Redesign of Staging Area Layout at Marunda Port with Systematic Layout Planning (SLP) Method and Its Effect on Ship Loading and Unloading

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Abstract. PT XYZ is an offshore oil and gas exploration and production company that uses Marunda Port as the primary land base to support logistics activities and personnel shifts. However, the operational process of Marunda Port is often encumbered by the presence of ships waiting in queues. This is due to several factors, including but not limited to: limited loading and unloading facilities, dock capacity, and suboptimal staging area layout. The objective of this research is to enhance the operational efficiency of the port by implementing the Systematic Layout Planning (SLP) method in the redesign of the staging area layout. The research was conducted through five primary stages, initiated with the collection of both primary and secondary data. This was followed by the creation of an Operation Process Chart and an Activity Relationship Chart. The subsequent stage involved the design of a new layout and the analysis of Discrete Event Simulation (DES) simulations. Numerical outcomes (e.g., % reduction in queue time, increased throughput) will be conducted in the future studies.

Keywords: Systematic Layout Planning, Discrete Event Simulation, Ship Loading and Unloading.

1 Introduction

PT XYZ is a company engaged in the exploration and production of offshore oil and gas. The company's working area, Block XYZ, covers 8,279.29 km² and stretches from the Thousand Islands to North Cirebon. Presently, the XYZ working area contributes approximately 5 % of oil production and 2 % of national gas production. All oil is allocated for domestic consumption, and gas is supplied to various industrial customers, including PLN Muara Karang, Pupuk Kujang, and Pertamina RU VI Balongan.

PT XYZ, an oil and gas company that prioritizes efficiency and integration in its operations, utilizes Marunda Port as the primary land base to support its offshore activities. These activities encompass the transportation of logistics and personnel shifts. A total of 30 vessels are operated on a scheduled basis to support production, projects, and well drilling and intervention activities. However, the operational processes at

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Marunda Port frequently encounter instances of vessels forming queues for loading and unloading, which has the potential to impede the efficiency of the supply chain.

The underlying causes of this queue include a multitude of factors, including the concurrent arrival of vessels, the constraints in loading and unloading equipment and labor, the limited dock capacity, and the suboptimal layout of the port staging area. The efficiency of the staging area layout is of paramount importance in accelerating the loading and unloading process, reducing ship waiting time, and enhancing work safety and overall port operational performance. The issue of inefficiency in the staging area at Marunda Port was identified through direct field observations and historical port performance data, which revealed the presence of vessel queues, prolonged waiting times, and delays in ship loading and unloading processes. These findings were further substantiated by interviews with field operators and logistics supervisors.

Systematic Layout Planning (SLP) is a facility layout design method developed by Muther in 1973 [11]. It is widely known for its systematic and organized approach. SLP underscores the analysis of activity relationships, spatial requirements, and material flow as the foundation for developing an efficient layout [13]. Despite the extensive implementation of this method across numerous industrial sectors, its integration within the domain of port operations, particularly in the context of optimizing staging areas to enhance the efficiency of ship loading and unloading processes, remains comparatively restricted.

Therefore, the objective of this study is to address the aforementioned gap by examining the application of SLP in the structuring of the Marunda Port staging area. This examination seeks to achieve two primary goals: first, the reduction of ship queues, and second, the enhancement of port operational efficiency. Trade-offs between minimizing travel distance, reducing waiting times, and ensuring safety are evaluated by identifying the number of potential conflict points (e.g., crossing paths). The fewer the conflict points and the greater the maneuvering space, the higher the safety score assigned to the layout.

2 Literature Overview

Layout can be defined as the arrangement of processing stages into different rooms and their interactions [12]. Layout arrangements play a pivotal role in ensuring the seamless operation of the production process, encompassing the utilization of space for machinery, support facilities, material flow, storage, and personnel [13]. A proper layout design has been shown to improve operational efficiency by reducing congestion, material handling costs, idle time, and improving resource utilization [2]. Conversely, inadequate design can incur substantial costs due to facility rearrangement [6]. The primary objective of layout planning is to minimize material handling costs, thereby reducing work in process, production time, and congestion [3]. The efficacy of Facility planning has been demonstrated to result in operational cost savings ranging from 10 % to 30 % [8].

Systematic Layout Planning (SLP) is a systematic and structured facility layout design method developed by Richard Muther in 1961 [11]. It is widely used in efficient layout design. The term "SLP" is frequently linked to the principles of lean manufacturing. The objective of SLP is to eliminate waste, optimize resources, and enhance operational efficiency. The implementation of this technology is anticipated to result in a reduction of material handling costs, decreased idle time, and enhanced utilization of labor, equipment, and space.

The implementation of the Systematic Layout Planning (SLP) method, when combined with the Discrete Event Simulation (DES) approach, has proven effective in reducing unloading time and minimizing material handling distances in various facilities such as warehouses, terminals, and manufacturing industries. These improvements ultimately lead to an increase in operational throughput. Yulianto and Pamungkas (2014) [12] conducted a study on the application of Systematic Layout Planning (SLP) and Discrete Event Simulation (DES) to improve the machine layout in a heavy equipment component manufacturing industