waiting, shows a strong correlation with the occurrence of defect waste. [ansyah&Kustiwan, 2025]. Operator fatigue resulting from excessive manual transportation activities has been identified as a latent factor that reduces work focus, thereby increasing the risk of gallons slipping or breaking during the loading process due to rough handling. Therefore, improvement strategies should not focus solely on machine-related enhancements, but also on redesigning the workplace layout to reduce transportation distances and eliminate unnecessary movements

3. Root Cause Analysis

After identifying defect as the most critical type of waste, with a contribution weight of 24.37% based on the Waste Assessment Model (WAM), the next step was to diagnose the root causes of this issue. The analysis was conducted using a Cause-and-Effect Diagram to examine the factors contributing to the high rate of gallon damage during the loading process. [Issu et al, 2023]

- Man: Human factors were identified as the dominant contributors to process variability. Based on observations and interviews, two critical issues were identified. The first is physical fatigue resulting from workload, where the high level of transportation activities involving manual handling of gallon products, as revealed by the PAM analysis, leads to accumulated operator fatigue. This fatigue reduces concentration levels and motor control during lifting activities, thereby triggering rough handling that results in gallons slipping or colliding with the sides of the truck bed. The second issue is a lack of discipline and focus, reflected in inconsistencies among operators in maintaining a stable working pace. During critical periods prior to breaks or shift changes, operator focus tends to decline, increasing the frequency of product handling errors.
- Method**:** The current work system and procedures contain gaps that allow variations in work practices among operators, particularly due to non-ergonomic work instructions. The existing loading Standard Operating Procedures (SOPs) are overly general and do not regulate ergonomic lifting techniques suitable for high-speed operations. As a result, each operator develops an individual lifting style, which is often unsafe for both product integrity and operator health. Furthermore, the absence of standardized procedures for rapid handling during conveyor congestion leads operators to take impulsive actions, such as forcibly pulling jammed gallons, which further exacerbates the risk of product damage [Rauch, 2022].
- Machine: Supporting infrastructure, particularly the conveyor system, constitutes a technical factor that hinders smooth material flow. Conveyor belt instability, resulting from fluctuating motor performance, frequently causes sudden jerking movements. This condition leads to collisions among gallons on the conveyor before they reach the loading dock, resulting in micro-cracks on the gallon body. In addition, insufficient preventive maintenance is indicated by the frequent occurrence of minor downtime due to mechanical congestion, suggesting that the machine maintenance schedule has not been optimally implemented to anticipate component wear. [Utami et al, 2023]
- Environment: The physical condition of the work area further exacerbates the potential for defects. The limited maneuvering space at the loading dock restricts operator movement during material handling [Abdullah, 2022]. This confined space forces operators to perform risky body-twisting movements, thereby increasing the likelihood of collisions between gallons and surrounding structures such as walls or support pillars. In addition, uneven floor conditions and suboptimal lighting inside the truck bed in several areas make it difficult for operators to arrange gallons with precision, thereby increasing the risk of unstable stacking and collapse.

Based on the results of the Root Cause Analysis, defects at PT XYZ are not isolated incidents, but rather the outcome of a systemic interaction between operator fatigue, caused by physically demanding manual work methods, and insufficient machine precision. Therefore, partial solutions such as merely reprimanding operators will not be effective. A comprehensive intervention is required, encompassing improvements in work ergonomics, including workplace re-layout to reduce material handling distances, as well as technical improvements to the

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conveyor system to maintain product flow stability.

4. Future State Mapping

Future State Mapping is designed by implementing three main interventions to improve the flow of materials and information.

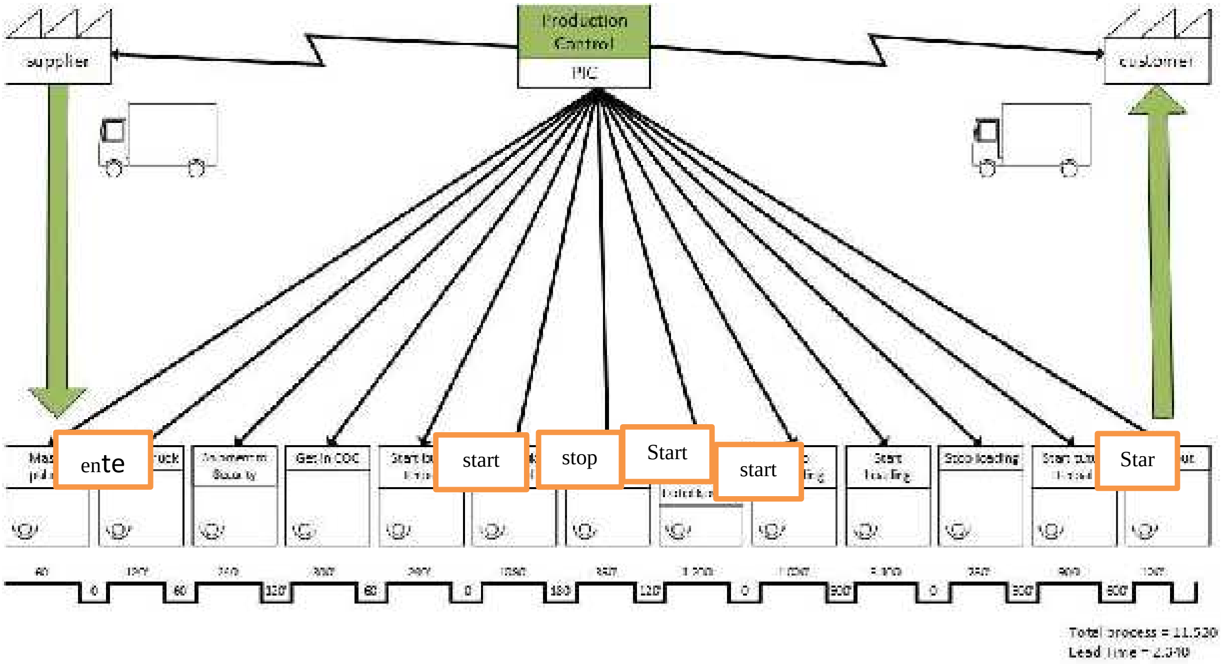

Figure 3. Future State Mapping

Based on the results of the Future State Mapping, the proposed improvements derived from the Process Activity Mapping (PAM) analysis are as follows:

- Technical Improvement of the Conveyor Line (Machine Reliability): In the future state map, the implementation of a preventive maintenance schedule is proposed, specifically for conveyor supports and motors. This measure aims to eliminate incidents of conveyor jamming, which have been the primary cause of gallon accumulation and product-to-product collisions. With reliable machinery, material flow becomes continuous, allowing waiting time caused by machine downtime to be reduced to zero.
- Work Standardization and Rest Break Management (Standardized Work): Current conditions indicate the presence of work variability due to operator fatigue and suboptimal rest break arrangements. In the Future State design, a more structured rotating rest break schedule is implemented to ensure that the loading workstation is never left unattended or understaffed, while still allowing operators sufficient recovery time. In addition, new Standard Operating Procedures are introduced for ergonomic manual lifting techniques to prevent rough handling, which is a major cause of gallon breakage.
- Upstream Quality Control (Quality at Source): To address the issue of leaking or non-sterile gallons passing into the loading area, the inspection system is tightened in the production area before products enter the finished goods warehouse. This ensures that material inputs entering the loading process consist entirely of defect-free products, so loading operators no longer need to spend time sorting or replacing defective products on the truck.

The implementation of the proposed Future State design is projected to have a significant impact on the company's key logistics performance indicators. Through improvements in conveyor reliability and rest management, material accumulation along the distribution line can be eliminated [Songkhwa,

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2025.] Product flow becomes smoother, transforming an unstable push system into a stable pull system.

With the elimination of Non-Value-Added activities such as waiting for conveyor repairs or replacing broken gallons, the proportion of effective operator working time increases.

Activities that previously generated only 63% value-added time are projected to increase as operational disruptions are reduced. As a result, total fleet loading service time becomes shorter and more consistent, leading to higher distributor satisfaction and improved logistics fleet utilization.

IV. CONCLUSION

This study has successfully identified and analyzed sources of inefficiency in the loading and unloading process at PT XYZ using an integrative Lean Manufacturing approach. Through Value Stream Mapping and weighting using the Waste Assessment Model, it was revealed that the company's distribution flow is hindered by the dominance of Non-Value Added activities.

The key finding of this study concludes that defects represent the most critical form of waste, contributing 24.37 percent to total waste variability. The high defect rate is directly correlated with excessive waiting time and unnecessary motion. Root Cause Analysis confirms that operator fatigue caused by repetitive manual handling, non-ergonomic work instructions, and conveyor performance instability are the main factors leading to product damage during loading.

As a strategic solution, the Future State Mapping design recommends the implementation of preventive maintenance on conveyor infrastructure, standardization of ergonomic work methods, and improvement of operator rest schedule management. The implementation of these recommendations is projected to eliminate bottlenecks, minimize the risk of defective products, and significantly improve distribution cycle time efficiency. This study provides a practical foundation for PT XYZ management to transform toward a lean and highly competitive logistics system.

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Holistic Effects of Supply Chain Digitalization on the Sustainability of Food MSMEs: Evidence from a PLS-SEM Hierarchical Model in Padang

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***Abstrack* - This study examines the effect of supply chain digitalization on the sustainability of food micro, small, and medium enterprises (MSMEs) in Padang, Indonesia. Sustainability is conceptualized as an integrated construct comprising economic, social, and environmental dimensions. A quantitative research design was employed using survey data collected from 50 food MSMEs, which were analyzed using Partial Least Squares–Structural Equation Modeling (PLS-SEM) with SmartPLS 3.0. The results show that supply chain digitalization has a significant positive effect on sustainability when assessed holistically, whereas its direct effects on the economic, social, and environmental dimensions individually are not statistically significant. These findings indicate that the contribution of digitalization to MSME sustainability is realized through an integrated mechanism rather than through isolated sustainability dimensions. Theoretically, this study contributes to literature by reinforcing the importance of a holistic sustainability perspective in explaining the impact of supply chain digitalization. Practically, the findings provide insights for policymakers and MSME practitioners to promote integrated digital adoption strategies that support long-term sustainable performance.**

***Keywords:* Digitalization, Supply Chain, Sustainability, PLS-SEM, MSMEs**

I. Introduction

Micro, small, and medium enterprises (MSMEs) of food are one of the important pillars in the regional economy in Padang. Based on data from the West Sumatra Provincial Industry and Trade Office (2023), there are more than 7,500 units of food MSMEs spread across various districts/cities, and this sector makes a significant contribution to the absorption of local labor and the increase in the Gross Regional Domestic Product (GDP) of the processing industry. In addition to their economic role, food MSMEs also contributes to the preservation of Minangkabau culinary specialties, which have high cultural value and strong competitiveness in the domestic and international markets. However, in the face of the digital era and global value chain dynamics, food MSMEs are still faced with various challenges in maintaining business sustainability, which include economic (efficiency and profitability), social (welfare of workers and local communities), and environmental (waste management and efficient use of resources). The complexity of these challenges increases along with changing consumer preferences that demand faster, more transparent, and digital-technology-based services. In addition, many MSMEs have not been able to manage the supply chain optimally, starting from raw material procurement, inventory management, production processes, and product distribution [Kurniawan dan Kusumawardhani, 2021].

Supply chain digitalization is one of the strategic approaches that continues to develop in an effort to increase the competitiveness of MSMEs. The use of technology such as cloud-based inventory systems, local e-commerce platforms, GPS-based distribution tracking, and MSME-scale ERP applications is believed to

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improve operational efficiency, minimize waste, and encourage sustainable value-added creation. [Z dan Ghazali, 2024]. In addition, the report [Sohnius et al, 2023]It shows that supply chain digitalization has the potential to reduce operational costs by up to 30% and accelerate demand fulfillment by around 40%, especially in the food and beverage sector in developing countries. Another study states that operational digitalization has a significant effect on improving the sustainable performance of MSMEs, especially when integrated with a collaborative and transparent supply chain system. [B dan Susanto, 2025].

From a theoretical perspective, the relationship between supply chain digitalization and sustainability dimensions is not always direct or immediate. Digitalization primarily serves as an enabling mechanism that enhances information transparency, coordination, and integration across supply chain activities. In the context of MSMEs, improvements in economic performance, social responsibility, or environmental practices often depend on complementary organizational capabilities, managerial readiness, and integrated implementation strategies. As a result, digitalization may not directly influence each sustainability dimension independently but instead contributes to sustainability through a holistic and systemic process [Tobing dan Nugroho, 2024]. This perspective supports the conceptualization of sustainability as an integrated construct and provides a theoretical explanation for why the overall effect of supply chain digitalization on sustainability is stronger than its direct effects on individual dimensions.

However, the adoption rate of digital technology in food MSMEs in Padang is still relatively low. This condition is influenced by limited infrastructure, low digital literacy of business actors, and a lack of policy support and technical assistance. In addition, research that discusses conceptually and empirically the contribution of supply chain digitalization to the sustainability of food MSMEs in this region is still very limited. This study uses a quantitative approach through a survey of MSMEs and the use of secondary data from related agencies. The results of this research contribute theoretically to developing the MSMES digitalization model and become a practical reference for local governments and industry players in encouraging sustainable digitalization.

II. RESEARCH METHODOLOGY

2.1. Hypothesis Formulation

Based on the research objectives stated above, the hypotheses of this study are formulated as follows:

H1: Supply chain digitalization has a positive effect on the sustainability of MSMEs in Padang.
H1a: Supply chain digitalization has a positive effect on the economic aspect.
H1b: Supply chain digitalization has a positive effect on the social aspect.
H1c: Supply chain digitalization has a positive effect on the environmental aspect.

2.2. Indicator Identification

At this stage, the initial step undertaken is the identification of all indicators related to supply chain digitalization and sustainability aspects. The first activity involves a systematic review of indicators relevant to the concepts of supply chain digitalization and sustainability. These indicators are identified, adapted, and refined based on various sources of scientific literature. Subsequently, indicators that are not aligned with the actual conditions of small and medium-sized industries are screened and excluded from the list. This filtering process aims to eliminate indicators that are irrelevant to the focus and context of the study.

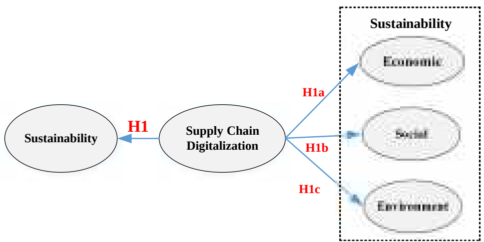

Figure 1. Hypothesis

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Furthermore, indicators and dimensions that share similar meanings or conceptual definitions are integrated and grouped into unified indicators or dimensions. This process of merging and classification is conducted to ensure conceptual clarity, reduce redundancy, and establish a coherent structure of indicators and dimensions used in the analysis.

2.3. Data Collection Techniques

Data collection was conducted through the distribution of questionnaires administered both in person and online (via Google Forms) to MSMEs in Padang, with a total of 50 respondents. According to Ghozali, (2021] In the Partial Least Squares–Structural Equation Modeling (PLS-SEM) approach, the minimum recommended sample size ranges from 30 to 100 respondents. The determination of the sample size may also follow a rule of thumb, which suggests that the minimum number of samples should be ten times the number of endogenous latent variables included in the research model. Based on the research model, there are only four endogenous latent variables, namely economic, sustainability, environment, and social. Therefore, referring to the PLS-SEM rule of thumb, the minimum required number of respondents is 40. The questionnaire consisted of respondent demographic information and assessed MSMEs of the research indicators, which were rated using a five-point Likert scale. Data collection was carried out over the period from July to November 2025.

2.4. Data Processing

Data analysis was conducted using the PLS-SEM (Partial Least Squares–Structural Equation Modeling) method with the assistance of SmartPLS 3.0 software. The data processing procedure comprised several stages. First, model conceptualization was performed to define the latent variables and their relationships based on the research framework. This was followed by the development of a path diagram to visually represent the proposed structural relationships among the constructions. Subsequently, the measurement model and structural model were evaluated to assess reliability, validity, and the strength of the relationships between variables. Finally, hypothesis testing was carried out to examine the significance and direction of the proposed effects. The PLS-SEM method was chosen because it can test predictive relationships between variables without the need for strong theories or big data, offers high flexibility in connecting theories and data, can analyze complex latent variables, and is effective in using small sample sizes without having to meet the assumption of data normality [Ghozali, 2021].

III. RESULT AND DISCUSSION

3.1. Identify Supply Chain Digitalization and Sustainability Indicators

At the initial stage, an identification process was conducted to determine various indicators related to supply chain digitalization and sustainability that are relevant to the conditions of MSMEs in Padang. These indicators were collected and adapted from a range of pertinent scientific publications. Subsequently, indicators that were considered inconsistent with the actual operational characteristics and context of MSMEs in Padang were eliminated. This screening process was intended to ensure that only indicators relevant to the focus and practical conditions of the study were retained. In addition, indicators with similar meanings or conceptual definitions were merged and reorganized into more representative indicators. The indicators of supply chain digitalization consisted of 11 indicators, which were adapted from [Joshi dan Sharma, 2022], [Lee et al, 2024], [Widowati et al, 2023], and [Zekhnini et al, 2022]. Meanwhile, the sustainability indicators were adopted from [Syahfitri, 2024] and comprised 7 economic indicators, 9 environmental indicators, and 9 social indicators.

3.2. Conceptualization of Model Construction

This stage involves the development of the structural model and the measurement model. The structural model (inner model) in this study is designed to represent the causal relationships among latent variables that form the conceptual framework of the influence of supply chain digitalization on the sustainability of MSMEs in Padang. The direction of the arrows in the model illustrates the cause-and-effect relationships established based on the formulated research hypotheses.

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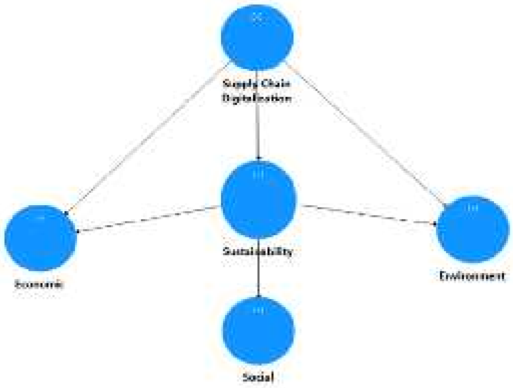

Figure 2. Inner Model

Subsequently, the measurement model (outer model) is developed to link latent variables with their corresponding measurement indicators. The measurement model (outer model) is designed to explain the relationship between manifest variables or indicators and the latent constructions they represent. These indicators function as measurement instruments that represent and describe latent variables that cannot be directly observed. [Ghozali, 2021].

3.3. Path Diagram Design

At this stage, the structural model (inner model) and the measurement model (outer model) are integrated to form a Hierarchical Component Model (HCM), as illustrated in Figure 4. The HCM approach is employed to represent the interrelated relationships between supply chain digitalization and sustainability constructs. Therefore, the model is structured hierarchically to clearly demonstrate the relationships between the main constructs and their corresponding sub-constructs.

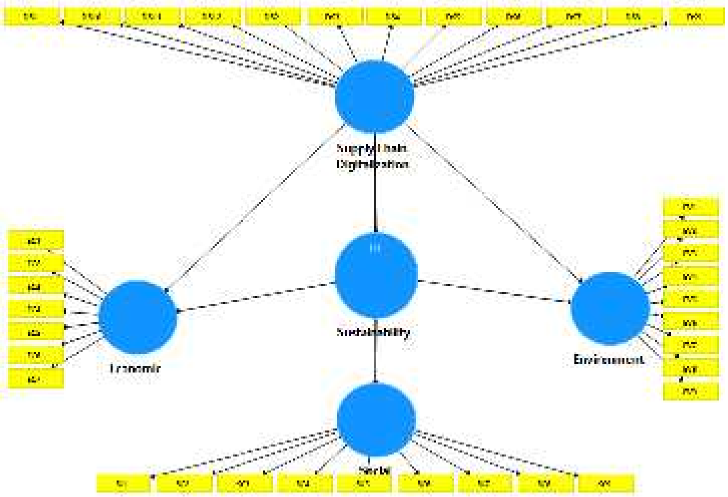

Figure 3. Path Diagram

3.4. Model Evaluation

The evaluation of the model was carried out by validity and reliability tests. According to [Ghozali, 2021]The measurement model (*outer model*) with indicators in the form of reflective is evaluated based on the *convergent validity* value and *the discriminant validity value* of the indicators that form the latent construct.

Convergent validity is related to the principle that the manifest variable (indicator) of a latent variable (construct) should have a high correlation. The value of the convergent validity test using SmartPLS 3.0 software can be seen from the value of the loading factor (outer loading) on each indicator. According to [Ghozali, 2021]for the early stages of research and measurement scale development, loading factor values in the range of 0.50–0.60 are still considered acceptable. However, indicators with loading factor values below 0.50 indicate a weak contribution to the

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construction and insufficient shared variance, which may reduce construct reliability and validity. Therefore, such indicators should be eliminated to improve the quality of the measurement model and ensure that each construct is well represented by its indicators.

Based on the outer loading results shown in Figure 2, six indicators have loading factor values below 0.50 and were consequently removed from the model, namely EC7 (There are efforts to improve product quality), EV4 (The use of materials used for product manufacturing is carried out optimally), SC4 (Attention to the health and safety aspects of employees), SC7 (Attention to the health and safety aspects of the customer), SC8 (Customer satisfaction level), and SC9 (The company's commitment to corruption prevention).

These indicators were eliminated because low outer loading values indicate that the indicators do not adequately reflect or share sufficient variance with their underlying constructs, implying a weak contribution to the explanation of the latent variables and a higher likelihood of introducing noise measurement rather than a meaningful signal. In PLS-SEM, indicators with low outer loadings are considered problematic as they may weaken convergent validity, reduce composite reliability, and impair the clarity and interpretability of the measurement model. Therefore, the elimination of such indicators is a common and recommended practice to improve overall measurement quality and ensure that retained indicators meaningfully represent their respective constructs. Previous empirical studies and methodological guidelines confirm that removing indicators with insufficient loading values is an essential step in refining reflective measurement models, particularly when indicators fail to meet the minimum loading threshold and do not contribute significantly to construct reliability and validity. [Safitri dan Huda, 2023].

For example, indicators such as EC7 and EV4 require formalized quality improvement processes and documented performance tracking, which many Indonesian food MSMEs have yet to adopt due to limited digital infrastructure and low digital literacy. This often results in reliance on informal practices rather than standardized or digital management systems, reducing the empirical observability of these indicators. [Bachtiar et al, 2025]. Similarly, indicators related to health and safety (SC4, SC7) and customer satisfaction (SC8) lack formal monitoring mechanisms in many small enterprises because operational procedures and digital feedback systems are rarely implemented, making them difficult to quantify. Moreover, normative practices such as anti-corruption commitment (SC9) are not typically operationalized in routine MSME activities, further weakening their statistical relevance in reflective measurement models [Aripin et al, 2024], [Anatan dan Nur, 2023].

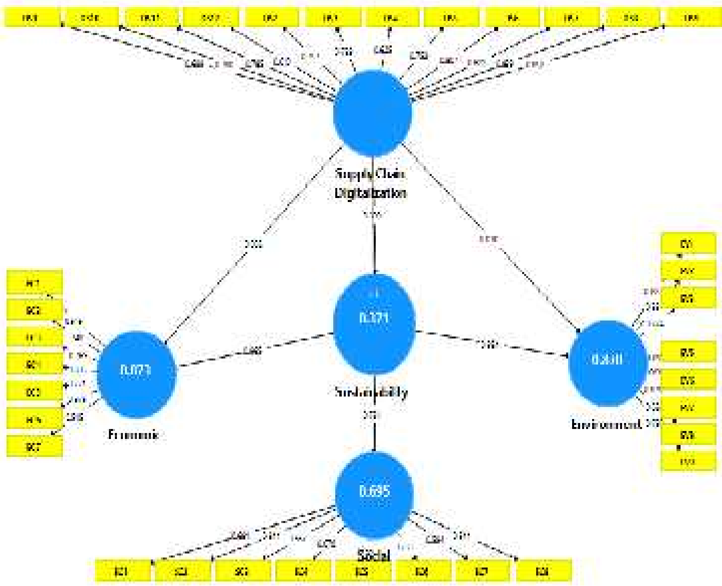

Figure 4. Outer Loading

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The model has also met the discriminant validity test because the crossloading value on the measurement indicator is greater than that of the other measurement indicators.

Furthermore, a reliability test was carried out, which aimed to prove the consistency, accuracy, and reliability of the research instrument in measuring constructs. Through SmartPLS 3.0 software, the reliability test is seen from the composite reliability (CR) value. According to [6]The composite reliability for confirmatory research must be greater than 0.7 (>0.70). Based on Table 1, the composite reliability value for all latent variables is greater than 0.7. Thus, it can be concluded that the reliability of the measurement instrument has been met and is acceptable.

Table 1. Composite Reliability

Variabel	Composite Reliability
Economic	0.893
Environment	0.923
Social	0.861
Supply Chain Digitalization	0.943
Sustainability	0.946

3.5. Hypothesis testing

Hypothesis testing is conducted using the bootstrapping procedure in SmartPLS 3.0. Several studies recommend employing 5,000 bootstrap samples to obtain more accurate standard error estimates, with a significant level of 5%. A hypothesis is considered supported when the resulting p-value is below 0.05 (alpha) or when the calculated t-statistic exceeds the critical t-value of 1.96 [6]. The alpha level (α) indicates the acceptable threshold of error tolerance in the study. Based on the results of data processing as shown in Table 2, only one hypothesis was accepted, namely H1, while the other hypothesis was rejected.

3.6. Discussion of Results

Based on the bootstrapping results obtained from SmartPLS 3.0, this study demonstrates that supply chain digitalization exerts a significant positive influence on overall sustainability, while its direct effects on the economic, social, and environmental dimensions are not statistically significant when examined individually. This pattern of results suggests that the contribution of digitalization to sustainability is systemic rather than isolated, indicating that digital technologies function as an enabling infrastructure that enhances sustainability performance through integrated and cumulative mechanisms.

The significant relationship between supply chain digitalization and overall sustainability implies that digital transformation facilitates coordination, transparency, and information sharing across supply chain actors, which collectively strengthen sustainability outcomes. Rather than directly improving each sustainability dimension, digitalization appears to operate as a mediating or integrative.

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Table 2. Hypothesis Testing

Hypothesis	Construct	T Statistics	P Values	Decision	Description
H1	Supply Chain Digitalization -> Sustainability	10.803	0.000	Accept H1	Significant Impact
H1a	Supply Chain Digitalization -> Economic	0.752	0.452	Reject H1a	Not Significant Impact
H1b	Supply Chain Digitalization -> Social	0.928	0.354	Reject H1b	Not Significant Impact
H1c	Supply Chain Digitalization -> Environment	0.379	0.705	Reject H1c	Not Significant Impact

mechanism that aligns economic efficiency, environmental responsibility, and social considerations into a unified sustainability framework. This finding supports prior studies emphasizing that digital supply chains promote sustainable development when technological adoption is accompanied by organizational readiness and strategic alignment. [Li et al, 2023].

Conversely, the non-significant direct effects on the economic, social, and environmental dimensions indicate that digitalization alone may be insufficient to generate immediate or measurable improvements in these areas. From an economic perspective, digital technologies may initially increase investment and operational complexity, thereby delaying observable financial benefits. Similarly, improvements in environmental and social performance often require complementary practices, such as regulatory compliance, green innovation, workforce engagement, and ethical governance, which extend beyond mere technological adoption. This explanation is consistent with previous research suggesting that digital transformation does not automatically translate into sustainability performance without adequate supply chain integration and managerial capability. [Damar dan Nursyamsyah, 2023].

Moreover, the findings highlight the importance of analytical and interpretive capabilities, such as big data analytics, in transforming digital data into actionable insights that support sustainability decision-making. Without such capabilities, digital tools may function primarily as operational instruments rather than strategic drivers of sustainability. [Lemoun et al, 2021]. This reinforces the argument that the impact of digitalization on sustainability is highly contingent on organizational strategy, data utilization, and the maturity of digital implementation.

Overall, this study contributes to the sustainability and supply chain literature by demonstrating that supply chain digitalization is more effective in enhancing sustainability at a holistic level rather than influencing each sustainability dimension independently. These results imply that managers and policymakers should view digitalization not as a standalone solution, but as part of an integrated sustainability strategy that combines technological, organizational, and analytical components to achieve meaningful and long-term sustainable outcomes. [Junge dan Straube, 2020].

V. CONCLUSION

This study examined the impact of supply chain digitalization on the sustainability of food MSMEs in Padang using a PLS-SEM approach with SmartPLS 3.0. The empirical results demonstrate that supply chain digitalization has a significant positive effect on sustainability when sustainability is conceptualized as an integrated construct comprising economic, social, and environmental dimensions. This finding confirms that the adoption of digital technologies across supply chain activities plays an important role in strengthening the overall sustainability of food MSMEs through systemic and cumulative mechanisms. However, the results also indicate that the direct effects of supply chain digitalization on the economic, social, and environmental dimensions individually are not statistically significant. This suggests that the benefits of digitalization are not immediately or independently reflected in specific sustainability dimensions. Instead, digitalization functions as an enabling infrastructure that supports sustainability

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outcomes holistically, rather than producing isolated improvements in economic performance, social responsibility, or environmental management.

In the context of food MSMEs in Padang, this condition can be explained by the relatively low level of digital maturity, limited organizational readiness, and the predominance of informal operational practices. Digital technologies are often adopted in a fragmented manner and have not yet been fully integrated into managerial decision-making, sustainability reporting, or performance evaluation systems. Consequently, digitalization alone is insufficient to generate measurable impacts on individual sustainability dimensions without complementary factors such as supply chain integration, managerial capability, data analytics utilization, and supportive institutional frameworks.

The findings of this study contribute theoretically by reinforcing the importance of adopting a holistic sustainability perspective when analyzing the impact of supply chain digitalization, particularly in MSME contexts. Practically, the results imply that policymakers and MSME practitioners should promote integrated digital transformation strategies rather than isolated technological adoption. Efforts to enhance MSME sustainability should therefore combine digital tools with organizational development, capacity building, and coordinated supply chain collaboration to achieve meaningful and long-term sustainable outcomes.

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Operational Readiness Improvement in Make-to-Order Carton Packaging Systems: An Applied Industrial Engineering Study

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***Abstract*— Make-to-order manufacturing systems are highly dependent on operational readiness to ensure that available production time is effectively converted into output. In practice, many production facilities experience idle production days, where scheduled production time is available but no output is realized, leading to inefficiencies that are not fully captured by machine-based performance indicators alone. This study aims to analyze operational readiness in a carton packaging production system by examining the relationship between available production time, execution readiness, and output realization. A quantitative case study approach was applied using daily operational data from a carton packaging workshop, including planned production time, downtime, output records, and production execution status. The analysis differentiates between active production days and idle production days to identify readiness-related gaps affecting production utilization. The results show that high machine availability does not necessarily guarantee effective production execution, as a significant proportion of available production time remains unutilized due to readiness issues related to scheduling, material availability, and setup preparedness. This study provides applied insights into operational readiness improvement and offers practical recommendations to enhance production time utilization in make-to-order manufacturing environments.**

***Key Words* : applied industrial engineering; operational readiness; make-to-order manufacturing; production execution; carton packaging**

I. INTRODUCTION

Make-to-order manufacturing systems require a high level of coordination between planning and execution to ensure that available production time is effectively converted into output. Unlike make-to-stock systems, make-to-order environments are characterized by high product variability, frequent setup changes, and dynamic production scheduling, which increase operational complexity and execution risk. (Rajagopalan, 2002; Upadhyay et al., 2023). In such conditions, production performance is not determined solely by machine capability but is strongly influenced by the readiness of operational elements that support production execution. In applied industrial engineering practice, production inefficiency has traditionally been associated with technical issues such as machine breakdowns, reduced speed, and quality defects. These issues are commonly evaluated using machine-centered performance indicators that focus on equipment utilization and reliability. (Chikwendu et al., 2020; My Abdelbar et al., 2019). While these indicators remain important for diagnosing technical performance, they do not fully capture execution-related inefficiencies that occur when machines are technically available, but production activities are not executed as planned. As a result, significant portions of available production time may remain unutilized without being classified as technical losses.

Empirical evidence from applied manufacturing studies indicates that high machine availability does not necessarily lead to high production output, particularly in systems with complex execution requirements (Tayal et al., 2021; Wasesa & Jumali, 2020). In many cases, production delays and idle time originate from organizational and operational factors rather than from equipment failure. These

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factors include delayed release of production orders, material unavailability, incomplete setup preparation, and misalignment between production planning and shop-floor execution (Bokrantz et al., 2016; Rakyta et al., 2024). Research in Indonesian manufacturing contexts has consistently highlighted the importance of system-level coordination in determining production performance. Applied studies by Jumali and colleagues demonstrate that production inefficiencies are often rooted in operational misalignment rather than machine limitations. Jumali et al. (2019) showed that inadequate capacity planning and execution coordination led to underutilized production time despite sufficient machine availability. In subsequent applied studies, Jumali et al. (2023) reported that improvements in material flow and layout organization significantly enhanced production performance without requiring changes to machine specifications. These findings emphasize the need to examine production systems as integrated operational entities.

Operational readiness provides a useful concept for understanding execution-related inefficiencies in manufacturing systems. Operational readiness refers to the condition in which all prerequisites required for production execution, such as released production orders, available materials, completed setups, and ready operators, are fulfilled prior to scheduled production time. When operational readiness is incomplete, production execution may be delayed or absent, resulting in idle production time even though machines are available and capable of operating. (Parra et al., 2024; Tortora et al., 2025). In make-to-order environments, operational readiness is particularly critical due to the dependency on timely information flow and coordination. Rajagopalan (2002) noted that make-to-order systems are inherently sensitive to execution delays because production activities are initiated only after customer orders are confirmed. Similarly, Upadhyay et al. (2023) found that variability in order release and material preparation significantly affects production continuity in customized manufacturing systems. These characteristics increase the likelihood of idle production days, where scheduled production time exists but no output is realized.

Applied industrial engineering studies have shown that idle production time represents a substantial source of inefficiency that is often underestimated. Jumali et al. (2025) demonstrated that in printing and packaging industries, minor setup delays and material handling issues accumulated into significant execution losses over time. In another applied case study, Utomo et al. (2022) found that production execution gaps were frequently caused by delayed coordination between planning and shop-floor activities, rather than by technical machine problems. These findings suggest that execution-related losses should be analyzed explicitly rather than being implicitly attributed to equipment performance. Despite these insights, many manufacturing performance evaluations continue to prioritize machine-based indicators as the primary measure of effectiveness. While such indicators are useful for monitoring equipment condition, they may obscure readiness-related losses that occur before production actually starts. (My Abdelbar et al., 2019; Tayal et al., 2021). Consequently, organizations may focus improvement efforts on maintenance and technical optimization while overlooking execution-level inefficiencies that have a direct impact on production utilization.

The distinction between machine readiness and production execution readiness is therefore critical. Machine readiness refers to the technical availability and functional capability of equipment, whereas production execution readiness encompasses organizational and operational conditions that enable machines to be used productively. When these two forms of readiness are misaligned, production systems may exhibit situations where machines are available, but output remains low. (Bokrantz et al., 2016; Zhong et al., 2023). Such conditions are commonly observed in applied manufacturing environments with high operational variability. Carton packaging production systems offer a relevant context for examining operational readiness issues. These systems typically operate under make-to-order conditions, producing customized packaging designs with varying dimensions and specifications. Frequent setup changes, dependence on custom cutting tools, and coordination with customer orders increase the risk of readiness-related disruptions. (Joachimiak-Lechman et al., 2019;

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Klemenčić et al., 2023)). Applied studies in packaging industries indicate that execution losses are often dominated by setup-related delays and material mismatches rather than by machine breakdowns. (Wasesa & Jumali, 2020).

In public service production units, such as government-operated technical workshops, operational readiness challenges may be further intensified by administrative procedures and resource constraints. Jumali et al. (2023) noted that production execution in public manufacturing units is frequently affected by delayed order approval, procurement lead times, and coordination across organizational units. These conditions increase the probability of idle production days and reduce overall production utilization. From a quantitative perspective, production utilization can be defined as the proportion of available production time that is actually converted into output. Idle production days have a direct and significant impact on this metric, regardless of machine availability or technical performance. (Fragapane et al., 2022; Goyal et al., 2022). Therefore, distinguishing between active production days and idle production days is essential for accurately diagnosing production system performance in make-to-order environments.

Several studies emphasize the importance of analyzing production data at a daily or shift-level resolution to capture execution-related inefficiencies. (Petropoulos et al., 2025; Ruiz-Rojas et al., 2024). Aggregated monthly indicators may conceal substantial variability in daily production behavior, particularly in systems with fluctuating readiness conditions. By examining daily operational records, applied industrial engineers can identify patterns of idle time that are directly linked to readiness gaps rather than to equipment failure. This study adopts a quantitative, applied industrial engineering approach to analyze operational readiness in a make-to-order carton packaging production system. The analysis focuses on daily production data to distinguish between days with realized output and days where production time was available but not executed. This approach enables a clearer identification of readiness-related inefficiencies that contribute to idle production time. Machine performance indicators are considered as supporting information, but the primary emphasis is placed on production execution behavior and operational readiness conditions.

The objective of this research is to quantitatively assess operational readiness and its impact on production execution in a real manufacturing environment. By identifying the extent and characteristics of idle production time, the study aims to provide practical insights for improving production utilization through enhanced scheduling alignment, material preparation, and setup readiness. Through this applied focus, the research contributes to industrial engineering practice by highlighting execution-level improvement opportunities that can be implemented without major capital investment.

II. RESEARCH METHOD

a. Result

Research Approach and Positioning

This study is designed as applied quantitative industrial engineering research with a focus on diagnosing operational problems and generating practical improvement insights. The research does not aim to build theoretical models or test abstract hypotheses; instead, it seeks to quantitatively examine how operational readiness affects production execution in a real make-to-order manufacturing system. This positioning is consistent with applied industrial engineering principles, where empirical operational data are used to support decision-making and continuous improvement initiatives. (Dwivedi et al., 2022; Tayal et al., 2021). The methodological focus of this study differs from conventional machine-centered performance evaluations. While machine availability and reliability remain important, this research emphasizes production execution behavior, particularly the occurrence of scheduled production days in which available production time does not result in output. Such conditions are treated as indicators of operational readiness gaps, rather than as purely technical machine failures.

Case Study

The empirical setting of this research is a make-to-order carton packaging production system characterized by customized products,

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variable order sizes, and frequent setup changes. The production process involves several core operations, including cutting, slotting, die-cutting, and laminating, which together form the main production flow. Due to the make-to-order nature of the system, production execution depends heavily on the timely release of production orders, material availability, and setup readiness prior to scheduled production time. Previous applied studies have shown that packaging and printing industries operating under make-to-order conditions are particularly vulnerable to execution-related inefficiencies when coordination between planning and shop-floor activities is weak (Wasesa & Jumali, 2020).

Data Type, Period, and Sources

This study uses quantitative operational data obtained from routine daily production records. These records are generated as part of normal production control activities and provide objective information on planned production time, downtime, and output realization. The use of operational records enhances data validity by reflecting actual execution conditions rather than subjective assessments.(Petropoulos et al., 2024). The analysis covers a continuous one-month production period, selected based on data completeness and consistency. Daily-level data are used to capture short-term execution variability that may not be visible in aggregated monthly indicators .

Unit of Analysis and Operational Classification

The unit of analysis in this research is the daily production day for each major machine. Each production day is classified based on execution outcome into one of two categories:

a. Active production day, where scheduled production time results in realized output.
b. Idle production day, where scheduled production time is available, but no output is produced.

This execution-based classification is essential for distinguishing operational readiness problems from technical machine failures. Idle production days are interpreted as indicators of readiness gaps, such as unavailable production orders, incomplete setup, or material unavailability.

Operational Variables and Measurement

To ensure transparency and replicability, all variables used in the analysis are operationally defined and measured using objective production data. Operational readiness is not measured through perception-based instruments; instead, it is inferred from observable execution outcomes recorded in daily production data. Table 1 presents the operational variables, their definitions, and measurement units. Machine-based performance indicators are included only as supporting diagnostics to help distinguish execution-related losses from technical losses, and they are not treated as primary outcome variables.

Table 1. Operational Variables and Measurement

Variable Category	Indicator	Operational Definition	Measurement Unit
Production Time	Planned Production Time	Total scheduled production time allocated per machine per day	Minutes/day
Production Time	Downtime	Total recorded downtime during scheduled production time	Minutes/day
Execution Time	Operating Time	Planned production time minus recorded downtime	Minutes/day
Execution Outcome	Production Output	Total quantity of products produced per machine per day	Units/day
Execution Quality	Defect Quantity	Number of defective products recorded per day	Units/day
Execution Status	Production Day Status	Output > 0 classified as active day; output = 0 classified as idle day	Binary
Supporting Indicator	Machine Availability	Ratio of operating time to planned production time	Percentage (%)

Classification of Production Days

Production days are classified based on execution outcome to identify operational readiness gaps. This classification avoids conflating idle production time with machine breakdowns and allows a more accurate diagnosis of execution-related inefficiencies.

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Table 2. Classification of Production Days Based on Execution Outcome

Production Day Type	Classification Criteria	Operational Interpretation
Active Production Day	Daily production output > 0	Scheduled production time successfully executed
Idle Production Day	Daily production output = 0 with available production time	Production was not executed due to an operational readiness gap

Data Analysis Procedure

The data analysis follows a structured quantitative procedure designed to support applied industrial engineering diagnosis. The analysis begins with data validation to ensure internal consistency between planned production time, downtime, and output records. Production days are then classified as active or idle, enabling the quantification of idle production time and production utilization. Subsequently, a comparative analysis across machines is conducted to identify differences in execution sensitivity and readiness-related behavior. The analysis focuses on identifying operational patterns that can inform practical improvement actions related to scheduling, setup preparation, and coordination between planning and execution.

Table 3. Data Analysis Procedure

Step	Analysis Activity	Output
1	Data validation and cleaning	Consistent daily operational dataset
2	Classification of production days	Active vs. idle production days
3	Production utilization calculation	Utilization rate and idle time proportion
4	Comparative analysis across machines	Execution sensitivity per operation
5	Contextual interpretation	Identification of readiness-related losses

Validity, Reliability, and Ethical Considerations

Internal validity is supported by the use of actual operational records generated during routine production activities. The daily resolution of the data allows the study to capture execution variability and readiness-related disruptions with sufficient detail. (Slater & Hasson, 2024). Reliability is ensured through the consistent use of standardized production records across the observation period. Because the methodology relies on commonly available operational data, it can be replicated in other make-to-order manufacturing environments with similar characteristics. All data are analyzed at the system level without reference to individual performance. No proprietary or sensitive organizational information is disclosed, ensuring ethical compliance.

III. RESULT AND DISCUSSION

a. RESULT

Monthly Machine Performance Including Idle Production Days

Table 1 presents the average monthly performance of the main carton packaging machines calculated using all scheduled production days, including days with available production time but zero output (idle production days). The results show that machine availability remained relatively high across all machines, with values exceeding 91%. However, the overall equipment effectiveness (OEE) values were considerably low. The monthly OEE ranged from 18.75% to 32.39%, indicating substantial underutilization of available production capacity. The lowest OEE value was observed for the slotter machine (18.75%), while the highest was recorded for the die-cutter (plong) machine (32.39%). These results indicate that the inclusion of idle production days significantly reduced monthly effectiveness values despite high machine availability. Monthly values are calculated using all scheduled production days, including idle production days.

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Table 1. Monthly OEE Performance Including Idle Production Days

Machine	Active Production Days	Avg. Availability (%)	Avg. Performance (%)	Avg. Quality (%)	Avg. OEE (%)
Board-to-Board Laminator	7	91.78	29.86	43.67	28.53
Die-Cutter (Plong)	6	91.59	34.49	36.77	32.39
Slitter	5	92.04	22.78	31.25	21.57
Slotter	4	92.56	19.88	24.69	18.75

Machine Performance on Active Production Days

To isolate execution-related losses from technical performance, OEE was recalculated using only active production days, defined as days with realized output. The results are shown in Table 2. When idle production days were excluded, all machines exhibited a substantial improvement in performance indicators. Average availability values exceeded 94%, while quality rates approached 100%. Notably, the die-cutter (plong) machine achieved an average OEE of 86.38%, exceeding the commonly referenced world-class benchmark of 85%. Values are calculated using only production days with output greater than zero.

Table 2. OEE Performance on Active Production Days

Machine	Active Production Days	Avg. Availability (%)	Avg. Performance (%)	Avg. Quality (%)	Avg. OEE (%)
Board-to-Board Laminator	7	96.17	68.26	99.82	65.22
Die-Cutter (Plong)	6	95.83	91.98	98.06	86.38
Slitter	5	94.52	72.89	100.00	69.02
Slotter	4	95.24	79.53	98.77	75.01

Comparison of Monthly and Active-Day OEE

Figure 1 compares average OEE values calculated using all scheduled production days with those calculated using only active production days. The figure clearly illustrates the magnitude of execution-related losses caused by idle production days. Comparing average OEE values (%) for each machine under two conditions: (1) monthly calculation including idle production days, and (2) calculation using only active production days. That shows a pronounced gap between monthly and active-day OEE values for all machines, confirming that low monthly effectiveness is primarily driven by execution gaps rather than by technical machine limitations.

b. DISCUSSION

Operational Readiness and Production Execution Gaps

The results demonstrate that idle production days are the primary contributor to low monthly effectiveness in the observed make-to-order carton packaging system. Although machine availability remained consistently high, a large proportion of scheduled production time did not result in output, indicating significant operational readiness gaps. This finding supports applied industrial engineering research showing that production execution failures often stem from organizational and coordination issues rather than equipment malfunction. (Jumali & Utomo, 2019; Wasesa & Jumali, 2020). When production orders are not released on time, materials are unavailable, or setups are incomplete, production execution may not occur even though machines are technically ready.

Implications for Production Utilization Assessment

The contrast between Tables 1 and 2 highlights the importance of distinguishing between technical performance and execution performance. Monthly OEE values underestimated the true technical capability of machines by conflating idle production days with machine-related losses. By separating active production days from idle production days, this study provides a more accurate diagnosis of utilization losses. Similar approaches have been recommended in applied manufacturing research, particularly for make-to-order systems where execution variability is high. (Goyal et al., 2022; Tayal et al., 2021).

Execution Sensitivity Across Machines

Differences in OEE improvement between machines suggest varying sensitivity to execution readiness constraints. The die-cutter machine exhibited the largest improvement when idle days were excluded, indicating that its low monthly OEE was not caused by technical

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inefficiency but by limited execution opportunities. Machines with higher setup complexity and greater dependence on material preparation, such as slotter and slitter machines, showed greater vulnerability to execution disruptions. These findings are consistent with prior studies in packaging industries, which identify setup readiness and material availability as dominant factors affecting execution continuity. (Joachimiak-Lechman et al., 2019; Klemenčić et al., 2023).

Applied Industrial Engineering Implications

From an applied industrial engineering perspective, the findings suggest that improvement initiatives should focus on enhancing operational readiness rather than solely improving machine performance. Practical actions include implementing daily readiness checklists, improving coordination between planning and execution, and standardizing setup preparation procedures. Additionally, performance evaluation systems should incorporate execution-based indicators, such as the proportion of idle production days, alongside conventional machine metrics. This integrated approach enables more targeted and cost-effective improvement strategies in make-to-order manufacturing environments.

IV. CONCLUSION

This study analyzed production execution in a make-to-order carton packaging system using a quantitative, applied industrial engineering approach. By distinguishing between active production days and idle production days, the study identified that low monthly production effectiveness was primarily driven by execution-related issues rather than by technical machine limitations. Although machine availability consistently remained high, a significant portion of scheduled production time did not result in output, indicating substantial underutilization of available capacity. The comparison between monthly performance indicators and performance calculated only on active production days revealed a clear execution gap. When production execution occurred, machines demonstrated high availability and quality levels, and one machine achieved effectiveness values consistent with commonly referenced world-class benchmarks. These results confirm that machine capability was not the dominant constraint; instead, the absence of production execution during scheduled time played a decisive role in reducing overall effectiveness.

From an applied industrial engineering perspective, the findings emphasize the importance of separating execution-related losses from technical losses in make-to-order manufacturing environments. Aggregated performance indicators that include idle production days may obscure the true sources of inefficiency and lead to incorrect conclusions regarding machine performance. An execution-based analysis at the daily level provides a more accurate diagnosis of production utilization losses. The study concludes that improving production performance in make-to-order systems requires greater attention to operational readiness. Ensuring timely production order release, material availability, and setup preparedness before scheduled production time is essential to reducing idle production days. Practical, low-cost interventions—such as daily readiness checks, standardized setup preparation, and improved coordination between planning and execution—can significantly enhance production utilization without major capital investment. Overall, this research demonstrates that execution-based quantitative analysis using existing operational data offers a practical and effective approach for diagnosing and improving production performance in applied manufacturing settings. The approach and findings are directly applicable to similar make-to-order production systems seeking to improve utilization and operational effectiveness.

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Productivity Improvement Knuckle Steering Production Line through the Objective Matrix (OMAX) Method

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***Abstract*—In the face of market dynamics and increasing demand, the company needs to optimise productivity in every production line, including the knuckle steering item line. This study aims to measure and evaluate productivity using the Objective Matrix (OMAX) method, which integrates several key performance ratios. The analysis results showed that the highest productivity occurred in March 2024 (517.2), while the lowest was in September 2024 (23.6). The lowest ratio was production achievement to machine capacity, contributing only 27 out of a total score of 131. The low productivity is due to the lack of operator competence, suboptimal machine maintenance, long process duration, and the high amount of defective material from the foundry process. These findings emphasise the importance of comprehensive improvements in human resources, machine maintenance, and raw material quality control to drive sustainable productivity improvements.**

Keyword: Productivity; Knuckle Steering; Objective Matrix; Foundry Process

I. Introduction

Productivity is the comparison or ratio between total output and total input used by a company. [Afianti et al, 2020]. Productivity is related to production efficiency, which is the ratio of products produced to resources used. This ratio can indicate a company's productivity level in relation to its operational processes, which are used to create more effective and efficient company activities. [Wahyuni et al, 2017]. The inefficient and ineffective use of raw materials, labor, energy, and machinery during production activities prompted the company to increase productivity. Therefore, companies need to measure productivity, which can ultimately support national productivity. [Mukhtar, 2019]. One such company is an automotive component manufacturer that is striving to increase its competitiveness.

There are two departments responsible for production, namely the Foundry Department, which is tasked with producing raw materials into semi-finished materials (castings), and the Machining Department, which is tasked with processing automotive components after they have been processed in the Foundry Department. Products are manufactured through a machining process using CNC (Computer Numerical Control) Milling and Turning machines. This machining process plays a major role in increasing production and ensuring product quality. In addition, there is an increase in orders from customers that must be fulfilled every month. The production line for Knuckle Steering items has unstable productivity every month. This item line experienced a decline in production in August. In 2025, production was 4.799 pieces, while in March 2025, production reached 6,439 pieces. This decline resulted in the company failing to meet its target. Over the past year, the number of orders for this item was 5.000 pieces/month. The average monthly production was around 5,300 pieces/month, so orders at that time could still be fulfilled. In December 2025, orders for this month increased to 6.000 pieces/month. With an average production volume of 5.365 from December 2020 to November 2025, the target for that month could not be met. Therefore, the company needs to measure productivity to identify the dominant factors affecting productivity levels and propose improvements that will be used as a basis for future productivity planning. [Priscilia, 2017].

The use of the OMAX Method for productivity analysis has been proven to solve productivity-related problems. The OMAX method is a productivity analysis method used to measure and determine productivity in each part of the company, with productivity criteria that are appropriate for that part. [Wibisono, 2019]. The OMAX method can measure and assess performance in each part of the company while identifying the factors causing productivity decline. [Mundari dan Firmansyah, 2023].

Previous research by [Supriyanto et al, 2017] on measuring the productivity of tofu companies using

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the Objective Matrix (Omax) method. This study aims to measure the productivity of tofu companies. The method used for this problem is the Objective Matrix (OMAX) method. The calculation of company productivity refers to three criteria, namely the number of orders, the use of raw materials, and the number of employees. The results of this study show that the productivity index obtained at the beginning of the period reached 1.13, then in the following periods it decreased until the seventh period, which reached -0.70. The number of tofu orders from consumers decreased due to seasonal influences. Raw material usage resulted in waste of 1.124 kg, and there were 49 unemployed employees, meaning that the company did not meet the standard productivity value[8].

Then, research conducted by [9] entitled Analysis of Productivity Using the Objective Matrix Method (Omax) on the Production Floor of a Beverage Bottle Company. This study aims to evaluate productivity decline by measuring productivity values based on three criteria, namely production efficiency, effectiveness, and machine working hours. The method used is the Objective Matrix (OMAX). The criterion that contributes less to productivity and needs improvement is the production efficiency criterion because the criterion value shows below-standard performance. Meanwhile, the effectiveness criterion and the inferential criterion (machine working hours) show values that tend to be good[Prakoso et al, 2022]. The quality and efficiency of raw material usage play an important role in increasing productivity at a ratio of 3, and creating an efficient production system.[Fitriani et al, 2023.]

II. RESEARCH METHOD

The OMAX method is a method that measures a company's productivity index using more than one productivity ratio that is considered important for the company. The OMAX method has advantages over other methods, namely: Several factors that influence productivity improvement can be identified properly and quantified, and there is a weighting system that reflects the influence of each factor on the company's productivity improvement, the determination of which requires management approval [Gaoul, 2025] This model also combines all factors that influence productivity improvement and assesses them into a single indicator or index. [Priyono dan Jaya, 2023].

The advantages of the OMAX model in measuring company productivity include: it is relatively simple and easy to understand, easy to implement, and does not require special expertise; the data is easy to obtain, it is more flexible, and it depends on the problems faced. [Ernawati, 2025].

The structure of the Objective Matrix method consists of several parts, as follows. [Ernawati, 2025]:

1. Productivity Criteria are activities and factors that support the productivity of the work unit whose productivity is being measured, expressed as a ratio. These criteria indicate the effectiveness, quantity, and quality of output; the efficiency and utilization of inputs; the consistency of operations; and specific measures or other factors indirectly related to the measured level of productivity.

Table 1. Criteria Priority Scale

Nilai	Nilai Tingkat Prioritas
1	CRITERION 1 is equally important compared to CRITERION 2
2	CRITERION 1 is slightly more important than CRITERION 2
5	CRITERION 1 is more important than CRITERION 2
7	CRITERION 1 is very important compared to CRITERION 2
9	CRITERION 1 is much more important than CRITERION 2

a. Production achievement against machine capacity = (Total products produced) / (Available working hours) × 100
b. Consumption of semi-finished materials = (Semi-finished materials used) / (Total products produced) × 100
c. Machine breakdown ratio = (Total machine breakdown hours) / (Available working hours) × 100
d. Defective product ratio = (Total defective products) / (Total products produced) × 100

2. Achievement Level, which is the ratio calculated based on productivity criteria, then this result is placed in the performance column with the identification of the Ratio parameter, Highest value, Lowest value, Performance value, Initial standard, and Target percentage.

$$\text{Performance} = \frac{\text{Highest value } + \text{ Lowest}}{2}$$

$$\text{Target Ratio} = (\text{Highest value x Target}) + \text{ Highest value}$$

3. Matrix scale cells: to fill in the matrix scale cells, we first determine standard level 3 (average), level 0 (worst performance ratio),

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and level 10 (target to be achieved).

Calculation of level 1 and level 2 increases in the ratio

$$\text{Interval } (1-2) \ = \frac{\text{Level 3} - \text{Level 0}}{(3-0)}$$

Calculation of level 4 and level 9 increases in the ratio

$$\text{Interval } (4-9) \ = \frac{\text{Level 10} - \text{Level 3}}{(3-0)}$$

4. Score, which is the result of the performance ratio achievement, whether the achievement is above, below, or exactly on the standard scale (3).
5. Weight, each criterion that has been determined has a different influence on the level of productivity measured. For this reason, it is necessary to include a weight that indicates the degree of importance (in percentage terms) that shows the relative influence of the criterion on the productivity of the work unit being measured. The total weight of the criteria is 100%.

$$W \quad ht_i \quad = \frac{W \quad ht\, V}{T \quad W \quad ht} \times 100\%$$

6. The value of the achievement obtained for each criterion in a given period is obtained by multiplying the score for that criterion by the weight of that criterion.

Value = Weight x score

7. Performance Indicator: During a specific period, the total value for each criterion is listed in the performance indicator box. The initial indicator value is 300 because all criteria receive a score of 3 when the matrix is first implemented. Productivity improvement is determined by the increase in the performance indicator.

Table 2. Criteria Priority Scale

Nilai	Nilai Tingkat Prioritas
1	CRITERION 1 is equally important compared to CRITERION 2
2	CRITERION 1 is slightly more important than CRITERION 2
5	CRITERION 1 is more important than CRITERION 2
7	CRITERION 1 is very important compared to CRITERION 2
9	CRITERION 1 is much more important than CRITERION 2

III. RESULT

The Machining Department is responsible for processing automotive components after they have been processed in the Foundry Department. Products are manufactured using CNC (Computer Numerical Control) milling and turning processes. One of the products is the steering knuckle, and production productivity on this line is unstable from month to month. In August 2025, this production line experienced a decrease in output to 4.799 pieces, while in March 2025, it produced 6.439 pieces. Over the past year, the order volume for this item has been 5.000 pieces per month. The average monthly production output is approximately 5.300 pieces per month, so orders at that time could still be fulfilled.

In December 2025, orders for this month increased to 6.000 pcs/month. With the average production volume in the last year still unable to meet the target for that month, the company needs to measure productivity in order to determine and analyze the productivity of the knuckle steering product production department and find alternatives to increase existing productivity. These results can be used by management to improve productivity based on the OMAX method. Several factors cause productivity in the Knuckle Steering line to be unstable/less than optimal, namely:

- Frequent casting shifts occur during the production process in the Foundry Department.
- Therefore, every time the casting number is changed, it must be set first.
- Production operators do not work professionally.
- Machines often break down because the production line still uses old machines.
- Defective products caused by the machining process, such as MC shifting, stepping, vibration, and others.
- Defective products caused by the Foundry Department process, such as sand, drop, slag, and others.

The data obtained from the company includes the number of products produced, semi-finished materials used, total machine downtime, total available working hours, and total defective products. This is illustrated in the table below.

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Table 3. Knuckle steering production data for 12 months

Month	Semi-finished Materials (Unit)	Products (Unit)	Product Defect (Unit)	Work Time (Hour)	Breakdown Machine (Hour)
1	5.267	5.194	43	480	18
2	5.516	5.417	34	480	16
3	5.458	5.351	44	480	23
4	6.530	6.439	35	480	10
5	5.622	5.524	38	480	15
6	5.163	4.974	97	480	31
7	5.441	5.350	39	480	21
8	5.401	5.326	79	480	23
9	4.857	4.699	98	480	26
10	5.487	5.386	44	480	20
11	5.283	5.179	51	480	27
12	5.655	5.552	57	480	19

From Table 3, the highest use of semi-finished materials occurred in March 2025 with a total of 6,530 pieces. Meanwhile, the lowest use of semi-finished materials occurred in August 2025 with a total of 4,857 pieces. The highest production occurred in June 2025, producing 6,439 pieces, and the lowest production occurred in August 2025, producing 4,699 pieces. The highest total number of defective products occurred in August 2025, reaching 98 pieces, and the lowest total number of defective products occurred in January 2025, reaching 34 pieces. All production hours from December 2024 to November 2025 were 480 hours. The highest number of machine breakdown hours occurred in October 2025, with 27 hours of repairs, and the lowest number of machine breakdown hours occurred in March 2025, with 10 hours of repairs.

1. *Determination of Ratio*

This research was conducted from December 2024 to November 2025 based on company production data. Data processing used the OMAX method based on data collected during the research. The data used in this study were collected from December 2024 to November 2025, specifically including data on the amount of semi-finished materials, total products produced, total defective products, hours worked, and total machine damage.

This ratio is determined based on production support factors.

a) Production achievement relative to machine capacity hours

$$= \frac{\text{Total product}}{A \qquad W \quad T} \; x\,100\,(R \qquad 1)$$

b) Consumption of semi-finished materials

$$= \frac{\text{Semi} - \text{finished Material}}{T \quad p} \; x\,100\,(R \qquad 2)$$

c) Ratio of Breakdown Machine

$$= \frac{\text{Total Hour Breakdown Machine}}{A \qquad W} \; x\,100\,(R \qquad 3)$$

d) Ratio of defective products

$$= \frac{\text{Total Product Defect}}{T \quad P} \; x\,100\,(R \qquad 4)$$

The results of each ratio calculation during the research period are shown in the table below.

Table 4. Ratio Data December 2024 – November 2025

Moonth	Production Achievement In Relation to Working Hours	Consumption of Semi-finished Materials	Damage Machine	Product Defect
1	1.097.29	10.,4	3.75	0.82
2	1.149.16	101.82	3.33	0.62
3	1.137.08	101.99	4.79	0.82
4	1.360.41	101.41	2.08	0.54
5	1.171.25	101.77	3.12	0.68
6	1.075.62	103.79	6.45	1.95
7	1.133.54	10.7	4.37	0.72
8	1.12.,2	101.4	4.79	1.48
9	1.01187	103.36	5.41	2.08
10	1.143.12	101.87	4.16	0.81
11	1.100.62	102	5.62	0.98
12	1.178.12	101.85	3.95	1.02

2. *Determination of Target Ratio Values*

The company's productivity target is the value that the company wants to achieve and will be placed at a score of 10. Based on the company's stipulations, the final goal to be achieved is a productivity increase target of 30%. Performance values are obtained by determining the highest and lowest values during the observation period and calculating the target using the highest value of each ratio during the observation period.

The calculation for performance value and target ratio is as follows:

$$P_t \qquad V \qquad = \frac{\text{High Value} + \text{Lower Value}}{2}$$

Target rasio 1 = (High Value x Target) + High Value

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= 1360.41 x 0,3 + 1360.41 = 1768.54
Target ratio 2 = High Value x Target
= 101.41 x 0,3 = 30.42
Target ratio 3 = High Value x Target
= 2.08 x 0.3 = 0.62
Target ratio 4 = High Value x Target
= 0.54 x 0.3 = 0.16

Table 5. Performance Values and Target Values

Ratio	High Value	Low Value	Performance Value	Mean	Target 30 %
1	1.360.41	1.011,87	1.186.14	1.140.27	1.768.54
2	101.41	103.79	102.6	102.03	30.42
3	2.08	6.45	4.27	4.32	0.62
4	0.54	2.08	1.31	1.04	0.16

Table 5 shows that Ratio 1 has a different calculation method from Ratios 2, 3, and 4. This is because in ratio 1, the target value is directly proportional, meaning that the higher the value, the better. In ratios 2, 3, and 4, the target value is inversely proportional, meaning that the lower the value, the better. The initial standard value, target value, and lowest value during the observation period will be used in creating the omax table.

3. *Matrix Scale Cells*
The levels used as reference points consist of 3 levels, namely:

a) Level 0: The value of level 0 is determined based on the lowest value.
b) Level 3: The value of level 3 is determined based on the average value.
c) Level 10: The value of level 10 is determined based on the target value.

For finding the interval distance is as follows:

a) Calculation of level 1 and level 2 increases at a ratio of 1

$$it \quad (1-2) = \frac{\text{level 3} - \text{Level 0}}{(3-0)}$$
$$= \frac{1.140.27\ -\ 1.01187}{3}$$
$$= 42.8$$

b) Calculation of level 4 and level 9 increases at a ratio of 1

$$it \quad (1-2) = \frac{\text{level 10} - \text{Level 3}}{(10-3)}$$
$$= \frac{1.768.54 -\ 1.140.27}{7}$$
$$= 89.75$$

Table 6. Interval Scale

Kenaikan Level Rasio 1	
1 sampai 2	42,8
4 sampai 9	89,75
Kenaikan Level Rasio 2	
1 sampai 2	-0,58
4 sampai 9	-10,23
Kenaikan Level Rasio 3	
1 sampai 2	-0,71
4 sampai 9	-0,52
Kenaikan Level Rasio 4	
1 sampai 2	-0,34
4 sampai 9	-0,12

4. *Determine Weight*
The weighting has been determined by the company's management. Table 4 shows the weighting value, which represents the priority scale of each ratio. The highest weighting is given to ratios 1 and 2, namely production achievement against machine capacity and use of semi-finished materials. The weighting calculation is as follows:

$$C \quad w \quad ht\,v = \frac{\text{Weigth Value}}{T \quad W \quad h\,V} \times 100\%$$

Table 7. Weight of Ratio

Rasio	Bobot	Bobot %
1	10	26,3
2	10	26.3
3	9	23.6
4	9	23.6
Jumlah	38	100

Level 0 in Table 5. shows the company's worst performance. Level 3 shows the company's standard performance. Meanwhile, level 10 is the best performance that the company should be able to achieve.

Example of score determination for each ratio:
For example, for ratio 2, the actual calculation data for December 2020 is 101.4. The value that can be achieved with this actual value is at level/score 3, which is 102.03. Ratio 2 for January 2020 is actually 101.82. The value that can be achieved with this actual value is at level/score 3, which is 102.03.

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Table 8. Measurement of OMAX Standard Productivity Values

	Production Achievement In Relation to Working Hours	Consumption of Semi-finished Materials	Damage Machine	Product Defect	Consumption of Semi-finished Materials
Performance	1.186.14	102.6	4.27	1.31	
10	1.768.54	30.42	0.6	0.16	Verry Good
9	1.678,.8	40.65	1.15	0.28	
8	1.589.03	50.88	1.68	0.41	Good
7	1.499.28	61.11	2.2	0.54	
6	1.409.53	71.34	2.73	0.66	
5	1.319.78	81.57	3.26	0.79	Fine
4	1.230.02	9i.,8	3.79	0.92	
3	1.140.27	102.03	4.32	1.04	
2	1.097.47	102.62	5.03	1.39	Poor
1	1.054.67	103.21	5.74	1.73	
0	1.011.87	103.79	6.45	2.08	Bad
Weight	26.3	26.3	23.6	2.,6	
Score	3	3	3	3	
Value	78.9	78.9	70.8	70.8	

Table 8 shows that the biggest cause of productivity decline in the Knuckle Steering production line is ratio 1, where ratio 1 is production achievement productivity against machine capacity. This ratio has the lowest total score of 27.

Table 9. Determining Productivity Levels

Moonth	Production Achievement In Relation to Working Hours	Consumption of Semi-finished Materials	Damage Machine	Product Defect
1	1	3	4	4
2	3	3	4	6
3	2	3	2	4
4	5	3	7	6
5	3	3	5	5
6	1	0	0	0
7	2	3	2	4
8	2	3	2	2
9	0	0	1	0
10	3	3	3	4
11	2	2	1	3
12	3	3	3	3
Jumlah	27	29	34	41

The productivity values in the table 10 are the sum of all ratio values. The productivity value (0) for ratio 1 is in August 2025, while ratio 2 is in May and August 2025. Ratio 3 is in May and October 2025. Ratio 4 is in May and August 2025. It can be concluded that the worst productivity values are in May and August 2025. The lowest value is in ratio 1 with a value of 736.4. Meanwhile, the highest value is in ratio 4 with a value of 944.

Table 10. Productivity Values for December 2024 - November 2025

No	Production Achievement In Relation to Working Hours	Consumption of Semi-finished Materials	Damage Machine	Product Defect	Index Value Productivity
1	26.3	78.9	94.4	94.4	294
2	78.9	78.9	94.4	141.,6	393.8
3	52.6	78.9	47.2	94.4	273.1
4	131.5	78.9	165.2	141.,6	517.2
5	78.9	78.9	118	118	393.8
6	26.3	0	0	0	26,3
7	52.6	78.9	47.2	94.4	273.1
8	52.6	78.9	47.2	23.6	202.3
9	0	0	23.6	0	23.6
10	78,.9	78.9	70.8	94.4	323
11	52.6	52.6	0	70.8	176
12	78.9	78.9	70.8	70.8	299.4
Jumlah	710.1	762.7	778,8	944	3.195.6

5. Productivity Change Analysis

From the results of productivity data processing, changes in productivity during the research period were then analyzed. The calculation of changes in productivity values is as follows:

$$Cha \quad i; \ p \quad v = \frac{\text{Productivity Overal} - \text{Productivity Provious}}{P \qquad \text{Provious}} \times 100\%$$

Table 11. Changes in Productivity Index Values

No	Overal Produktivity	Provious	Index value of change compared to the previous period's productivity
1	294	0	0
2	39.,8	294	33.9
3	27.,1	393.8	-30.6
4	517.,2	273.1	89,.6
5	393.8	517.2	-23.8
6	26.3	393.8	-93.3
7	273.1	26.3	938,.
8	202.3	273.1	-25.9
9	23.6	202.3	-88.3
10	323	23.6	1.268.6
11	176	323	-45.5
12	299.4	176	70.1

Table 11 shows that a positive sign (+) indicates an increase in company productivity and vice versa. The highest productivity was in March 2021 at

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517.2, while the lowest productivity was in August 2021 at 23.6. The highest productivity index was in September 2021 at 1,268.6, while the highest decline in productivity occurred in July 2020 at (minus) -93.3.

6. Score Achievement

Table 9 shows that the highest productivity is at ratio 4, which is the productivity of defective products with a score of 41. The biggest cause of the decline in productivity on the production line is ratio 1, with a score of 27.

Table 12. Total Score Achievement

Productivity on the production line	Produktivity	Cumulative Count	Cumulative %
Productivity Production achievement relative to machine capacity hours	27	27	21%
Productivity consumption materials semi-finished	29	56	43%
Machine breakdown productivity	34	90	69%
Produktivitas produk cacat	41	131	100%

Ratio 1 is the productivity of production achievement against machine capacity, which is the ratio between the number of products produced and the number of working hours used on the Knuckle Steering production line. The low productivity achieved is caused by several factors, the main one being low output. Output can be caused by suboptimal machine performance or frequent breakdowns. Not only that, but it is also influenced by other variables such as frequent employee absences, substandard materials, inappropriate work methods, and others.

IV. CONCLUSION

The lowest productivity was in August 2025, with a productivity value of 23.6, and the highest productivity was in March 2025, with a value of 517.2. Based on the Pareto chart, of the four ratios, the lowest performance was shown by ratio 1, namely the level of production achievement relative to machine capacity hours, which did not contribute to an increase in production line productivity. Its productivity value is only 27 out of a total of 131 overall productivity values. The factors hindering production achievement are caused by unprofessional operators, inexperienced operators, lack of supervision of operators, lack of machine maintenance resulting in frequent breakdowns, lengthy production processes, and many defective materials from the Foundry department, such as drops, sand, slag, pitting, shifting, and grease.

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Optimizing Charter Scheme Selection for Coal Transport Vessels Through Capital Budgeting Indicators

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Coal distribution via maritime transport is essential to meeting Indonesia's national energy demands, creating business opportunities for bulk carrier operators and prompting a financial feasibility study on four investment schemes at a Surabaya-based shipping company: MV. Alpha (owned vessel) and MV. Beta (chartered vessel), each under Voyage Charter and Time Charter contracts. The assessment employs capital budgeting methods—Payback Period (PP), Net Present Value (NPV), and Benefit-Cost Ratio (BCR). Results show that all schemes are financially feasible. MV. Alpha–Voyage Charter records a PP of 4.6 months, NPV of Rp 41.1 billion, and BCR of 1.15, while Time Charter results in PP 7.4 months, NPV Rp 16.5 billion, and BCR 1.11. MV. Beta–Voyage Charter has a PP of 12.1 months, NPV Rp 15.3 billion, and BCR 1.03; whereas Time Charter achieves a PP of 5.3 months, NPV Rp 44.4 billion, and BCR 1.09. Incremental analysis reveals that MV. Alpha–Voyage Charter yields an incremental benefit of Rp 147.8 billion over Time Charter with an additional cost of Rp 123.2 billion, resulting in an incremental BCR of 1.20. For MV. Beta, Voyage Charter incurs Rp 29 billion in extra costs without added benefits, producing an incremental BCR of 0, making Time Charter the more efficient option.

Keywords: Investment Feasibility, Bulk Carrier Operations, Voyage Charter Contract, Time Charter Contract, Capital Budgeting Analysis.

I. INTRODUCTION

Indonesia, as an archipelagic nation, faces an increasing electricity demand, most of which is still supplied by coal-fired power plants (PLTU). According to the Ministry of Energy and Mineral Resources (ESDM), there are currently 253 PLTU units operating across the country, with the highest concentration in Kalimantan (26 units), followed by Banten and East Java with 22 units each (Indira, 2023). The total capacity of these coal-fired power plants has reached 45.35 gigawatts (GW), based on data from the Global Energy Monitor. Given the bulk volume and distance of coal distribution, maritime transport serves as the most effective logistics mode for coal delivery (Dovana, 2024), presenting promising business opportunities for dry bulk carrier operations.

A shipping company based in Surabaya specializes in bulk carrier operations and currently operates two owned vessels—MV. Alpha and MV. Charlie—and one chartered vessel, MV. Beta, with deadweight tonnage ranging from 29,000 to 58,000 MT. These vessels operate under two types of charter contracts: Time Charter and Voyage Charter. Time Charter involves renting a vessel for a specific period, while Voyage Charter involves chartering for a specific voyage or route (Kosasih, 2012). Given the potential for switching between charter types based on market needs, evaluating the feasibility and profitability of each alternative is essential.

To address this, the study employs capital budgeting analysis—specifically Payback Period (PP), Net Present Value (NPV), and Benefit-Cost Ratio (B/C)—to assess the financial viability of four vessel operation alternatives. The alternatives include combinations of ownership (owned vs. chartered) and contract type (Voyage vs. Time Charter). The goal is to determine the most financially optimal investment scenario. The study is also supported by incremental analysis to refine investment decisions between feasible alternatives, aligning with the strategic capital

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planning needs of maritime logistics businesses (Akhmad, 2019; Pujawan, 2019).

II. RESEARCH METHODOLOGY

2.1 Type and Research Approach

This study adopts a quantitative descriptive-evaluative approach, aiming to measure and compare the investment feasibility of owned and chartered bulk carrier vessels under two contractual schemes: Voyage Charter and Time Charter. The analysis is based on historical operational cost data and estimated revenue in order to assess the efficiency and profitability of each investment alternative.

2.2 Research Object

This research focuses on the operation of two vessels owned and operated by a shipping company based in Surabaya, namely MV. Alpha (owned vessel) and MV. Beta (chartered vessel). Both vessels are analyzed under two contractual schemes: Voyage Charter and Time Charter. Thus, a total of four investment alternatives are evaluated to determine the most financially feasible scenario. The general specifications (ship particulars) of each vessel are presented in Table 1.

Table 1. Ship Particular MV. Alpha dan MV. Beta.

SHIP PARTICULAR									
		MV. ALPHA			Ann.	MV. BETA			Ann.
A. Main Specification									
Gross Tonnage	:	26,059.00			MT	31,117.00			MT
Nett Tonnage	:	14,880.00			MT	18,159.00			MT
B. Cargo Capacity									
Grain Capacity	:	57,208.00			m³	65,044.98			m³
Bale Capacity	:	55,565.00			m³	-			
Avg. Coal Stowage Factor	:	1.23			m³/MT	1.23			m³/MT
Approx. Max Capacity	:	46,510.57			MT	52,882.10			MT
C. Present Speed & Daily Fuel Consumption									
Avg. MFO Viscosity	:	0.9448			Kg/L				
Avg. MGO Viscosity	:	0.8542			Kg/L				
At Sea - Ballast									
Speed	:	11.00		Kts		12.00		Kts	
MFO	:	20.41	MT/Day	21,600	L/Day	25.00	MT/Day	26,461	L/Day
MGO	:	-	MT/Day	-	L/Day	0.20	MT/Day	234	L/Day
At Sea - Laden									
Speed	:	9.50		Kts		11.50		Kts	
MFO	:	20.41	MT/Day	21,600	L/Day	26.00	MT/Day	27,519	L/Day
MGO	:	-	MT/Day	-	L/Day	0.20	MT/Day	234	L/Day
At Port - Idle									
MFO	:	-	MT/Day	-	L/Day	3.50	MT/Day	3,704	L/Day
MGO	:	1.03	MT/Day	1,200	L/Day	0.20	MT/Day	234	L/Day
At Port - Working									
MFO	:	-	MT/Day	-	L/Day	5.80	MT/Day	6,139	L/Day
MGO	:	2.46	MT/Day	2,880	L/Day	0.20	MT/Day	234	L/Day
Maneuvering									
MFO	:	-	MT/Port	-	L/Port	-	MT/Port	-	L/Port
MGO	:	1.54	MT/Port	1,800	L/Port	-	MT/Port	-	L/Port
Fresh Water	:	15.00		MT/Day		-		MT/Day	

2.3 Data Analysis Technique

The data analysis in this study is conducted through the following stages:

1. Identification of Financial Components
   - Estimating the annual operational expenses (OPEX) for the four contractual schemes.
   - Estimating the annual revenue for each of the four contractual schemes.
2. Cash Flow Modeling
   - Preparing five-year cash flow projections for all four contractual schemes.
3. Investment Feasibility Analysis

Calculating investment feasibility indicators using the following methods:

a. Payback Period (PP)

Payback Period refers to the time required to recover the initial investment using the

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project's net cash inflows or proceeds. It represents the duration needed for an investor to fully regain the capital invested in a project (Akhmad, 2019).
The formula used for calculating the Payback Period is presented in Equation 1.

$$P \qquad P = \frac{C \qquad \times\ 1\ t\ hu}{P} \qquad (1)$$

Description:
Outlay = The total investment or capital expenditure incurred.
Proceeds = The total cash inflow or revenue received.

An investment alternative is considered feasible if the result of the Payback Period analysis is the shortest among all options or shorter than the planning horizon.

b. Net Present Value (NPV)

According to Akhmad (2019), Net Present Value (NPV) is the difference between the present value of total proceeds and the present value of total investment. If the present value of proceeds is greater than or equal to the present value of the investment, then the investment proposal is accepted. Conversely, if the present value of proceeds is less than the present value of the investment, the proposal is rejected. Another definition states that NPV is a method to calculate the present value of a series of future cash flows by considering the time value of money. The formula used for calculating the NPV is presented in Equation 2.

$$N \quad = \sum_{t=1}^{n} \frac{R}{(1+i)^t} - C_c \qquad (2)$$

Description:
NPV = Net Present Value
CF_t = Cash flow in period t
t = Time period (0, 1, 2, 3...n)
r = Discount rate
C_0 = Initial investment

An investment alternative is considered feasible if the result of the NPV analysis is greater than 0.

c. Benefit-Cost Ratio (BCR)

According to Kosasih (2012), the Benefit-Cost (B/C) Ratio is the comparison between the present value of business revenue and the present value of cash expenditures, including investment outlays and debt repayments related to the investment. If during the payback period the B/C ratio is greater than 1, it indicates that the present value of cash inflows is sufficient to cover the present value of cash outflows, making the investment financially feasible to proceed.
An alternative is considered feasible if the result of the B/C ratio analysis is greater than 1. The formula used for calculating the BCR is presented in Equation 3.

$$B \quad = \frac{P_B}{P_C} \qquad (3)$$

Description:
PV_B = Present Value of Total Benefit
PV_C = Present Value of Total Cost

An investment option is deemed financially viable when the Benefit-Cost Ratio (B/C) exceeds 1.0, indicating that the present value of expected benefits outweighs the present value of associated costs.

III. RESULT AND DISCUSSION

The investment feasibility analysis begins with the identification of key financial components, namely the estimated annual operating expenses (OPEX) and annual revenue for four vessel operation alternatives: MV. Alpha and MV. Beta, each evaluated under both Voyage Charter and Time Charter schemes. These estimates are derived from historical operational data of a national shipping company based in Surabaya, reflecting actual and relevant field conditions. The results are presented in summary tables to provide an initial overview of the financial characteristics of each investment alternative.

Subsequently, a five-year operational cash flow model is developed. The initial investment is determined based on the highest estimated operational cost under each charter scheme, representing the maximum funding requirement. This information serves as the foundation for constructing the cash flow projections and conducting a comprehensive investment feasibility analysis in the following stage. Table 2 presents the projected cash flow for the MV. Alpha alternative under the Voyage Charter scheme.

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Table 2. 5th Cash Flow-MV. Alpha-Voyage Charter.

YEAR		MV. ALPHA VOYAGE CHARTER CASH FLOW	
0	2025	-Rp	4,973,266,462
1	2026	Rp	12,967,319,400
2	2027	Rp	13,226,665,788
3	2028	Rp	13,491,199,104
4	2029	Rp	13,761,023,086
5	2030	Rp	14,036,243,548

Projected cash flow for MV. Alpha Time Charter alternative shown in the table below.

Table 3. *5th Cash Flow*-MV. Alpha-*Time Charter*.

YEAR		MV. ALPHA TIME CHARTER CASH FLOW	
0	2025	-Rp	3,484,503,200
1	2026	Rp	5,635,961,606
2	2027	Rp	5,748,680,838
3	2028	Rp	5,863,654,455
4	2029	Rp	5,980,927,544
5	2030	Rp	6,100,546,095

Projected cash flow for MV. Beta Voyage Charter alternative shown in table below.

Table 4. 5th Cash Flow-MV. Beta-Voyage Charter.

YEAR		MV. BETA VOYAGE CHARTER CASH FLOW	
0	2025	-Rp	6,056,297,436
1	2026	Rp	6,009,624,516
2	2027	Rp	6,129,817,007
3	2028	Rp	6,252,413,347
4	2029	Rp	6,377,461,614
5	2030	Rp	6,505,010,846

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Projected cash flow for MV. Beta Time Charter alternative shown in table below.

Table 5. 5th Cash Flow-MV. Beta-Time Charter.

YEAR		MV. BETA TIME CHARTER CASH FLOW	
0	2025	-Rp	6,307,714,687
1	2026	Rp	14,258,881,540
2	2027	Rp	14,544,059,171
3	2028	Rp	14,834,940,355
4	2029	Rp	15,131,639,162
5	2030	Rp	15,434,271,945

After estimating the five-year cash flow projections for each investment alternative, the next step is to conduct a capital budgeting analysis. This analysis involves applying three financial evaluation methods: Payback Period (PP), Net Present Value (NPV), and Benefit-Cost Ratio (BCR). The Payback Period is used to determine how long it takes for an investment to recover its initial cost. The NPV method evaluates the net value generated by the investment by discounting future cash flows to their present value. Meanwhile, the BCR assesses the ratio of the present value of benefits to the present value of costs, serving as a measure of the investment's overall financial efficiency. Together, these methods provide a comprehensive assessment of the feasibility and attractiveness of each operational scheme.

A. Payback Period Analysis (PP)

Based on the discussion in the previous chapter and by applying the formula stated in Equation 1, the Payback Period for each investment alternative has been calculated. The results of these calculations are presented in Table 6 below, providing a comparative overview of the time required to recover the initial investment under each operational scheme.

Table 6. Payback Period Analysis

MV. ALPHA VOYAGE CHARTER CASH FLOW		PAYBACK PERIOD In Month	PAYBACK PERIOD In Year	MV. ALPHA TIME CHARTER CASH FLOW		PAYBACK PERIOD In Month	PAYBACK PERIOD In Year
-Rp	4,973,266,462	4.6	0.38	-Rp	3,484,503,200	7.4	0.62
Rp	12,967,319,400			Rp	5,635,961,606		
Rp	13,226,665,788			Rp	5,748,680,838		
Rp	13,491,199,104			Rp	5,863,654,455		
Rp	13,761,023,086			Rp	5,980,927,544		
Rp	14,036,243,548			Rp	6,100,546,095		
MV. BETA VOYAGE CHARTER CASH FLOW		**PAYBACK PERIOD In Month**	**PAYBACK PERIOD In Year**	**MV. BETA TIME CHARTER CASH FLOW**		**PAYBACK PERIOD In Month**	**PAYBACK PERIOD In Year**
-Rp	6,056,297,436	12.1	1.01	-Rp	6,307,714,687	5.3	0.44
Rp	6,009,624,516			Rp	14,258,881,540		
Rp	6,129,817,007			Rp	14,544,059,171		
Rp	6,252,413,347			Rp	14,834,940,355		
Rp	6,377,461,614			Rp	15,131,639,162		
Rp	6,505,010,846			Rp	15,434,271,945		

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The results of the Payback Period analysis show that MV. Alpha under the Voyage Charter scheme requires approximately 4.6 months, or 0.38 years, to recover its initial operational investment. Under the Time Charter scheme, MV. Alpha requires 7.4 months, or 0.62 years. For MV. Beta, the Payback Period under the Voyage Charter scheme is 12.1 months, equivalent to 1.01 years, while under the Time Charter scheme, the required period is 5.3 months, or 0.44 years. These findings indicate the duration needed for each operational alternative to return the initial investment and reflect the relative financial efficiency of each scheme in terms of capital recovery.

B. Net Present Value (NPV)

Based on the methodology outlined in the previous chapter and by applying the established formula presented in Equation 2, the Net Present Value (NPV) for each vessel operation scheme has been calculated. The NPV analysis aims to assess the present value of net cash flows over a five-year operational horizon, discounted at a predetermined rate that reflects the company's required rate of return. The results are shown in Table 7.

Table 7. Net Present Value Analysis

MV. ALPHA VOYAGE CHARTER	NPV (Net Present Value)		MV. ALPHA TIME CHARTER	NPV (Net Present Value)	
CASH FLOW	DF (i=14%)	Present Value	CASH FLOW	DF (i=14%)	Present Value
-Rp 4,973,266,462	1	-Rp 4,973,266,462	-Rp 3,484,503,200	1	-Rp 3,484,503,200
Rp 12,967,319,400	0.8772	Rp 11,374,841,579	Rp 5,635,961,606	0.8772	Rp 4,943,825,970
Rp 13,226,665,788	0.7695	Rp 10,177,489,834	Rp 5,748,680,838	0.7695	Rp 4,423,423,236
Rp 13,491,199,104	0.6750	Rp 9,106,175,115	Rp 5,863,654,455	0.6750	Rp 3,957,799,738
Rp 13,761,023,086	0.5921	Rp 8,147,630,366	Rp 5,980,927,544	0.5921	Rp 3,541,189,239
Rp 14,036,243,548	0.5194	Rp 7,289,985,064	Rp 6,100,546,095	0.5194	Rp 3,168,432,477
	NPV	Rp 41,122,855,495		NPV	Rp 16,550,167,461

MV. BETA VOYAGE CHARTER	NPV (Net Present Value)		MV. BETA TIME CHARTER	NPV (Net Present Value)	
CASH FLOW	DF (i=14%)	Present Value	CASH FLOW	DF (i=14%)	Present Value
-Rp 6,056,297,436	1	-Rp 6,056,297,436	-Rp 6,307,714,687	1	-Rp 6,307,714,687
Rp 6,009,624,516	0.8772	Rp 5,271,600,453	Rp 14,258,881,540	0.8772	Rp 12,507,790,825
Rp 6,129,817,007	0.7695	Rp 4,716,695,142	Rp 14,544,059,171	0.7695	Rp 11,191,181,264
Rp 6,252,413,347	0.6750	Rp 4,220,200,917	Rp 14,834,940,355	0.6750	Rp 10,013,162,184
Rp 6,377,461,614	0.5921	Rp 3,775,969,241	Rp 15,131,639,162	0.5921	Rp 8,959,145,112
Rp 6,505,010,846	0.5194	Rp 3,378,498,795	Rp 15,434,271,945	0.5194	Rp 8,016,077,205
	NPV	Rp 15,306,667,112		NPV	Rp 44,379,641,904

Based on the Net Present Value (NPV) analysis, all four vessel operation schemes demonstrate positive outcomes, indicating financial feasibility. The NPV for MV. Alpha under the Voyage Charter scheme is Rp 41.122.855.495, while under the Time Charter scheme it is Rp 16.550.167,461. For MV. Beta, the NPV under the Voyage Charter scheme is Rp 15.306.667.112, and under the Time Charter scheme, it reaches Rp 44.379.641.904. A positive NPV signifies that the present value of expected cash inflows exceeds the initial investment, meaning the investment is projected to generate a net financial gain over the analysis period. Therefore, all four investment alternatives are considered financially viable.

C. Benefit Cost Ratio (BCR)

Based on the explanations presented in the previous chapter and by applying the formula outlined in Equation 3, the Benefit-Cost Ratio (BCR) results for each investment alternative have been obtained and are presented in Table 8. The BCR analysis provides a ratio that compares the present value of benefits to the present value of costs. A BCR greater than 1 indicates that the benefits outweigh the costs, thus confirming that the investment is financially viable and should be considered for implementation.

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Table 8. BCR - MV. Alpha - Voyage Charter.

BCR (Benefit-Cost Ratio)					
Benefit/Revenue	Cost/OPEX	DF (i=14%)	PV Benefit	PV Cost	BC Ratio
Rp -	Rp 4,973,266,462	1	Rp -	Rp 4,973,266,462	1.15
Rp 89,030,000,000	Rp 76,062,680,600	0.8772	Rp 78,096,491,228	Rp 66,721,649,649	
Rp 90,810,600,000	Rp 77,583,934,212	0.7695	Rp 69,875,807,941	Rp 59,698,318,107	
Rp 92,626,812,000	Rp 79,135,612,896	0.6750	Rp 62,520,459,737	Rp 53,414,284,622	
Rp 94,479,348,240	Rp 80,718,325,154	0.5921	Rp 55,939,358,712	Rp 47,791,728,346	
Rp 96,368,935,205	Rp 82,332,691,657	0.5194	Rp 50,051,005,163	Rp 42,761,020,099	
		Total PV	Rp 316,483,122,780	Rp 275,360,267,285	

As for MV. Alpha - Time Charter shown in table 9. on this below

Table 9. BCR - MV. Alpha - Time Charter.

BCR (Benefit-Cost Ratio)					
Benefit/Revenue	Cost/OPEX	DF (i=14%)	PV Benefit	PV Cost	BC Ratio
Rp -	Rp 3,484,503,200	1	Rp -	Rp 3,484,503,200	1.11
Rp 47,450,000,000	Rp 41,814,038,394	0.8772	Rp 41,622,807,018	Rp 36,678,981,047	
Rp 48,399,000,000	Rp 42,650,319,162	0.7695	Rp 37,241,458,910	Rp 32,818,035,674	
Rp 49,366,980,000	Rp 43,503,325,545	0.6750	Rp 33,321,305,341	Rp 29,363,505,603	
Rp 50,354,319,600	Rp 44,373,392,056	0.5921	Rp 29,813,799,516	Rp 26,272,610,276	
Rp 51,361,405,992	Rp 45,260,859,897	0.5194	Rp 26,675,504,830	Rp 23,507,072,353	
		Total PV	Rp 168,674,875,614	Rp 152,124,708,153	

As for MV. Beta - Voyage Charter shown in Table 10. on this below

Table 10. BCR - MV. Beta - Voyage Charter.

BCR (Benefit-Cost Ratio)					
Benefit/Revenue	Cost/OPEX	DF (i=14%)	PV Benefit	PV Cost	BC Ratio
Rp -	Rp 6,056,297,436	1	Rp -	Rp 6,056,297,436	1.03
Rp 146,685,300,000	Rp 140,675,675,484	0.8772	Rp 128,671,315,789	Rp 123,399,715,336	
Rp 149,619,006,000	Rp 143,489,188,993	0.7695	Rp 115,126,966,759	Rp 110,410,271,617	
Rp 152,611,386,120	Rp 146,358,972,773	0.6750	Rp 103,008,338,679	Rp 98,788,137,762	
Rp 155,663,613,842	Rp 149,286,152,229	0.5921	Rp 92,165,355,660	Rp 88,389,386,419	
Rp 158,776,886,119	Rp 152,271,875,273	0.5194	Rp 82,463,739,275	Rp 79,085,240,480	
		Total PV	Rp 521,435,716,163	Rp 506,129,049,051	

As for MV. Beta - Time Charter shown in Table 11. on this below

Table 11. BCR - MV. Beta - Time Charter.

BCR (Benefit-Cost Ratio)					
Benefit/Revenue	Cost/OPEX	DF (i=14%)	PV Benefit	PV Cost	BC Ratio
Rp -	Rp 6,307,714,687	1	Rp -	Rp 6,307,714,687	1.09
Rp 146,685,300,000	Rp 132,426,418,460	0.8772	Rp 128,671,315,789	Rp 116,163,524,965	
Rp 149,619,006,000	Rp 135,074,946,829	0.7695	Rp 115,126,966,759	Rp 103,935,785,495	
Rp 152,611,386,120	Rp 137,776,445,765	0.6750	Rp 103,008,338,679	Rp 92,995,176,495	
Rp 155,663,613,842	Rp 140,531,974,681	0.5921	Rp 92,165,355,660	Rp 83,206,210,548	
Rp 158,776,886,119	Rp 143,342,614,174	0.5194	Rp 82,463,739,275	Rp 74,447,662,070	
		Total PV	Rp 521,435,716,163	Rp 477,056,074,259	

The results of the Benefit-Cost Ratio (BCR) analysis indicate that all investment alternatives are financially viable. MV. Alpha operating under a Voyage Charter scheme yields a BCR of 1.15, while the Time Charter scheme produces a BCR of 1.11. Similarly, MV. Beta under the Voyage Charter scheme results in a BCR of 1.03, and the Time Charter scheme achieves a BCR of 1.09. Since all values are greater than 1, each option is considered feasible. A BCR value above 1 implies that the present value of benefits exceeds the present value of costs, indicating that the investment is expected to generate net positive returns and is therefore economically justified.

Due to limited capital, the company can operate only two vessels—one owned (MV. Alpha) and one chartered (MV. Beta)—so only one contract scheme per vessel can be selected. To identify the most financially optimal choice, this study uses incremental analysis, which compares additional benefits and costs between feasible alternatives. Following Hilton et al. (2000), this method isolates key financial differences to support better investment decisions. The analysis starts by comparing each scheme against the status quo, with results ranked by Present Value (PV) of Benefit and summarized in Table 12.

Table 12. MV. Alpha - PV Benefit Rank

ALTERNATIVE	PV BENEFIT	PV COST	B/C
MV. ALPHA VOYAGE CHARTER	Rp 316,483,122,780	Rp 275,360,267,285	1.15
MV. ALPHA TIME CHARTER	Rp 168,674,875,614	Rp 152,124,708,153	1.11
QUO STATUS ALTERNATIVE	Rp 0	Rp 0	0

In the incremental analysis approach, the alternative with a lower PV Benefit "challenges" the higher one to assess whether the additional benefit justifies the additional cost. Therefore, the Quo Status is first compared to MV. Alpha – Time Charter. If Time Charter proves financially feasible, it then challenges the highest PV Benefit alternative—Voyage Charter—to determine the optimal scheme. This step-by-step analysis is presented through calculations of incremental benefit, incremental cost, and incremental B/C ratio, as shown in Table 13 for MV. Alpha.

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Table 13. MV. Alpha - Incremental Analysis

MV. ALPHA					
INITIAL ALTERNATIVE	COMPARATIVE ALTERNATIVE	INCREMENTAL BENEFIT	INCREMENTAL COST	INCREMENTAL B/C RATIO	CONCLUSION
MV. ALPHA TIME CHARTER	QUO STATUS ALTERNATIVE	Rp 168,674,875,614	Rp 152,124,708,153	1.11	MV. ALPHA TIME CHARTER
MV. ALPHA VOYAGE CHARTER	MV. ALPHA TIME CHARTER	Rp 147,808,247,166	Rp 123,235,559,132	1.20	MV. ALPHA VOYAGE CHARTER

Incremental analysis on MV. Alpha operations show that Time Charter is more feasible than the Quo Status, with an incremental B/C ratio of 1.11. When Voyage Charter is compared to Time Charter, it yields a higher incremental B/C ratio of 1.20, indicating greater financial benefits relative to additional costs. Therefore, Voyage Charter is the most optimal and profitable investment option for MV. Alpha. As for MV. Beta rank can be shown in Table 14.

Table 14. MV. Beta - PV Benefit Rank

ALTERNATIVE	PV BENEFIT	PV COST	B/C
MV. BETA VOYAGE CHARTER	Rp 521,435,716,163	Rp 506,129,049,051	1.03
MV. BETA TIME CHARTER	Rp 521,435,716,163	Rp 477,056,074,259	1.09
QUO STATUS ALTERNATIVE	Rp 0	Rp 0	0

As for MV. Beta incremental analysis can be shown in Table 15. Below

.**Table 15.** MV. Beta - Incremental Analysis

MV. BETA					
INITIAL ALTERNATIVE	COMPARATIVE ALTERNATIVE	INCREMENTAL BENEFIT	INCREMENTAL COST	INCREMENTAL B/C RATIO	CONCLUSION
MV. BETA TIME CHARTER	QUO STATUS ALTERNATIVE	Rp 521,435,716,163	Rp 477,056,074,259	1.09	MV. BETA TIME CHARTER
MV. BETA VOYAGE CHARTER	MV. BETA TIME CHARTER	Rp 0	Rp 29,072,974,792	0	MV. BETA TIME CHARTER

Incremental analysis on MV. Beta operations indicate that Time Charter is financially feasible compared to the Quo Status, with an incremental B/C ratio of 1.09, exceeding the minimum viability threshold. When compared to Voyage Charter, both alternatives show identical PV benefits; however, Voyage Charter incurs additional costs without generating added financial gains, resulting in an incremental B/C ratio of 0. This suggests inefficiency. Therefore, MV. Beta – Time Charter is the most appropriate and cost-effective investment option.

IV. CONCLUSION

Based on the results of the analysis that has been carried out and discussed, the following conclusions are obtained:

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1. Based on the capital budgeting analysis using Payback Period (PP), Net Present Value (NPV), and Benefit-Cost Ratio (B/C), all four investment alternatives—MV. Alpha and MV. Beta under Voyage Charter and Time Charter is financially feasible. MV. Alpha under Voyage Charter shows the best outcome with a PP of 4.6 months, NPV of Rp 41.1 billion, and B/C ratio of 1.15. Meanwhile, MV. Beta under Time Charter yields a PP of 5.3 months, NPV of Rp 44.4 billion, and B/C ratio of 1.09, making it the more favorable option.
2. To determine the optimal investment, incremental analysis was applied. For MV. Alpha, Voyage Charter outperformed Time Charter with an incremental benefit of Rp 147.8 billion, incremental cost of Rp 123.2 billion, and an incremental B/C ratio of 1.20, making it the optimal choice. Meanwhile, MV. Beta's Voyage Charter incurred an additional cost of Rp 29 billion without an added benefit, resulting in an incremental B/C ratio of 0. Thus, Time Charter is deemed the more efficient option. In conclusion, the optimal investment combination is MV. Alpha under Voyage Charter and MV. Beta under Time Charter.

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Applied Lean Warehousing-Based Optimization of Warehouse Processes at PT. XYZ Using Value Stream Mapping

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***Abstract*—Incoming warehouse operations are essential for maintaining material readiness in manufacturing systems. In practice, inefficiencies within these operations may increase lead time and generate activities that do not contribute to value creation. This study focuses on enhancing the performance of the incoming warehouse process at PT. XYZ through the application of lean warehousing supported by Value Stream Mapping (VSM). The study was carried out by examining the actual condition of receiving, recording, and storage activities using direct observation, time measurement, and process mapping. All identified activities were categorized according to their contribution to value creation. Process performance was assessed using Process Cycle Efficiency (PCE) to quantify the ratio of value-added time to total lead time. The results indicate that the existing incoming warehouse process required 296 minutes to complete, with a PCE of 74.66%, reflecting the presence of non-value-added activities, particularly related to waiting and unnecessary movement. Improvement actions were then formulated using future state value stream mapping and workplace organization. The proposed future condition reduced the total lead time to 273 minutes and increased the PCE to 80.95%. These findings show that lean warehousing implementation can effectively improve process efficiency by reducing non-value-added activities in incoming warehouse operations. The study provides practical insight for manufacturing companies seeking to improve inbound warehouse performance through structured waste reduction initiatives.**

Keywords: Lean warehousing; Value stream mapping; Incoming warehouse; Process cycle efficiency; Lead time minimization.

I. INTRODUCTION

Warehousing plays a crucial role in supporting logistics and production performance in manufacturing industries. Inefficient warehouse operations can increase lead time, raise operational costs, and disrupt material availability for production activities. The incoming warehouse process, in particular, is a critical control point because it handles material reception, inspection, recording, and storage before materials are released to production. Inefficiencies at this stage may propagate throughout the supply chain and negatively affect overall operational performance.

In warehouse operations, various forms of waste frequently occur, including waiting, unnecessary motion, and overprocessing. These activities don't add value to the product but consume significant time and resources. Barry et al. (2023) identified waiting time as a dominant source of inefficiency in inbound warehouse activities, particularly during document verification and material handling processes. Similarly, Mahen et al. (2023) reported that excessive non-value-added activities increase total lead time and reduce productivity in warehouse operations. These results emphasize the need for a structured approach to identifying and reducing waste within incoming warehouse operations.

Lean warehousing is an approach derived from lean principles that aims to improve warehouse performance by minimizing waste and maximizing value-added activities. Lean warehousing emphasizes process simplification, work standardization, and continuous improvement to enhance operational efficiency. (Afif & Sudarto, 2022). Putra & Widjajati (2025) Further emphasized that lean warehousing implementation can reduce operational inefficiencies by focusing on eliminating activities that do not contribute directly to customer value.

Recent studies emphasize that lean warehousing has become a dominant approach for improving

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warehouse operational efficiency by focusing on waste elimination and flow optimization. Ikatrinasari (2023) demonstrated that warehouse activities such as receiving, storage, and material handling often contain a high proportion of non-value-added activities, which can be effectively identified using value stream mapping (VSM) and improved through 5S implementation.

Furthermore, Adeodu et al. (2023) showed that applying lean-oriented warehouse improvement frameworks results in notable gains in key performance metrics, especially lead time and process cycle efficiency (PCE), by systematically reducing waiting time and unnecessary movements. These findings are supported by Julião & Reis (2025), who proposed a structured lean-driven framework for warehouse optimization, emphasizing the importance of visual process mapping and continuous improvement to sustain performance gains.

Although previous studies have extensively discussed lean implementation in warehouse environments, research focusing on detailed optimization of incoming warehouse processes in manufacturing companies remains limited. This gap indicates the need for applied studies that integrate VSM and efficiency measurement to improve inbound warehouse performance, such as the case examined at PT. XYZ.

Value Stream Mapping (VSM) is commonly applied in lean warehousing to visualize material and information flows throughout a process and to distinguish between value-added activities, non-value-added activities, and necessary non-value-added activities. (Ramadhanti et al., 2023). Pamungkas & Aryanny (2025) demonstrated that VSM is effective in identifying waste and process imbalance in warehouse flow activities, thereby supporting data-driven decision-making for process improvement.

Several studies have confirmed the effectiveness of lean warehousing and VSM in improving warehouse performance. Ardysti & Ernawati (2025) reported that lean warehousing implementation successfully reduced waiting and motion waste in warehouse operations. In addition, Nurulita (2024) found that the application of lean principles improved operational efficiency and process consistency in logistics service providers. However, most existing studies focus on general warehouse operations or outbound logistics, while detailed quantitative evaluations of incoming warehouse processes in manufacturing environments remain limited.

In manufacturing companies that have partially adopted digital warehouse systems, inefficiencies may persist due to system connectivity limitations, unstandardized administrative procedures, and an imbalance in workload distribution. These conditions create a gap between the potential efficiency offered by digitalization and the actual operational performance observed in daily activities. Therefore, an integrated analysis combining lean warehousing principles and Value Stream Mapping is required to comprehensively evaluate incoming warehouse processes and identify practical improvement opportunities.

Considering the identified challenges, this study examines the optimization of the incoming warehouse process at the company by implementing a lean warehousing framework based on Value Stream Mapping. The objectives include analyzing activity classifications, measuring process efficiency through Process Cycle Efficiency (PCE), and formulating improvement proposals aimed at reducing lead time and waste. The findings of this research are expected to provide practical insights for improving incoming warehouse performance and contribute to empirical studies on lean warehousing implementation in manufacturing logistics systems.

II. RESEARCH METHOD

A. Research Design

The study was conducted by examining a specific case of an incoming warehouse process to assess its performance and identify opportunities for improvement. The descriptive approach was used to capture the actual conditions of warehouse activities, while the analytical approach was applied to identify inefficiencies and propose improvement initiatives. This research integrated quantitative analysis, in the form of time measurement and efficiency calculation, with qualitative analysis, including observation and process interpretation, to obtain a comprehensive evaluation of warehouse performance. (Afif & Sudarto, 2022).

The research framework was based on lean warehousing principles, which focus on waste elimination and process efficiency improvement. The study utilized Value Stream Mapping (VSM) as the principal analysis tool, as it allows process flows to be mapped in detail and supports the

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identification of non-value-added activities. (Ramadhanti et al., 2023).

B. Research Object and Scope

The object of this research was the incoming warehouse process at PT. XYZ, specifically within the Warehouse Part area. The incoming process consisted of receiving, recording, and storing activities. The scope of the study was limited to internal warehouse operations, excluding external transportation activities, to maintain analytical focus and data consistency.

The research emphasized the evaluation of process lead time, waste occurrence, and process efficiency, as these indicators are commonly used to assess warehouse operational performance. (Mahen et al., 2023). The limitation of scope allowed for detailed observation and precise measurement of activities that directly contribute to incoming warehouse performance.

C. Data Collection Methods

Data collection was conducted through direct observation, time study, and document review. Direct observation was carried out to understand the actual workflow and operational practices within the incoming warehouse process. A time study was performed to measure the duration of each activity, enabling the identification of bottlenecks and time-consuming tasks.

Document review included the examination of work instructions, operational records, and system-generated data to validate the observed process flow. This combination of data collection methods ensured data reliability and minimized observation bias, as recommended in warehouse efficiency studies. (Barry et al., 2023).

D. Process Mapping Using Value Stream Mapping

Value Stream Mapping (VSM) was applied to represent the sequence of material and information flows throughout the incoming warehouse process, starting from receiving activities to storage. The mapping process involved identifying each operational step, determining cycle time, and documenting information flow between operators and systems.

The VSM analysis was carried out through two stages. The current state mapping captured the actual operating conditions and identified sources of inefficiency, while the future state mapping depicted the redesigned process following improvement initiatives. The use of VSM enabled a structured visualization of process performance and supported systematic improvement planning. (Pamungkas & Aryanny, 2025).

E. Activity Classification and Waste Identification

Activities mapped using VSM were categorized into three types based on their contribution to value creation, namely VA, NVA, and NNVA. This classification aims to distinguish productive activities from those that do not contribute directly to customer value.

Waste identification focused on activities categorized as NVA and NNVA. The dominance of waste was identified based on the frequency and duration of non-value-added activities, with particular attention to waiting, overprocessing, and motion. These waste types are commonly found in warehouse operations and significantly affect lead time and productivity. (Ardysti & Ernawati, 2025).

F. PCE (Process Cycle Efficiency)

Process efficiency was assessed using Process Cycle Efficiency (PCE), a metric that represents the proportion of value-added time relative to the overall process lead time. The PCE value was determined using the following equation.:

$$P = \frac{V \quad A}{T \quad L \quad T_l} x\, 100\% \quad (1)$$

PCE was applied as the main indicator to examine incoming warehouse efficiency, with calculations performed under existing conditions and after the proposed improvements to assess their impact. PCE is widely used in lean-based warehouse studies to quantify process efficiency and identify improvement potential (Putra & Widjajati, 2025).

G. Root Cause Analysis

To identify the sources of waste, a root cause analysis was carried out using a fishbone diagram that categorized inefficiencies into man, machine, method, and material factors. This approach facilitated structured problem identification and supported the formulation of targeted improvement strategies.

The fishbone analysis enabled the identification of issues such as administrative delays, limited equipment availability, unstandardized procedures, and material handling constraints.

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Similar analytical approaches have been applied effectively in warehouse waste reduction studies. (Nurulita, 2024).

H. Development of Improvement Proposals

The proposed improvements were derived from the results of waste analysis and the identification of underlying causes. Lean warehousing principles were applied to redesign the process flow, focusing on reducing waiting time, minimizing overprocessing, and improving workplace organization. The proposed improvements incorporated process standardization and workplace organization concepts, such as 5S, to support sustainable efficiency improvement.

The proposed improvements were visualized using Future State Value Stream Mapping, which illustrated the expected process condition after implementation. This approach aligns with previous studies that emphasize the importance of visual tools in supporting lean-based improvement initiatives. (Dzulkifli & Ernawati, 2021).

I. Evaluation of Improvement Results

The effectiveness of the proposed improvements was evaluated by comparing Current State and Future State performance indicators. The primary indicators used were total lead time and PCE. The comparison aimed to assess the extent to which lean warehousing implementation reduced waste and improved overall process efficiency.

This evaluation approach enabled objective assessment of improvement outcomes and provided quantitative evidence of the effectiveness of the proposed solutions, consistent with methodologies used in applied industrial engineering research. (Shafalah et al., 2025).

The selection of value stream mapping (VSM) as the primary analytical tool in this study is consistent with recent warehouse optimization research. Ikatrinasari (2023) showed that Value Stream Mapping enables the visualization of process flows and facilitates the categorization of warehouse activities into value added activities and non-value-added activity types.

Furthermore, PCE serves as a quantitative metric for examining the performance outcomes of lean implementation in warehouse activities. Adeodu et al. (2023) utilized PCE to assess efficiency improvement in warehouse operations and confirmed its suitability for measuring the impact of waste reduction initiatives. The use of fishbone diagrams for root cause analysis in this study also aligns with the lean-driven warehouse frameworks proposed by Julião & Reis (2025), which integrate cause–effect analysis to identify sources of inefficiency systematically.

III. RESULTS AND DISCUSSION

A. Analysis of Current State Incoming Warehouse Process

The analysis of the incoming warehouse process at PT. XYZ was initiated by mapping the existing condition using Current State Value Stream Mapping (VSM). The incoming process consists of three main stages, namely receiving, recording, and storage. Each stage involves several activities that contribute differently to process performance.

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Table 1. Incoming Process Activity Table

No	Incoming Activity Detail	VA	NVA	NNVA
	Receiving			
1	Driver reports to receiving officer and submits the delivery note for verification.			2
2	Receiving officer checks vehicle condition, KIR document, and the condition of the goods inside the vehicle.			5
3	Driver moves pallets in preparation for unloading.			10
4	Unloading process is performed by the driver	61		
5	The receiving officer checks the completeness and condition of goods according to the delivery documents	46		
6	Transfer of inspected goods to temporary warehouse area (direct items) and to designated locations (indirect items)	32		
7	Receiving officer documents the delivery note through MITA Insight system.		5	
8	Receiving officer hands over the delivery note to the warehouse admin for the data entry process			2
	Record			
1	Input incoming goods data into the nice system	25		
2	Scanning delivery notes for digital archiving			14
3	Sorting delivery notes and invoices to be sent to Purchasing & Logistics department		5	
	Storage			
1	Move goods to the designated warehouse location	12		
2	Unpacking goods by packaging unit		20	
3	Checking quantity and type of goods against labels			8
4	Material testing by Quality Control	30		
5	Registration process in the My Warehouse system		4	
6	Storing goods according to the assigned location	15		

Based on time study results, the total lead time of the current incoming warehouse process was 296 minutes. Activity classification showed that 221 minutes were categorized as Value Added (VA), while the remaining time consisted of Non-Value Added (NVA) and Necessary Non-Value Added (NNVA) activities. Using these data, the Process Cycle Efficiency (PCE) of the current process was calculated at 74.66%, indicating that more than one-quarter of the process time did not directly contribute to value creation.

These findings suggest that although the incoming process already demonstrates a relatively high proportion of value-added activities, there remains significant potential for improvement through waste reduction. Similar conditions have been reported in warehouse operations where administrative delays and waiting time dominate non-value-added activities (Barry et al., 2023).

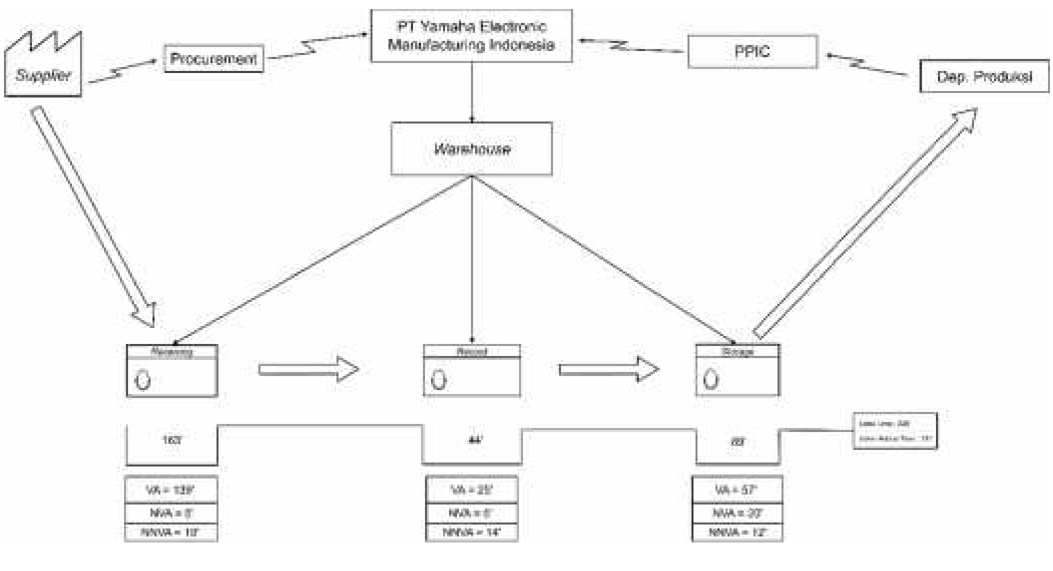

Figure 1. Current Value Stream Mapping

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These findings suggest that although the incoming process already demonstrates a relatively high proportion of value-added activities, there remains significant potential for improvement through waste reduction. Similar conditions have been reported in warehouse operations where administrative delays and waiting time dominate non-value-added activities. (Barry et al., 2023).

B. Waste Identification in the Incoming Warehouse Process

Waste identification was conducted based on activity classification results. The dominant waste types identified in the current incoming process were waiting, overprocessing, and motion. Waiting waste occurred primarily during document verification, pallet availability, and system input processes. Overprocessing waste was found in repetitive document scanning and manual administrative procedures, while motion waste resulted from unnecessary material handling during unloading and storage preparation.

Table 2. Waste Identification in Incoming Warehouse Activities

No	Waste Type	Incoming Activity Detail	Operation
1	Waiting	Driver reports to the receiving officer and submits the delivery note for verification.	Receiving
2	Waiting	The receiving officer checks vehicle condition, KIR documents, and the condition of the goods inside the vehicle.	Receiving
3	Waiting	Driver waits for pallets in preparation for unloading	Receiving
4	Waiting	The receiving officer documents the delivery note through MITA Insight, delayed due to a poor signal.	Receiving
5	Waiting	Receiving officer hands over the delivery note to the warehouse admin for the data input process	Receiving
6	Overprocessing	Scanning delivery notes for digital archiving	Record
7	Overprocessing	Sorting delivery notes and invoices to be sent to the Purchasing & Logistics department	Record
8	Motion	Unpacking goods by packaging unit without nearby trash bins	Storage
9	Waiting	Checking the quantity and type of goods against labels	Storage
10	Waiting	The registration process in the My Warehouse system is delayed due to a poor signal.	Storage

Waiting waste was identified as the most significant contributor to inefficiency, particularly during receiving and storage activities. These results align with previous studies that identified waiting as the most dominant waste in warehouse inbound processes. (Ardysti & Ernawati, 2025). Excessive waiting increases lead time without adding value and negatively impacts warehouse productivity.

C. Root Cause Analysis of Identified Waste

To identify the underlying causes of waste, a fishbone diagram was developed focusing on four main factors: man, machine, method, and material. From the human factor, inefficiencies were caused by limited coordination between operators and incomplete document preparation by drivers. Machine-related issues included limited availability of pallets and forklifts, as well as unstable system connectivity. From the method perspective, unstandardized document formats and administrative procedures extended processing time. Material-related factors included improper material arrangement and the delayed arrival of goods.

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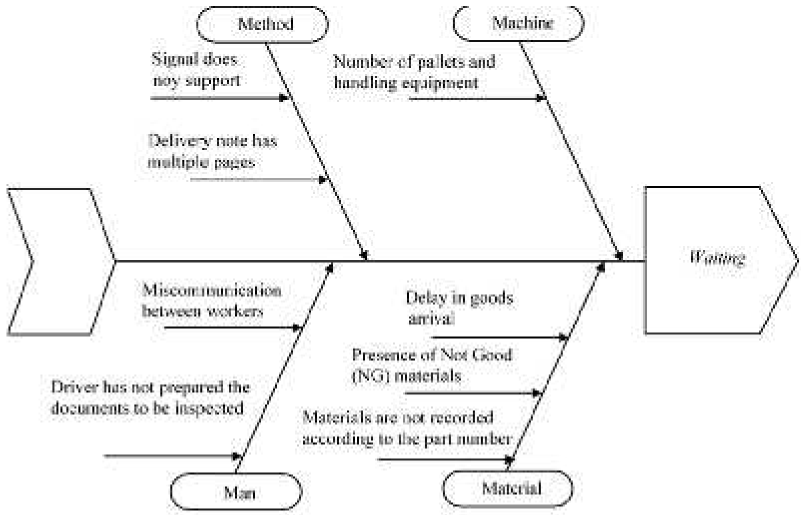

Figure 2. Fishbone Diagram of Waste Causes in Incoming Warehouse Process

This analysis confirms that waste in the incoming warehouse process is not caused by a single factor but by an interaction of operational, technical, and procedural issues. Similar findings were reported by Nurulita (2024), who emphasized the importance of addressing both technical and human factors in warehouse waste reduction initiatives.

D. Improvement Proposals Based on Lean Warehousing

Based on waste identification and root cause analysis, improvement proposals were developed using lean warehousing principles, particularly through the application of 5S and process standardization. The proposed improvements included optimizing pallet allocation, standardizing document formats, improving material layout based on part number visibility, and enhancing system access for administrative activities.

The implementation of 5S was aimed at reducing waiting and motion waste by improving workplace organization and ensuring that necessary tools and materials were readily available. Previous studies have demonstrated that the application of 5S effectively supports waste reduction and operational efficiency in warehouse environments. (Dzulkifli & Ernawati, 2021).

E. Future State Analysis and Process Improvement Results

The proposed improvements were visualized using Future State Value Stream Mapping. After improvement, the total lead time was reduced from 296 minutes to 273 minutes, representing a reduction of 23 minutes. Process Cycle Efficiency (PCE) increased from 74.66% to 80.95%, indicating a substantial improvement in process efficiency.

Table 3. Future Incoming Warehouse Activity Details

No	Incoming Activity Detail	VA	NVA	NNVA
	Receiving			
1	The driver reports to the receiving officer and submits the delivery note for inspection.			2
2	The receiving officer checks the vehicle condition, the KIR document, and the condition of the goods inside the vehicle			2
3	The driver moves pallets in preparation for unloading.			2
4	The unloading process is carried out by the driver	61		
5	Receiving officer checks the completeness and condition of goods in accordance with the delivery documents	46		
6	Transfer of inspected goods to the temporary warehouse area (direct items) and to designated locations (indirect items)	32		
7	The receiving officer documents the delivery note through the MITA Insight system.		3	
8	The receiving officer hands over the delivery note to the warehouse admin for data entry			2
	Record			
1	Input incoming goods data into the nice system	25		
2	Scanning delivery notes for digital archiving			14

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The increase in PCE demonstrates that the reduction of non-value-added activities significantly improved the performance of the incoming warehouse process. These results are consistent with previous studies that reported improved efficiency following the implementation of lean warehousing and VSM (Shafalah et al., 2025).

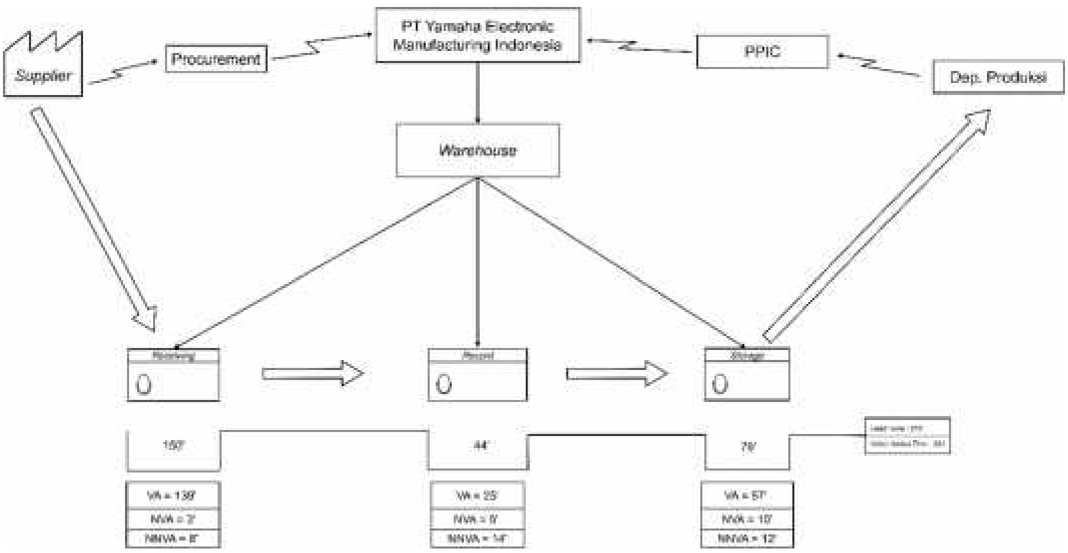

Figure 3. Future State Value Stream Mapping

The improvement results obtained at PT. XYZ is consistent with previous warehouse improvement studies applying lean warehousing principles. Adeodu et al. (2023) found that warehouse performance improved substantially, as indicated by shorter lead times and higher process cycle efficiency following the elimination of non-value-added activities. Similarly, Purnomo & Kien (2025) found that the application of lean warehousing and value stream mapping in Indonesian warehouse settings led to measurable improvements in value-added time and overall process efficiency.

From a process flow perspective, improvements achieved through layout adjustment, workplace organization, and reduction of unnecessary movement in this study align with findings by Briones-chávez et al. (2025), who emphasized that optimized material flow and reduced motion waste are critical factors in improving warehouse performance. These similarities indicate that the proposed lean warehousing improvements at PT. XYZ are not only contextually relevant but also empirically supported by prior studies.

F. Discussion of Findings

The results of this study confirm that lean warehousing combined with Value Stream Mapping is effective in improving incoming warehouse performance. The reduction in lead time and increase in PCE indicate that waste elimination directly contributes to improved operational efficiency. Compared to previous studies, this research provides a detailed quantitative evaluation of incoming warehouse processes in a manufacturing environment that integrates both manual and digital systems.

From a practical perspective, the findings highlight the importance of standardizing administrative procedures and improving material handling coordination. Theoretically, this study confirms that lean warehousing provides a systematic means of improving efficiency in inbound warehouse operations.

IV. CONCLUSION

The findings show that implementing lean warehousing supported by Value Stream Mapping (VSM) enhances the efficiency of the incoming warehouse process at PT. XYZ. An assessment of current operations identified several non-value-added activities that contributed to longer lead times and lower process performance. The mapping of material and information flows enabled a systematic identification of

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inefficiencies within receiving, recording, and storage activities.

The analysis indicates that the initial incoming warehouse process required a total lead time of 296 minutes, with a Process Cycle Efficiency (PCE) of 74.66%. Following the implementation of improvement initiatives based on lean warehousing principles—such as process standardization and workplace organization—the total lead time decreased to 273 minutes, while the PCE increased to 80.95%. These results demonstrate a substantial decrease in non-value-added activities and a more streamlined workflow within the incoming warehouse process.

The findings further emphasize that the elimination of waste, particularly waiting, overprocessing, and unnecessary motion, is essential for improving warehouse operational performance. Lean warehousing tools, including Value Stream Mapping (VSM) and 5S, enable a systematic approach to identifying inefficiencies and designing improvement actions within inbound warehouse processes.

Despite the positive results, this study has several limitations. The analysis was limited to internal incoming warehouse activities and did not consider external transportation or supplier-related factors that may influence warehouse performance. In addition, the evaluation of improvement effectiveness was based on simulated future-state conditions rather than long-term implementation results.

The findings of this study further support existing evidence that lean warehousing is an effective approach for improving warehouse operational performance. Consistent with prior studies, the integration of value stream mapping, process cycle efficiency analysis, and structured improvement initiatives has been shown to reduce non-value-added activities and enhance process efficiency in warehouse environments (Ikatrinasari, 2023).

Future research is recommended to extend the scope of analysis to include outbound processes and supplier coordination, as well as to evaluate the long-term sustainability of lean warehousing implementation. Further studies may also integrate advanced digital warehouse technologies to enhance real-time data accuracy and decision-making in inbound logistics processes.

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Mental Workload Analysis of Student Members of the Mosque Management Committee at Campus X Using NASA-TLX

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***Abstract*— Students who serve as administrators of campus mosques often face dual responsibilities: fulfilling academic obligations while simultaneously managing various religious activities on campus. Balancing these roles can lead to a considerable mental workload. This study aims to assess the level of mental workload experienced by students actively involved as campus mosque administrators. The research was conducted at a university mosque located in Yogyakarta. Mental workload was measured using the NASA-TLX instrument, which evaluates six key dimensions of cognitive load. Findings revealed an average mental workload score of 71.14, categorized as high. A total of 80% of participants reported experiencing high to very high levels of mental stress. The most prominent contributing dimensions were mental demand, effort, and performance. These results highlight the need for effective workload management strategies, including equitable task distribution, engagement of external volunteers, stress and time management training, and promoting awareness of the importance of balancing academic and organizational commitments.**

***Keywords*: Mental Workload, NASA-TLX, Organizations, Students**

I. INTRODUCTION

Students' lives at the university level are often characterized by diverse dynamics that extend beyond academic activities alone. [Ariani et al, 2025]. In addition to focusing on formal academic responsibilities such as attending lectures, participating in laboratory sessions, and completing assignments, many students are also actively involved in various student organizations. [Making et al, 2023]. Participation in these organizations provides opportunities to develop personal interests, expand social networks, and enhance soft skills. [Yolanda et al, 2024]. Such activities often require substantial commitment of time and energy, even as students continue to manage their academic workload. Despite demanding academic schedules, some students remain actively engaged in student organizations, including socio-religious organizations such as the Mosque Management Committee.

Campus mosques serve not only as places of worship but also as centers for religious, social, and educational activities within the academic community. [Isan et al, 2024]. A dynamic and active mosque is typically reflected in the implementation of various programs, including regular religious studies, leadership training grounded in Islamic values, social initiatives, public lectures, and the commemoration of Islamic holidays. [Saridudin, 2021]. The presence of an effective Mosque Management Committee is essential to ensuring the continuity and success of these programs, from planning and implementation to evaluation. [Arsam et al, 2024].

Students who serve as members of the Mosque Management Committee face a dual challenge [Armanda dan Pramana, 2023]. They are required not only to excel academically but also to manage a wide range of mosque-related responsibilities that demand a high level of commitment. [Maisaroh et al, 2023]. Their involvement reflects a strong motivation to contribute to religious education and community development on campus. At the same time, the interaction between academic workload and organizational responsibilities raises important questions regarding its potential impacts.

This considerable workload has the potential to trigger stress among students. [Yulizar et al, 2025]. Balancing academic obligations,

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coursework, organizational duties, and responsibilities as members of the Mosque Management Committee poses a significant challenge. These burdens may lead to various consequences, including mental stress that warrants serious attention. [Peristianto dan widyana, 2023]. Organizational pressures, combined with academic demands, can affect students' psychological well-being. [Kuswanto, 2025]. Previous studies, such as those by Casya et al., have shown that students tend to experience high levels of mental stress when confronted with academic tasks and heavy cognitive demands. [Casya et al, 2024]. Research by Hidayati & Basyari also indicates that the average mental workload among working students is high. [Hidyati dan Basyari, 2024].

Given this context, it is important to identify the level of mental stress experienced by students who are simultaneously active in organizational activities and responsible for mosque administration. One appropriate method for assessing mental workload is the NASA-TLX, as it effectively captures mental workload in situations requiring simultaneous engagement in multiple tasks, such as those typically encountered by members of the Mosque Management Committee [Li et al, 2022]. This study focuses on assessing the level of mental workload among university students who manage academic responsibilities while actively participating in the Mosque Management Committee at a campus mosque in Yogyakarta. Previous studies employing the NASA-TLX method have predominantly examined mental workload in academic activities, student executive organizations, or part-time work contexts [Hidyati dan Basyari, 2024] [Aryntya et al, 2023]. However, limited research has focused on campus religious organizations, particularly mosque management committees, where responsibilities are continuous rather than incidental. Unlike most student organizations that operate on an event-based basis, campus mosque management involves daily administrative, religious, and social duties, creating a distinct and persistent mental workload context [Ikhsanudi dan Rudini, 2021]. This study addresses this gap by extending the application of the NASA-TLX framework to a volunteer-based, non-profit, and value-driven organizational setting. The findings contribute theoretically by broadening mental workload analysis beyond task-oriented and academic environments, and practically by providing insights to support workload management and organizational policy development in campus mosque institutions. Based on the identified research gap and the continuous nature of responsibilities within campus mosque management activities, this study aims to quantitatively assess the mental workload of student members of a campus mosque management committee using the NASA-TLX framework. Specifically, this study seeks to identify the dominant mental workload dimensions and evaluate their relative contributions to overall mental workload in the context of continuous organizational, religious, and administrative responsibilities performed alongside academic obligations. Furthermore, this research aims to provide practical insights to support workload distribution, task management, and organizational policy development within campus mosque management institutions.

II. METHODS

Campus X is an Islamic university in Yogyakarta where dakwah constitutes an integral part of its institutional mission. The campus mosque functions as a central religious hub serving both the academic community and the surrounding neighborhoods. Beyond routine worship services, the mosque manages continuous religious, administrative, and social activities and provides guidance to several nearby mosques. Consequently, members of the Mosque Management Committee are engaged in sustained organizational responsibilities that extend beyond event-based activities, creating a distinctive and persistent work context.

The study focuses on analyzing the mental workload experienced by students who serve as members of the Mosque Management Committee at Campus X. The population of this study consisted of 23 active student members of a campus mosque management committee, and a total sampling approach was employed in which all active committee members were included as respondents. The respondents represented various academic programs and organizational roles within the mosque management structure, encompassing both executive and operational responsibilities. Data were collected using the NASA-TLX questionnaire, which was administered in June, near the end of the academic year during the second semester. At this stage, respondents had experienced sustained organizational involvement, including the completion of major religious events such as Ramadan and Eid al-Adha programs. Participants were asked to assess their mental workload based on their cumulative experience in performing daily organizational, religious, and administrative tasks alongside academic responsibilities, ensuring that the measured workload reflected continuous rather than incidental organizational demands. The mental workload assessment was conducted using the NASA-TLX method, which measures six dimensions of mental workload. The stages of the NASA-TLX procedure were carried out as follows:

1) Dimension Weighting

In this stage, respondents compare pairs of mental workload dimensions to determine which dimension is more dominant in influencing their task performance. Each respondent completed 15 pairwise comparisons, as required in the standard NASA-TLX procedure for six dimensions. The weight of each dimension was determined by counting the number of times the dimension was selected as more dominant across the comparisons, resulting in a weighting score ranging from 0 to 5.

Table 1. Pairwise Comparison of Dimensions

	MD	**PD**	**TD**	**OP**	**EF**	**FR**
MD						
PD						
TD						
OP						
EF						
FR						

A description of the mental workload dimensions assessed in this study is provided in Table 2.

Table 2. Description of NASA-TLX Dimensions

Mental Workload Dimensions	**Description**
Mental Demand (MD)	The extent to which the task requires cognitive processes such as reasoning, problem-solving, remembering information, or making decisions.
Physical Demand (PD)	The amount of physical involvement needed to carry out the task, including bodily movement or physical manipulation of tools and equipment.
Temporal Demand (TD)	The level of time-related pressure experienced during task performance, including the pace of work and how rushed the respondent feels.
Own Performance (OP)	The respondent’s personal judgment regarding how effectively or successfully they believe they completed the task.
Effort (EF)	The overall amount of mental and physical exertion required to meet the task objectives at a satisfactory performance level.
Frustration (FR)	The degree of negative emotions—such as irritation, tension, worry, or stress—felt by the respondent while performing the task.

2) Mental Workload Dimension Rating

During this stage, respondents provided ratings for each NASA-TLX dimension based on their cumulative experience in performing daily organizational, religious, and administrative tasks as members of the Mosque Management Committee. Each dimension was rated using a 0–100 scale, where higher scores indicate greater perceived workload. [Rahman dan Pratama,

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2022]. An illustration of the rating scheme is presented in Figure 1.

1. Mental Demand (MD)
How much mental and perceptual activity was required to accomplish the task?

0 *Low*	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100 *High*

2. Physical Demand (PD)
How much physical activity was required to accomplish the task?

0 *Low*	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100 *High*

3. Temporal Demand (TD)
How much time pressure did you feel due to the rate or pace at which the tasks occurred?

0 *Low*	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100 *High*

4. Performance (OP)
How successful do you think you were in accomplishing the tasks?

0 *Low*	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100 *High*

5. Effort (EF)
How hard did you have to work mentally and physically to accomplish the task?

0 *Low*	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100 *High*

6. Frustration (FR)
How insecure, discouraged, irritated, stressed, and annoyed did you feel during the task?

0 *Low*	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100 *High*

Figure 1. Mental Workload Dimension Rating Scale

a. Product Score Calculation

After the rating process, each dimension rating was multiplied by its corresponding weight obtained from the dimension weighting stage to produce a product score, as shown in Equation (1).

$$P = D \quad R \times D \quad W \quad ht \tag{1}$$

b. Weighted Workload (WWL) calculation

The Weighted Workload (WWL) for each respondent was calculated by summing the product scores across all six dimensions, as presented in Equation (2).

$$W = \sum P \quad (2))$$

c. Overall *Weighted Workload* (WWL) score

To obtain the overall mental workload score, the WWL value was divided by 15, which represents the total number of pairwise comparisons in the NASA-TLX weighting procedure, as shown in Equation (3).

$$S = \frac{W}{15} \tag{3}$$

3) Score Interpretation

The resulting mental workload scores, calculated for each respondent and averaged across participants, were categorized into five interpretation levels, as presented in Table 3 [Alfani, 2023].

Table 3. Score Interpretation

Classification	Score
Low	0-9
Moderate	10-29
Moderately High	30-49
High	50-79
Very High	80-100

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III. RESULT AND DISCUSSION

The NASA-TLX procedure consisted of the following steps:

1. Dimension Weighting

Dimension weights were obtained by comparing the relative importance of each mental workload dimension. The resulting weighting scores are presented in Table 4.

Table 4. Dimension Weighting Scores

Respondent	Dimension					
	MD	**PD**	**TD**	**OP**	**EF**	**FR**
1	2	1	5	4	3	0
2	2	2	2	4	4	1
3	2	2	4	3	3	1
4	5	3	3	1	1	2
5	3	2	2	2	4	2
6	2	2	2	5	4	0
7	5	3	2	4	1	0
8	2	3	5	1	3	1
9	2	2	4	3	4	0
10	1	4	2	2	5	1
11	1	1	5	2	4	2
12	2	3	4	3	3	0
13	0	5	4	2	3	1
14	4	2	5	2	1	1
15	4	1	2	4	3	1
16	3	4	4	1	3	0
17	4	2	4	2	3	0
18	4	3	3	1	4	0
19	3	4	3	3	1	1
20	5	1	3	4	2	0
21	3	0	5	2	2	3
22	2	3	2	0	3	5

2. Dimensional Assessment (Rating)

Respondents provide a rating for each NASA-TLX dimension based on how they experienced the task. Ratings are recorded on a 0–100 scale for every dimension. [1Rahman dan Pratama, 2023]. See Table 5 for the dimensional rating form.

Table 5. Dimensios Ratings

Respondent	Dimension					
	MD	**PD**	**TD**	**OP**	**EF**	**FR**
1	2	2	3	3	3	2
2	2	1	5	4	3	0
3	2	2	2	4	4	1
4	2	2	4	3	3	1
5	5	3	3	1	1	2
6	3	2	2	2	4	2
7	2	2	2	5	4	0
8	5	3	2	4	1	0
9	2	3	5	1	3	1
10	2	2	4	3	4	0

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Respondent	Dimension					
	MD	PD	TD	OP	EF	FR
11	1	4	2	2	5	1
12	1	1	5	2	4	2
13	2	3	4	3	3	0
14	0	5	4	2	3	1
15	4	2	5	2	1	1
16	4	1	2	4	3	1
17	3	4	4	1	3	0
18	4	2	4	2	3	0
19	4	3	3	1	4	0
20	3	4	3	3	1	1
21	5	1	3	4	2	0
22	3	0	5	2	2	3
23	2	3	2	0	3	5

3. Calculation of WWL Scores

The calculation of the Weighted Workload (WWL) scores is presented in Table 6.

Table 6. WWL Scores

Respondent	Dimension						WWL
	MD	PD	TD	OP	EF	FR	
1	150	160	210	225	240	150	1135
2	140	65	350	300	210	0	1065
3	50	10	60	320	120	5	565
4	100	20	80	240	240	0	680
5	475	240	270	70	100	180	1335
6	270	150	80	170	380	120	1170
7	100	160	100	500	400	0	1260
8	425	90	70	280	50	0	915
9	140	120	450	80	195	70	1055
10	150	140	340	240	280	0	1150
11	40	240	70	80	250	30	710
12	100	90	400	180	320	120	1210
13	130	180	200	180	180	0	870
14	0	500	320	180	300	60	1360
15	400	100	300	160	30	80	1070
16	320	50	140	360	255	30	1155
17	300	400	80	85	285	0	1150
18	300	178	200	180	240	0	1098
19	340	240	180	90	380	0	1230
20	195	280	135	60	75	20	765
21	400	70	210	400	170	0	1250
22	240	0	425	150	170	210	1195
23	100	225	160	0	240	425	1150

4. Interpretation of WWL Scores

After obtaining the WWL scores, the average WWL was calculated, and the results were categorized into predefined workload levels. The interpretation criteria are shown in Table 7.

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Table 7. WWL Score Classification

Respondent	Mean WWL	Category
1	75.67	High
2	71.00	High
3	37.67	Moderately High
4	45.33	Moderately High
5	89.00	Very High
6	78.00	High
7	84.00	Very High
8	61.00	High
9	70.33	High
10	76.67	High
11	47.33	Moderately High
12	80.67	Very High
13	58.00	High
14	90.67	Very High
15	71.33	High
16	77.00	High
17	76.67	High
18	73.20	High
19	82.00	Very High
20	51.00	High
21	83.33	Very High
22	79.67	Very High
23	76.67	High

Based on the NASA-TLX results shown in Table 7, the overall mean WWL was 71.14, which falls into the high category. Among the respondents, 3 individuals (13%) were classified as moderately high, 13 respondents (57%) as high, and 7 respondents (30%) as very high.

Table 8. Frequencies of Category WWL

Frequencies of Category

Category	Counts	% of Total	Cumulative %
Very High	7	30.4%	30.4%
High	13	56.5%	87.0%
Moderately High	3	13.0%	100.0%

In total, 80% of participants experienced a high level of mental workload. This elevated workload is likely related to the responsibilities of serving on the mosque management committee, a role that encompasses spiritual guidance and community engagement both within the campus and in the surrounding neighborhoods.

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Table 9. NASA-TLX Dimension Scores

Descriptives

	MD	PD	TD	OP	EF	FR
N	23	23	23	23	23	23
Mean	212	161	210	197	222	65.2
Minimum	0	0	60	0	30	0
Maximum	475	500	450	500	400	425

Across the six NASA-TLX dimensions, Effort (EF), Mental Demand (MD), and Temporal Demand (TD) exhibited the highest mean scores, indicating a substantial mental workload among campus mosque management committee members. This pattern reflects the complex nature of committee responsibilities, which include administrative coordination, religious service management, and social program execution. In addition to routine daily activities, committee members are required to organize large-scale religious events such as Ramadan programs and major religious holidays, which demand careful planning, logistical coordination, and sustained physical and cognitive effort. [Handayani dan Susanti, 2023]. These responsibilities place considerable performance expectations on student committee members who must simultaneously manage academic obligations.

High scores in the Mental Demand and Effort dimensions suggest prolonged cognitive engagement and sustained exertion, which may increase the risk of mental fatigue if not properly managed. The elevated Own Performance score further indicates strong internal and external pressure to perform effectively, a condition that can intensify perceived workload and psychological strain in value-driven organizational contexts. [Nisa dan Widyastuti, 2020]. Overall, the dominance of Mental Demand, Effort, and Temporal Demand suggests that mental workload in campus mosque management is persistent rather than episodic, arising from continuous responsibilities and fixed religious schedules rather than short-term task intensity. [Hidyati dan Basyari, 2024].

These findings are consistent with recent mental workload studies involving students engaged in multiple concurrent roles, which report elevated Mental Demand, Effort, and Temporal Demand due to overlapping academic and organizational commitments [Hidyati dan Basyari, 2024][Rahayu dna Rosdiana, 2025]. However, unlike prior research that primarily examines academic activities or event-based student organizations, the present study highlights a workload pattern driven by continuous and routine organizational demands. This distinction emphasizes the role of responsibility persistence in shaping mental workload within campus religious organizations.

Conceptually, the high Mental Demand observed can be attributed to the need for continuous coordination of administrative, religious, and social activities, requiring frequent decision-making and attention switching. [Ishak et al, 2023]. Elevated Effort reflects sustained cognitive and emotional engagement over extended periods, particularly as students balance organizational duties with academic responsibilities. Meanwhile, high Temporal Demand is associated with fixed religious schedules, routine daily activities, and intensified workloads during major religious events such as Ramadan and Eid celebrations. [Yasmin et al, 2023]. Together, these factors create a cumulative mental workload that differentiates mosque management activities from task-specific or episodic organizational contexts.

Given the continuous and multifaceted nature of these responsibilities, systematic workload management is recommended. Practical measures may include equitable task distribution, recruitment of additional volunteers during peak periods, promotion of work–role balance awareness, and periodic evaluation of committee

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workload to support the sustainability of student involvement.

IV. Conclusion

This study demonstrates that student members of a campus mosque management committee experience a high level of mental workload, primarily driven by Mental Demand, Effort, and Temporal Demand. The findings indicate that the mental workload encountered by committee members is not episodic but persistent in nature, arising from continuous administrative, religious, and social responsibilities that must be balanced alongside academic obligations. This workload pattern distinguishes campus mosque management activities from typical event-based student organizations.

From a conceptual perspective, the results highlight that sustained cognitive engagement, prolonged effort, and fixed religious schedules are key factors contributing to cumulative mental workload in campus religious organizations. Practically, these findings underscore the importance of implementing systematic workload management strategies within campus mosque institutions. These strategies may include proportional task distribution among committee members, the provision of additional volunteer support during peak religious periods, and the development of organizational policies that promote balance between academic responsibilities and mosque-related duties. By addressing these factors, campus mosque institutions may better support student well-being while maintaining effective organizational performance.

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Design and Build Household Electrical Power Limiters Based on Priority Lines for Electricity Usage with Arduino Microcontroller Based

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Abstract - To realize energy savings, especially electrical energy on a household scale, one thing that is usually done is turning off unnecessary equipment. However, this kind of conventional method requires high discipline and the success rate is quite low due to many factors, one of which is forgetting. One solution that can be applied to this problem is the need for tools that can force electricity users to turn off electricity if usage has exceeded a certain limit. To be able to measure electricity consumption, an energy measuring sensor is used which is then processed on the microcontroller and drives the circuit breaker relay. In making this tool using the experimental method, by planning based on references from the literature and experiments directly to the equipment. With this, it is hoped that the expected tools will be realized and can contribute to saving energy in the community.

Keywords :*KWh Sensor, Arduino Nano, Electrical Power Meter*

I. INTRODUCTION

Currently, saving electrical energy has become a topic that is commonly discussed in the community. This is due to the increase in the price of electricity bills that must be paid. One of the reasons for this high electricity bill is the use of electricity for non-essential purposes. Uses that are not important, for example the use of garden lights or pond pumps, whose presence will not be a problem if the equipment is turned off.

The saving steps that have been taken so far have been carried out manually through a switch so that these efforts are very limited and inefficient. Therefore, we need a tool that can make users limit electricity consumption by turning off electrical equipment whose use is not important, such as garden lights, decorative lights and the like. This tool must be able to calculate / estimate the use of electricity so that when the estimated usage exceeds the predetermined target, the relay will cut off the power line for equipment that is not prioritized.

Broadly speaking, this tool uses several main components, namely Arduino Nano as a data processing and processing center, PZEM-004T sensor as an energy sensor that measures the amount of electrical energy consumption, RTC as a timer, Relay as a circuit breaker and several other supporting components. .

This research has several objectives as follows:

1. To find out how to measure KWh using an energy sensor.
2. To find out how to limit the use of electricity on non-priority lines if the total electric power has met the specified threshold.

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II. METHODS

This product is basically a measure of the power used in household electricity using a current sensor and a voltage sensor which is then calculated based on the priority of the type of electrical equipment used.

To be able to determine the priority of using this electricity, household appliances are first sorted based on the type of need. In the design of this tool, household appliances are separated based on 2 types of priorities, namely:

1. Priority Line, contains household appliances which are equipment that must zbe turned on without any restrictions.

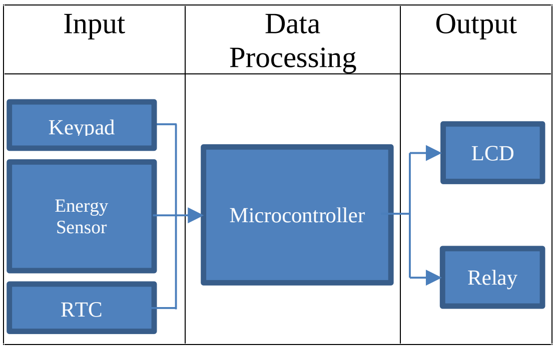

Figure 1 . Diagram Design

   These appliances include house lights, refrigerators, etc.

2. Non Priority Line, contains household appliances whose presence is not too important and is not a problem if turned off but will make electricity use wasteful if turned on continuously. This equipment includes garden lights, decorative lights, fountain pumps in ponds, etc.

Broadly speaking, this equipment is divided into several parts, as shown in the following block diagram:

The input part of this tool is a current sensor, voltage sensor, and RTC which is then processed by the microcontroller. The results of the microcontroller will be applied to the relay which can disconnect or connect the power line and the LCD as a display of the work of the microcontroller.

The explanation for each block diagram is as follows:

1. Input block , in this section consists of current sensors, voltage sensors and RTC. The current sensor functions to measure electric current in each line where in this design it is determined that there are 2 lines, namely the priority line which is the path of electrical equipment that must be continuously lit and the non-priority line which contains electrical equipment that is not required to be lit. The sensor used is PZEM-004T. The next component used is RTC. This component functions to find out the date and time in real time. This RTC is used to determine the time to reset the KWh meter data.
2. Data Processing Block , in this section data processing from the input block is carried out. Data from current and voltage sensors will be taken and processed every few moments to be able to find out the power used at any time.
3. Output block , in this section the results of data processing are visible. The value of the used voltage, current and power will be displayed on the LCD. The results of this data processing will also produces a measured and accumulated power value in the last month and will be seen on the relay which can cut off the current if the accumulated usage in that month has exceeded the specified limit.

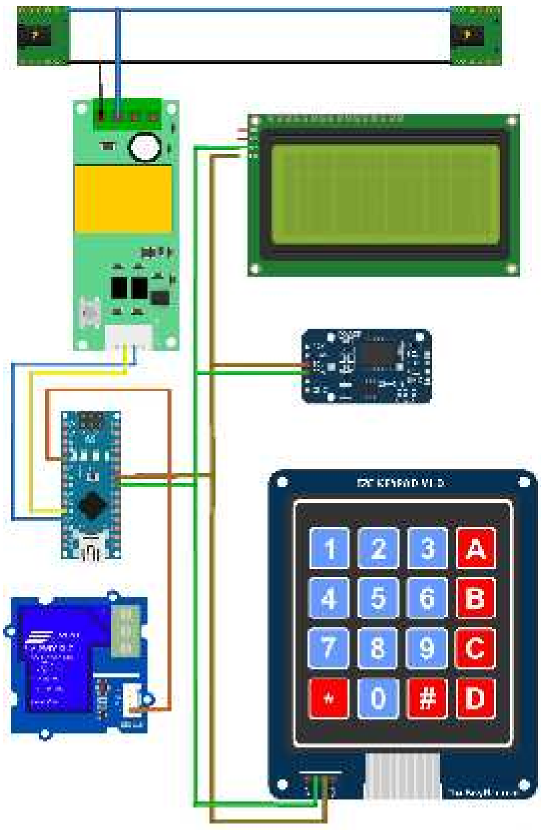

Figure 2. Device Circuit Schematic

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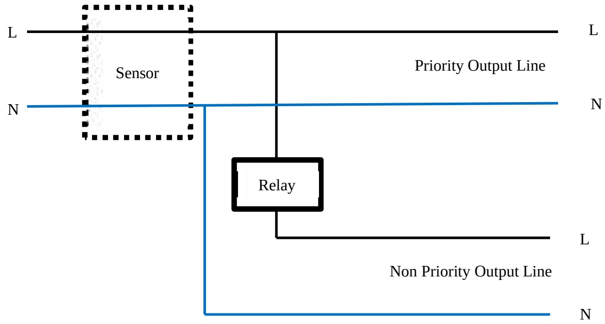

Figure 3. Electrical Line Schematic

Figure 2 shows a complete circuit of the components used. LCD, RTC and keypad use I²C data lines that use the same 2 data lines to simplify wiring and each of these components can be accessed separately using a different address. The PZEM-004T sensor is accessed by the microcontroller using serial communication.

Figure 3 describes the image of the power line which is a priority line and a non-priority line. On the input line, sensors are placed to measure the energy used, after that the power line is branched into 2 lines, namely the priority line and the non-priority line. On the non-priority line, a relay is added as a breaker if the desired energy limit has been reached.

III. RESULTS AND DISCUSSION

After carrying out the design stage, the tool is made according to the circuit drawing with the result in the form of equipment as shown in Figure 4.

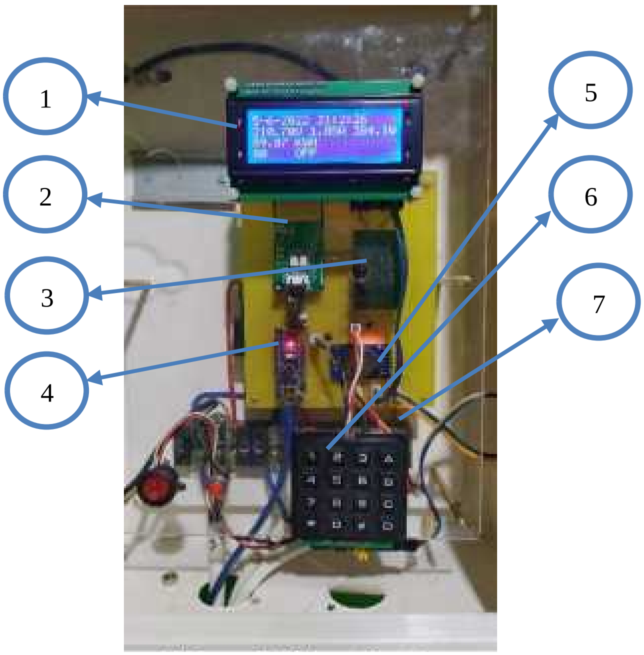

Figure 4. Photo Tool

Component Description :

1. LCD
2. Sensor
3. Power Supply
4. Microcontroller
5. RTC
6. Keypad
7. Relay

After making hardware, then proceed with making software. Making software using the Arduino IDE application which is the default application for making Arduino software. The software development is divided into several parts, among others, the data reader section, both sensors, keypad and RTC, the data processing section and the data display section to the LCD and relay drive.

The results of the evaluation on the results of this equipment, the equipment can function as expected by the researcher. The weakness of this tool is that the display on the LCD is difficult to read, so in the future it may be necessary to use an LCD model that can display more characters so that it is easier for users to read the display from the device.

How the Tool Works

In the design of the electrical power limiter based on the priority of use, it has the following way of working:

1. This tool is installed at the entrance to the installation to be measured and its use is limited.
2. The tool will read the voltage, current and energy using sensors for further processing on the microcontroller.
3. Users can set their own limit on how many KWh non-priority lines will be turned off. This number limit entered will be stored in the EEPROM of the arduino. Entering the KWH limit is enough to do once as long as there is no change the value will still be stored.
4. Every month the measured KWh value will be reset back to 0. This reset date can be determined by the user and will be stored in the Arduino EEPROM.
5. When the KWh value read on the sensor has reached the limit value according to the number entered (as explained in number 3), the non- priority line will be turned off by the relay.

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6. Every month that coincides with the date as entered in the explanation of number 4, the KWh number on the sensor will be reset to 0 and the non-priority line will turn on again.

Data Analysis

standard measuring instrument was used as a reference for measurement. The tool used is an electric meter from Sinotimer. The measurement test process can be seen in Figure 5.

Figure 5. Sensor Testing Process

The test results on the equipment used give the following results:

Table 1. Current Measurement Test Results

No	Measurement Time (Hour)	Measurement Results (A)		Error Percentage
		Current Sensor	Ampere Meter	
1	07.00	1.21	1.17	3.42
2	08.00	1.15	1.10	4.55
3	09.00	2.41	2.35	2.55
4	10.00	1.34	1.29	3.88
5	11.00	1.61	1.54	4.55
6	12.00	4.41	4.42	0.23
7	13.00	1.38	1.32	4.55
8	14.00	1.06	1.02	3.92
9	15.00	1.58	1.48	6.76
10	16.00	1.67	1.62	3.09
11	17.00	1.60	1.51	5.96
12	18.00	2.10	1.94	8.25
13	19.00	2.15	2.05	4.88
14	20.00	2.10	2.03	3.45
15	21.00	1.78	1.71	4.09
Average				4.27

In table 1 , the results of measurements and calculations of the percentage of current measurement errors from the 15 data taken are obtained, the average value of the measurement error is 4.27%.

Table 2. Voltage Measurement Test Results

No	Measurement Time (Hour)	Measurement Results (V)		Error Percentage
		Voltage Sensor	Voltmeter	
1	07.00	212.50	213.90	0.65
2	08.00	210.80	210.00	0.38
3	09.00	213.90	212.00	0.90
4	10.00	211.40	212.10	0.33
5	11.00	209.80	210.90	0.52
6	12.00	211.00	210.00	0.48
7	13.00	211.00	211.50	0.24
8	14.00	211.30	211.60	0.14
9	15.00	211.10	212.00	0.42
10	16.00	210.70	210.50	0.10
11	17.00	205,90	206.30	0.19
12	18.00	206,10	206,10	0.00
13	19.00	210.90	209.70	0.57
14	20.00	209.50	209.00	0.24
15	21.00	207.60	207,40	0.10
Average				0.35

In table 2 , the results of measurements and calculations of the percentage of voltage measurement errors are obtained from the 15 data taken, the average value of the measurement error is 0.35%.

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Table 3. Energy Measurement Test Results

No	Measurement Time (Hour)	Measurement Results (KWH) Energy Sensor	KWH meters	Error Percentage
1	07.00	43.26	42.50	1.79
2	08.00	43.48	42.70	1.83
3	09.00	43.78	43.00	1.81
4	10.00	44.10	43.30	1.85
5	11.00	44.38	43.60	1.79
6	12.00	44.85	44.10	1.70
7	13.00	45.32	44.50	1.84
8	14.00	45.56	44.80	1.70
9	15.00	45.85	45,10	1.66
10	16.00	46,16	45,40	1.67
11	17.00	46.49	45,70	1.73
12	18.00	46.89	46,10	1.71
13	19.00	47.42	46,60	1.76
14	20.00	47,90	47,00	1.91
15	21.00	48,20	47,40	1.69
Average				1.76

In table 3 , the results of measurements and calculations of the percentage of energy measurement errors are obtained from the 15 data taken, the average value of the measurement error is 1.76%. The results from table 3 can be illustrated by the graph in Figure 6.

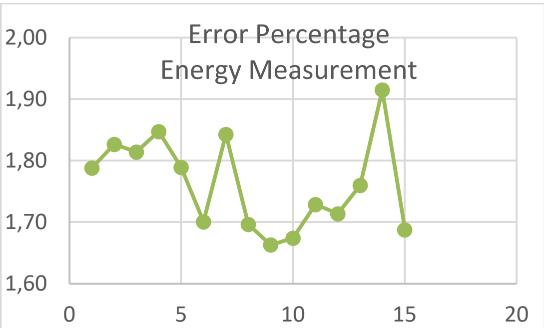

Figure 6. Graph of Energy Measurement Test Results

After testing the results of the energy sensor, then proceed with making software to limit electrical power according to the value entered by the user.

Table 4. Software Test Results

No	Test Type	Experiment result
1	Line limiting relay	Succeed
2	Automatic energy reset	Succeed

From the tests carried out on the software that has been made, the results are as in table 4.

IV. CONCLUSION

From the research and testing of this tool, it can be concluded as follows:

1. This equipment serves to limit the use of electrical energy on electrical lines that are not a priority.
2. This tool works by utilizing the PZEM-004T sensor as an energy reading sensor.
3. The desired power limit to be limited is entered manually by the user at the time of setting up the equipment.
4. Every month the energy data will be reset back to zero automatically.

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Optimizing Vehicle Routing with Soft Time Windows Using a Hybrid Genetic Algorithm

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***Abstract*—Determining delivery routes that minimize total cost is a key issue in goods distribution. This study focuses on a bottled drinking water (AMDK) company in City X that distributes its products to multiple retail outlets with different service time requirements. Such conditions fall within the scope of the Vehicle Routing Problem with Time Windows (VRPTW). In this study, a soft time windows approach is adopted, allowing vehicles to serve retailers beyond their specified time limits at the expense of penalty costs. The main objective is to identify optimal delivery routes under the soft time windows policy while minimizing total cost. The results demonstrate that the Hybrid Genetic Algorithm outperforms the initial solution in terms of total cost reduction. The initial routes are generated using the Nearest Insertion Heuristic and subsequently refined through mutation processes within the genetic algorithm framework.**

***Index Terms*—Distribution Routing Optimization; VRPTW; Nearest Insertion Heuristic; Hybrid Genetic Algorithm; Soft Time Windows; Total cost minimization.**

I. INTRODUCTION

Minimizing distribution costs for goods or services is a primary objective in logistics and distribution systems. Distribution efficiency is a critical lever for improving operational performance and cost effectiveness, and the absence of structured routing methods often results in inefficient travel distances and increased distribution costs [1]. Accordingly, determining optimal vehicle routes becomes essential, as reflected in cold-chain logistics studies where optimized distribution path design can reduce costs while maintaining customer satisfaction [2].

The Vehicle Routing Problem (VRP) concerns serving a set of customers from a depot using a fleet of vehicles subject to operational constraints such as travel distance, time, and vehicle capacity. A prominent variant is the Vehicle Routing Problem with Time Windows (VRPTW), which incorporates service- availability constraints at the customer level. In VRPTW, routes are scheduled for a limited number of vehicles with fixed capacities and travel times originating from a depot to serve geographically dispersed customers, while respecting customer- specific time windows for service initiation. Because the service windows may differ across customers, routing decisions must jointly consider travel efficiency and schedule feasibility to produce implementable routes [3]. In this context, prior work also indicates that hybrid solution strategies, such as combining genetic algorithms with other heuristics, including Ant Colony Optimization (ACO) and Tabu Search (TS), can provide promising trade-offs between time feasibility and cost efficiency [4].

In VRPTW, time-window constraints may be categorized as hard or soft. Under hard time windows, vehicles must arrive before a specified deadline to be considered feasible [3]. By contrast, soft time windows allow deviations from the specified interval but impose penalty costs that directly influence the total cost objective. Three time-related components are particularly influential in this setting: waiting time, service time, and tardiness. Waiting time arises when a vehicle arrives before the service window opens and must wait, whereas tardiness occurs when service begins after the latest allowable time and typically incurs lateness penalties [5]. However, many VRPTW studies simplify the treatment of these time deviations by assuming equivalent penalty costs for waiting time and tardiness, which eases

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modeling and computation [6]. This simplifying assumption can be limiting in applications where the operational consequences of tardiness may be more severe than waiting, thereby shifting the optimal routing decisions. Consequently, practical VRPTW implementations benefit from approaches that explicitly balance travel efficiency with the cost impacts of both waiting and tardy conditions as part of the total cost minimization objective [7]

A wide range of metaheuristics has been employed to address VRPTW, including Simulated Annealing (SA), Tabu Search (TS), Ant Colony Optimization (ACO), Genetic Algorithm (GA), and Particle Swarm Optimization (PSO), and these methods are recognized for producing high-quality solutions. Yudong, et al. [8] demonstrated the effectiveness of such metaheuristics across multiple VRP scenarios, while Chai, et al. [9] emphasized their robustness relative to traditional heuristics. Comparative findings also suggest that different metaheuristics exhibit complementary strengths, ACO can outperform SA and GA in certain routing contexts [10], and hybridizing GA with PSO can improve performance beyond using either method alone [11]. These results support the broader view that hybrid approaches are attractive for complex VRPTW settings because they can integrate fast constructive mechanisms with powerful global search behavior.

In this research, a Genetic Algorithm (GA) is utilized to resolve the VRPTW. GA is inspired by biological evolution, in which a population of candidate solutions (individuals) evolves through selection and variation operators. In GA, chromosomes represent solution structures and are composed of genes that encode specific traits, and improved solutions emerge through iterative evolution [12, 13]. Crossover combines genetic material from parent chromosomes to generate offspring and promote the propagation of beneficial traits [12, 14]. Mutation introduces random gene changes to maintain diversity and mitigate premature convergence, where search may otherwise become trapped in suboptimal regions [15]. In addition, adaptive mechanisms that adjust crossover and mutation rates according to population fitness have been shown to enhance GA effectiveness [13, 16].

Building on these foundations, this study proposes a Hybrid Genetic Algorithm that combines GA with the Nearest Insertion Heuristic. The Nearest Insertion Heuristic is used to construct an initial solution efficiently, which is then refined through GA-based evolutionary search to improve solution quality. By leveraging a constructive heuristic for initialization and GA operators for exploration and exploitation, the proposed hybrid approach is expected to produce vehicle routes that minimize total cost while accounting for the operational implications of time-window deviations under soft time windows. Contributions of this study are as follows: (1) it addresses VRPTW in a cost-oriented setting where time-window deviations are represented through penalty mechanisms embedded in the objective function; (2) it develops a Hybrid Genetic Algorithm that integrates Nearest Insertion for initial solution generation with GA-based improvement; and (3) it targets route solutions that reduce overall distribution cost while maintaining feasibility with respect to vehicle and scheduling constraints.

II. Methods

This section describes the methodology (Figure 1) used to solve the Vehicle Routing Problem with Time Windows (VRPTW) under a soft time windows policy using a Hybrid Genetic Algorithm. It outlines the problem context, the mathematical formulation, the required input data, and the procedure for generating an initial solution and subsequently improving it through evolutionary optimization.

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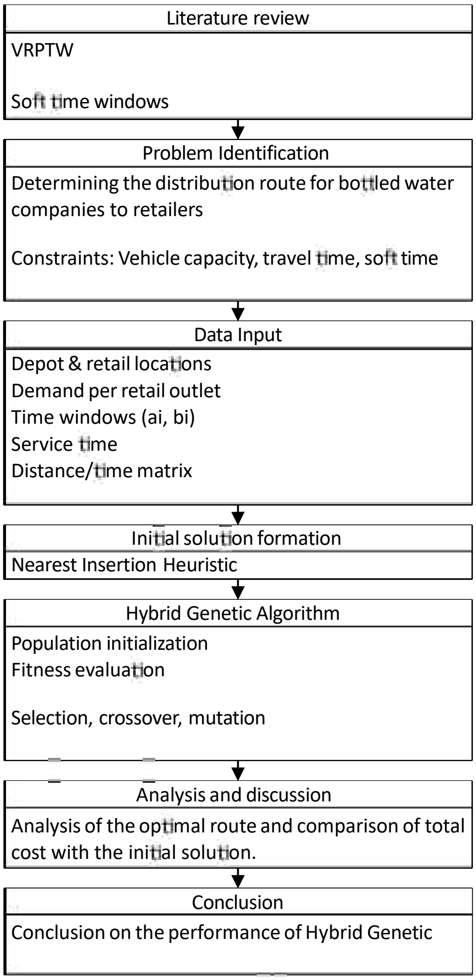

Figure 1. Hybrid Genetic Algorithm for VRPTW with Soft Time Windows Flowchart

A. Problem Identification

This study addresses the problem of determining delivery routes for bottled drinking water (AMDK) distribution from a depot to retailers in City X. The objective is to obtain routing plans that minimize the total distribution cost, which consists of travel-related costs and time-window–related penalty costs, while ensuring that operational constraints (e.g., vehicle capacity and service schedules) are satisfied.

B. Mathematical Formulation of VRPTW

The VRPTW is an extension of the Capacitated Vehicle Routing Problem (CVRP) in which the service at each customer must start within a specified time interval (time window). Under a soft time windows policy, arriving earlier than the allowed service start time may produce waiting-related costs, while arriving later than the service deadline leads to penalty costs for tardiness.

Notation:

T_{ik} : service start time at customer i using vehicle k .

C_{ij}: Travel cost from i to k (source: i" to k").

S_i: Service time at customer i

t_{ij}: Travel time required from i to j

a_i: earliest time customer i

b_i: latest time customer i

q_i: Quantity of goods (demand) to be picked up from customer i

Q: Capacity of vehicle k

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Mathematical Formulation [17]:

Objective Function:

$$Min \sum_{k \in K} \sum_{(i,j) \in A} C_{ij} X_{ij} \tag{1}$$

Subject to:

$$\sum_{k \in K} \sum_{j \in \sigma-(i)} X_{ij} = 1 \quad \forall i \in N, \tag{2}$$

$$\sum_{j \in \sigma+(v)} X_{0jk} = 1 \quad \forall k \in K, \tag{3}$$

$$\sum_{i \in \sigma-(j)} X_{0jk} - \sum_{i \in \sigma+(j)} X_{ijk} = 0 \quad \forall k \in K, j \in K, \tag{4}$$

$$\sum_{j \in \sigma-(n+1)} X_{i,n+1,k} = 1 \quad \forall k \in K, \tag{5}$$

$$X_{ijk}(T_{ik} + S_i + t_{ij} - T_{jk}) \leq 0 \quad \forall k \in K, (i,j) \in A, \tag{6}$$

$$a_i \leq T_{ik} \leq b_i \quad \forall k \in K, i \in V, \tag{7}$$

$$\sum_{i \in N} q_i \sum_{j \in \sigma+(1)} X_{ijk} \leq Q \quad \forall k \in K \tag{8}$$

$$X_{ijk} \in \{0,1\} \quad \forall k \in K, (i,j) \in A, \tag{9}$$

The objective function in Equation (1) minimizes the total cost. The constraint in Equation (2) ensures that each customer is assigned to exactly one route. Equation (3) enforces that service begins from the depot, ensuring that customers are visited as part of feasible delivery routes originating from the depot. Constraints in Equations (4) and (5) define flow conservation for each vehicle route, such that the number of incoming arcs equals the number of outgoing arcs for each visited customer, thereby constructing valid source-to-sink paths. Equations (6) and (7) maintain schedule feasibility by regulating the service start time at each customer with respect to the specified time windows, including early-arrival waiting and late-arrival tardiness under the soft time windows setting. Finally, Equation (8) ensures capacity feasibility by requiring that the total demand served on each route does not exceed the vehicle capacity.

C. *Hybrid Genetic Algorithm*

Genetic Algorithms (GA) were first introduced by John Holland in the 1960s and later formalized in Adaptation in Natural and Artificial Systems (1975) [18]. GA is inspired by evolutionary principles in which individuals with better “fitness” have a higher probability of surviving and reproducing, while less fit individuals are gradually eliminated. In the GA framework, each candidate solution is encoded as a chromosome and evaluated using a fitness function. Through repeated generations, the population is improved by applying genetic operators—parent selection, crossover, and mutation—so that new offspring can inherit advantageous traits and achieve better fitness values.

In this study, GA is combined with the Nearest Insertion Heuristic to form a Hybrid Genetic Algorithm The hybridization is introduced primarily at the initialization stage to avoid starting from purely random solutions. The Nearest Insertion Heuristic is known to be efficient for vehicle routing problems [19], and embedding heuristic-based initialization within GA can accelerate the search process because the initial population is closer to promising regions of the solution space [20]. As a result, the subsequent evolutionary search is expected to require fewer generations to reach high-quality routing plans.

. The initial population consists of a set of chromosomes, each representing a candidate routing plan for the VRPTW. In this representation, each chromosome encodes customer visit sequences that form vehicle routes; genes correspond to customers, and the gene order determines the service order. The number of chromosomes in the population (popsize) is determined according to the scale of the problem being solved. After the population is formed, each chromosome is evaluated using the fitness function defined in this study, namely total cost. Chromosomes with better fitness values are then more likely to be chosen as parents to generate the next generation.

New solutions are generated by recombining parent chromosomes through crossover. This tudy employs Heuristic Crossover as a local-search-oriented recombination operator [21]. Rather than

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exchanging genes randomly, Heuristic Crossover constructs offspring by selecting genes while considering inter- customer distances and route structure inherited from the parents, with the aim of producing coherent routes that preserve good building blocks from both solutions. To maintain diversity and prevent premature convergence, the offspring produced by crossover are subsequently modified through mutation. Mutation changes the gene sequence within a chromosome (i.e., within the same route representation), thereby introducing new customer orderings that may yield alternative and potentially better routing configurations. The mutated chromosomes constitute the offspring population, which is then evaluated again using the same fitness measure.

Finally, offspring are compared against their parents or the current population based on fitness value. Because the fitness in this study is total cost, solutions with lower total cost are preferred and retained to form the population for the next generation. This iterative process continues until the termination condition defined for the experiment is met, producing a set of vehicle routes that minimizes total cost under the given operational constraints.

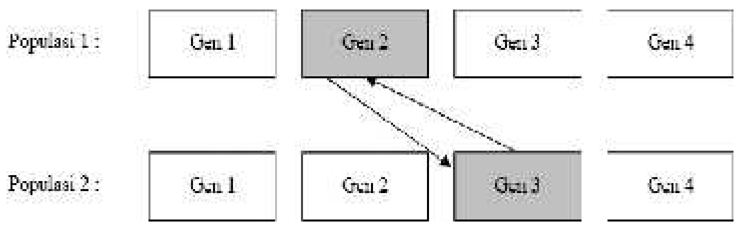

Figure 2. Illustration of the crossover process

Figure 3. Illustration of the mutation process

III. Result And Discussion

This section describes how the solution is calculated to determine the route with the minimum total cost by optimizing total travel time. The distribution of bottled drinking water (AMDK) to retailers in City X involves several cost components, which are incorporated into the objective function to minimize total cost. Penalty costs for earliness and tardiness are treated as equivalent in prior work [22]; however, in this study tardiness is assumed to be twice as costly as waiting (earliness) to reflect the higher operational and service impact of late deliveries.

The average vehicle speed is set at 43 km/h, which is equivalent to 0.72 km/min. Fuel consumption while driving is assumed to be 1 liter per 9 km, and the diesel price is Rp 9,800.00 per liter. Therefore, the fuel cost per kilometer is Rp 9,800.00/9 = Rp 1,088.9 per km. The transportation cost per minute is then obtained by multiplying the cost per kilometer by the distance traveled per minute (0.72 km/min), resulting in Rp 1,088.9 × 0.72 = Rp 780.4 per minute.

In addition to travel-related fuel costs, fuel consumption during idling is also considered. Idling fuel consumption is assumed to be 1.5 liters per hour, or 0.03 liters per minute. Based on the same diesel price, the waiting cost is calculated as Rp 9,800.00 × 0.03 = Rp 245 per minute. The tardiness cost is assumed to be twice the waiting cost, yielding Rp 245 × 2 = Rp 490 per minute.

The first stage of the hybrid Genetic Algorithm is the construction of an initial population as the starting set of feasible solutions. This study uses the Nearest Insertion Heuristic to generate the initial routes by iteratively inserting the next

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customer based on the shortest incremental travel time from the partially constructed route. With respect to time windows, this study adopts soft time windows, meaning that vehicles may arrive before the opening time or after the closing time of each retail outlet; such violations are permitted but incur penalty costs corresponding to earliness (waiting) and tardiness (late arrival), respectively.

A. Formation of the initial population using the Nearest Insertion Heuristic method

The Nearest Insertion Heuristic is a route determination method that inserts the selected route into the previously created initial route. This route insertion is done by considering the closest travel time. The initial vehicle will depart from the warehouse and return to the warehouse. From the distance matrix, the retail location with the closest travel time from the warehouse will be searched for. For the first vehicle route, the selected retailer is SB. After obtaining the G-SB-G route, the next step is to select a retailer to be inserted between G- SB or SB-G. The selected retailer BJ is inserted into SBG, so that retailer BJ is placed after SB. When the vehicle capacity is full, if there are still retailers that have not been included in the route, a new route is created.

In Table 1 the vehicle will depart from the warehouse at 7:00 a.m., then it will search for the retailer with the closest travel time from the warehouse, which is SB. Retailer SB has a travel time of 27 minutes from the warehouse, with a demand of 176.6 kg. The retailers selected in the route will be checked in advance to see if they meet the specified restrictions. The first restriction is that the total demand for each retailer must be less than the vehicle's capacity, which is 1200 kg. In addition to considering capacity, it is necessary to have opening hours from 7:00 a.m. to 12:00 p.m. Because the time windows in this study are soft time windows, vehicles can pass through the time windows owned by retailers but will be subject to additional costs (penalty costs). For SB retailers, vehicles will arrive at 7:27 a.m. and no penalties will be incurred. Penalties occur at retailers S1 and LM. At these two retailers, vehicles arrive late. The total delay is 210 minutes. If the first route has met the capacity limit, create a new route for other retailers that have not considered the time windows of each retailer. Each retail outlet has different time windows. For retail outlet SB, the vehicle will arrive at 7:27 a.m. and there will be no penalty. Penalties occur at retail outlets S1 and LM. At these two retail outlets, the vehicle arrives late. The total delay is 210 minutes. If the first route has reached its capacity limit, create a new route for the other retail outlets that have not yet been selected.

The following results present the routes obtained for the two vehicles and the corresponding total cost calculation for each route. For Vehicle 1, the selected route is $G \rightarrow S \rightarrow B \rightarrow L \rightarrow M \rightarrow S \rightarrow A \rightarrow S1 \rightarrow L \rightarrow G$. The transportation cost is computed based on a total travel time of 179 minutes and a unit transportation cost of Rp 780.370 per minute, yielding 179×780.370 =Rp 139,686.296. The penalty cost consists of waiting and tardiness components. In this route, the waiting time is 0 minutes, so the waiting cost is 0×245 =Rp 0. The tardiness is 210 minutes, and with a tardiness cost of Rp 490 per minute, the tardiness cost is 210×490 =Rp 102,900.0. Therefore, the total cost for Vehicle 1 is the sum of transportation and penalty costs, resulting in Rp 242,586.296.

For Vehicle 2, the selected route is $G \rightarrow P \rightarrow G \rightarrow B \rightarrow S \rightarrow H \rightarrow B \rightarrow P \rightarrow S \rightarrow G$.

The transportation cost is calculated using a total travel time of 248 minutes and the same unit transportation cost of Rp 780.370 per minute, resulting in 248×780.370 =Rp 193,531.852. The penalty cost is then determined in the same manner. The waiting time is 0 minutes, producing a waiting cost of 0×245 =Rp 0. The tardiness is 275 minutes, and thus the tardiness cost is 275×490 =Rp 134,750.0. Consequently, the total cost for Vehicle 2 is Rp 328,281.851.

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Table 1. Determining Route 1 for Vehicles using the NI method

R	D	CD	DP	TT (Min)	UT (Min)	AT (WIB)	OT (WIB)	CT (WIB)	FT (WIB)	EP	LP	TP
G												
SB	176.6	176.6	0	00.27.00	00.30.00	07.27.00	07.00.00	12.00.00	07.57.00	0	0	0
BJ	105.1	281.7	0	00.25.00	00.30.00	08.22.00	07.00.00	14.00.00	08.52.00	0	0	0
LA	112.2	393.9	0	00.19.00	00.30.00	09.11.00	08.00.00	14.00.00	09.41.00	0	0	0
MM	140.6	534.5	0	00.32.00	00.30.00	10.13.00	08.00.00	15.00.00	10.43.00	0	0	0
SC	158.7	693.2	0	00.11.00	00.30.00	10.54.00	08.00.00	11.00.00	11.24.00	0	0	0
AJ	96.9	790.1	0	00.12.00	00.30.00	11.36.00	08.00.00	14.00.00	12.06.00	0	0	0
S1	128.5	918.6	0	00.17.00	00.30.00	12.23.00	08.00.00	11.00.00	12.53.00	0	1	1
LM G	153.2	1071.8	0	00.14.00 00.22.00	00.30.00	13.07.00 13.59.00	08.00.00	11.00.00	13.37.00	0	1	1
			Total	02.59.00		Tardy	03.30.00	Waiting	0.00.00			
			Minute	179.00		Minute	210.00	Minute	0.00			

B. Crossover

After the initial solution (initial population) is generated, the subsequent step is to apply crossover using the Heuristic Crossover method. The initial population constructed in the previous stage serves as the set of parent solutions for this operation. In genetic algorithms, crossover is generally defined as the process of exchanging genetic information (genes) between two parent chromosomes to produce new offspring solutions. In this study, the heuristic crossover is performed using two parent vehicle routes.

The two parent routes are defined as follows: the first parent route (RK 1) is $G \rightarrow S \rightarrow B \rightarrow L \rightarrow M \rightarrow S \rightarrow A \rightarrow S1 \rightarrow L \rightarrow G$, and the second parent route (RK 2) is $G \rightarrow P \rightarrow G \rightarrow B \rightarrow S \rightarrow H \rightarrow B \rightarrow P \rightarrow S \rightarrow G$. Because each route contains eight customer nodes (i.e., eight genes, excluding the depot), a random integer is generated within the interval from 1 to 8 to determine the gene position used in the crossover process. In this case, the selected random number is 1.

Next, the inter-gene distances required for the heuristic decision rules are retrieved from the distance matrix. Based on these distance values, the crossover operation is then performed between the two vehicle routes to generate offspring solutions, which can be seen in Tables 2 and 3. The same procedure is applied in both directions, meaning that Vehicle 1 is crossed with Vehicle 2 and, conversely, Vehicle 2 is crossed with Vehicle 1, to ensure that the heuristic exchange mechanism is consistently evaluated across the two parent structures. Table 2 and 3 show select the genes with the minimum distance and Table 4 show crossover result.

Table 2. Crossover RK 1 with RK 2

From	To	Distance
G	PA	00.29.00
G	GM	00.43.00
G	**BD**	00.20.00
G	SM	00.59.00
G	HB	00.52.00
G	BG	00.39.00
G	PB	00.39.00
G	SR	00.46.00

Table 3. Crossover RK 2 with RK 1

From	To	Distance
G	SB	00.27.00
G	BJ	00.40.00
G	LA	00.27.00
G	MM	00.24.00
G	SC	00.39.00
G	AJ	00.33.00
G	S1	00.50.00
G	**LM**	00.22.00

Table 4. Crossover result

	Crossover							
C1	**BD**	SR	LA	MM	SC	AJ	A1	**PA**
C2	**LM**	GM	SB	SM	HB	BG	PB	SR

C. Mutation

The crossover operation produces two intermediate solutions (i.e., two crossover outputs which can be seen in Table 4), which are subsequently subjected to mutation in order to generate offspring. In genetic algorithms, mutation is generally defined as an operation that modifies a chromosome by altering the arrangement of genes within the same individual solution (i.e., within the same

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route). In this study, mutation is implemented as an intergenic exchange guided by distance-based considerations. The procedure is performed as follows.

First, one gene position is selected at random from a chromosome consisting of eight genes (excluding the depot). A random integer between 1 and 8 is generated, and in this case the selected value is 3 which shown in Table 5. Next, the distance between gene 2 and gene 3 is computed using the distance matrix. Based on the matrix, the distance from retail SR (gene 2) to LA (gene 3) is 33. After that, in Table 6 the shown distance from gene 2 to all other genes in the same chromosome is evaluated. From these candidate distances, select one gene that has the minimum distance from gene 2 and must be less than the distance from gene 2 to gene 3. Based on the calculation, gene 3 is selected because it has a distance of 20 from gene 2, which satisfies the selection rule. The intergenic mutation is then executed as shown in Table 7, by exchanging the relevant gene positions according to the defined mutation mechanism. The same mutation procedure is applied to the second offspring (offspring 2) to obtain its mutated form, can be seen in Table 8. Following crossover and mutation, the resulting offspring solutions are compared against the parent solutions. If an offspring yields a better objective value (i.e., a lower total cost), the solution is updated by replacing the corresponding parent with the improved offspring. In this study, the crossover and mutation operators were applied for three iterations. Although this setting is sufficient to demonstrate the procedure, additional iterations may be performed to potentially obtain better solutions.

Table 5. Random Integer Selection (value = 3)

Crossover 1							
BD	SR	**LA**	MM	SC	AJ	A1	PA

Table 6. Distances from Gene 2 to Other Genes

Crossover 1		
From	To	Distance
SR	BD	00.21.00
SR	**MM**	00.20.00
SR	SC	00.35.00
SR	AJ	00.41.00
SR	S1	00.35.00
SR	PA	00.34.00

Table 7. Intergenic mutation for offspring 1

Offspring 1							
BD	SR	LA	MM	SC	AJ	A1	PA

Table 8. Intergenic mutation for offspring 2

Offspring 2							
HB	GM	SB	SM	LM	BG	PB	SR

D. Evaluation of fitness values for each mutation route

Fitness value evaluation is conducted to ensure that the offspring routes satisfy the problem constraints and can be considered feasible solutions. The primaryfeasibility constraint evaluated in this stage is vehicle capacity. An offspring route is acceptable only if the total demand served across the assigned retail outlets does not exceed the vehicle's capacity.

Beyond feasibility, the fitness measure used in this study is the total cost which can be seen in Table 9. This fitness measure serves as the basis for comparing candidate solutions and selecting the best route. The total cost consists of transportation cost and penalty cost (waiting and tardiness). For offspring 1, the evaluation indicates that waiting occurs at retail BD. The vehicle arrives at 07:20, whereas BD opens at 08:00, requiring the vehicle to wait for 40 minutes before service can begin. For offspring 2, the evaluation shows waiting at retail LM. The vehicle arrives at 07:49, while LM opens at 08:00, resulting in an 11-minute waiting time. After completing service at LM, the vehicle continues to the next retail outlet according to the route schedule.

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Table 9. Fitness evaluation for offspring 1

	R	D	CD	DP	TT (Min)	UT (Min)	AT (WIB)	OT (WIB)	CT (WIB)	FT (WIB)	EP	LP	TP
Offspring 1	G												
	BD	136.6	136.6	0	00.20.00	00.30.00	07.20.00	08.00.00	15.00.00	07.50.00	1	0	1
	SR	100.9	237.5	0	00.21.00	00.30.00	08.11.00	07.00.00	10.00.00	07.30.00	0	0	0
	MM	140.6	378.1	0	00.20.00	00.30.00	07.50.00	08.00.00	15.00.00	08.30.00	1	0	1
	LA	112.2	490.3	0	00.32.00	00.30.00	09.02.00	08.00.00	14.00.00	08.30.00	0	0	0
	SC	158.7	649	0	00.28.00	00.30.00	08.58.00	08.00.00	11.00.00	08.30.00	0	0	0
	AJ	96.9	745.9	0	00.12.00	00.30.00	08.42.00	08.00.00	14.00.00	08.30.00	0	0	0
	S1	128.5	874.4	0	00.17.00	00.30.00	08.47.00	08.00.00	11.00.00	08.30.00	0	0	0
	P	147.8	1022.2	0	00.30.00	00.30.00	09.00.00	07.00.00	11.00.00	07.30.00	0	0	0
	A				00.29.00		.						
	G												
				Total	03.29.00		Tardy	00.00.00	Waiting	00.50.00			
				Minute	209.00		Minute	0.00	Minute	50.00			

Note. R: Retail; D: Demand; CD: Cumulative Demand; DP: Demand Penalty; TT: Travel Time; UT: Unloading Time; AT: Arrival Time; OT: Open Time; CT: Close Tme; FT: Finish Time; EP: Early Penalty; LP: Late Penalty; TP: Total Penalty

The total cost for offspring 1 is calculated based on its transportation and penalty components. The transportation cost is derived from the total travel time of 209 minutes, multiplied by the transportation cost rate of Rp 780.370 per minute, resulting in 209 × 780.370 = Rp 163,097.407. In addition to transportation cost, the penalty cost arises from time window considerations. Offspring 1 incurs a waiting time of 50 minutes, which corresponds to a waiting cost of 50 × 245 = Rp 12,250.0, while no tardiness is observed, leading to a tardiness cost of Rp 0. Consequently, the total cost for offspring 1 amounts to Rp 175,347.407. The results indicate that although offspring 1 achieves a relatively short total travel time, the waiting penalty contributes noticeably to the overall cost. This suggests that the delivery sequence generated for offspring 1 arrives earlier than the allowable service time at several retail locations, leading to increased waiting time. Nevertheless, the absence of tardiness penalties implies that the route successfully complies with the upper bounds of the time windows. Overall, the cost structure of offspring 1 reflects a trade-off between efficient travel time and early arrival, highlighting the importance of balancing route efficiency and time window compliance in minimizing total distribution cost.

Table 10. Fitness evaluation for offspring 2

	R	D	CD	DP	TT (Min)	UT (Min)	AT (WIB)	OT (WIB)	CT (WIB)	FT (WIB)	EP	LP	TP
Offspring 1	G												
	HB	210	210	0	00.52.00	00.30.00	07.52.00	07.00.00	11.00.00	08.22.00	0	0	0
	GM	210	420	0	00.50.00	00.30.00	09.12.00	07.00.00	14.00.00	07.30.00	0	0	0
	SB	176.6	596.6	0	01.00.00	00.30.00	08.30.00	07.00.00	12.00.00	07.30.00	0	0	0
	SM	110	706.6	0	00.31.00	00.30.00	08.01.00	08.00.00	09.00.00	07.30.00	0	0	0
	LM	153.2	859.8	0	00.19.00	00.30.00	07.49.00	07.00.00	11.00.00	08.30.00	1	0	1
	BG	130.5	990.3	0	00.27.00	00.30.00	08.57.00	07.00.00	13.00.00	07.30.00	0	0	0
	PB	105.2	1095.5	0	00.30.00	00.30.00	08.00.00	07.00.00	12.00.00	07.30.00	0	0	0
	SR	100.9	1196.4	0	00.39.00	00.30.00	08.09.00	07.00.00	10.00.00	07.30.00	0	0	0
	G				00.46.00		.						
				Total	05.54.00		Tardy	00.00.00	Waiting	00.11.00			
				Minute	354.00		Minute	0.00	Minute	11.00			

Note. R: Retail; D: Demand; CD: Cumulative Demand; DP: Demand Penalty; TT: Travel Time; UT: Unloading Time; AT: Arrival Time; OT: Open Time; CT: Close Tme; FT: Finish Time; EP: Early Penalty; LP: Late Penalty; TP: Total Penalty

Similarly, the total cost for offspring 2, as presented in Table 10, is calculated based on a total travel time of 354 minutes. The transportation cost is obtained by multiplying the total travel time by the transportation rate, resulting in 354 × 780.370 = Rp 276,251.111. In addition to transportation cost, the penalty cost is derived from time window violations. As shown in the table, offspring 2 experiences a waiting time of 11 minutes, which leads to a waiting penalty of 11 × 245 = Rp 2,695.0, while no tardiness is observed, resulting in a

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tardiness penalty of Rp 0. Consequently, the total cost incurred by offspring 2 amounts to Rp 278,946.111. The results in Table 10 indicate that the delivery route generated for offspring 2 satisfies most of the time window constraints, as reflected by the absence of tardiness penalties and the relatively small waiting penalty. This suggests that the routing sequence produced by the Hybrid Genetic Algorithm is able to balance travel efficiency and service time compliance, leading to a lower overall penalty cost while maintaining an acceptable transportation cost.

Overall, the Hybrid Genetic Algorithm produces a lower total cost compared to the initial routes generated using the Nearest Insertion Heuristic, as summarized in Table 11. The comparison clearly shows that the offspring solutions consistently outperform the parent routes in terms of total cost. The most significant improvement is primarily attributed to a substantial reduction in penalty costs, especially the elimination of tardiness penalties across all offspring solutions. This indicates that the Hybrid Genetic Algorithm is effective in generating delivery routes that better comply with time window constraints while maintaining efficient travel times.

Furthermore, although the transportation costs of some offspring routes are comparable to or slightly higher than those of the parent routes, the absence of tardiness penalties results in a considerably lower overall cost. As a consequence, the offspring routes are able to replace the parent routes as the updated best solutions in the evolutionary process. Among the evaluated offspring candidates, offspring 3 and offspring 4 achieve the minimum total cost, demonstrating the best balance between transportation cost and penalty cost. Therefore, these two offspring routes are selected as the final solutions in this study.

Table 11. Comparison of total route costs for parents and offspring

Parent	Transportation Cost	Penalty cost		Total cost	Ttot Cost
		Waiting cost	Tardy cost		
RK 1	Rp 139686.296	Rp -	Rp 102900.0	Rp 242586.29	Rp 570868.148
RK 2	Rp 193531.852	Rp -	Rp 134750.0	Rp 328281.852	
Offspring - i					
Offspring -1	Rp 163097.407	Rp 12250.0	Rp -	Rp 175347.407	Rp 454293.519
Offspring - 2	Rp 276251.111	Rp 2695.0	Rp -	Rp 278946.111	
Offspring - 3	Rp 156074.074	Rp 2450.0	Rp -	Rp 158524.074	Rp 357872.407
Offspring - 4	Rp 196653.333	Rp 2695.0	Rp -	Rp 199348.333	
Offspring - 5	Rp 163877.778	Rp 5880.0	Rp -	Rp 169757.778	Rp 369260.370
Offspring - 6	Rp 195092.593	Rp 4410.0	Rp -	Rp 199502.593	

IV. Conclusion

This section summarizes the conclusions of the study by presenting the selected distribution routes for bottled drinking water (AMDK) in City X and highlighting the cost implications of applying the Hybrid Genetic Algorithm (HGA) in comparison with the initial solution generated using the Nearest Insertion Heuristic. The findings demonstrate that incorporating retailer time windows into routing decisions leads to substantial changes in the overall cost structure when compared with approaches that focus solely on minimizing travel time. In particular, penalty costs emerge as a dominant component of the total cost, with tardiness penalties contributing significantly higher costs than waiting (earliness) penalties. This emphasizes that minimizing late arrivals plays a critical role in achieving a minimum-cost distribution solution.

Furthermore, although the HGA framework allows for a larger number of iterations that could potentially enhance solution quality, this study implemented only three iterations. Despite this limitation, the results indicate that the HGA effectively improves route selection by consistently replacing higher-cost parent routes with lower-cost offspring routes. This outcome suggests that the evolutionary search mechanism embedded in the HGA is capable of efficiently exploring and exploiting the solution space, even with a limited number of iterations, and is well suited for handling routing problems with soft

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time window constraints.

Based on the best-performing offspring, the final routes recommended for implementation are as follows: RK 1 is $G \rightarrow S \rightarrow B \rightarrow S \rightarrow B \rightarrow S1 \rightarrow A \rightarrow S \rightarrow L \rightarrow G$, and RK 2 is $G \rightarrow P \rightarrow G \rightarrow M \rightarrow H \rightarrow L \rightarrow B \rightarrow P \rightarrow S \rightarrow G$

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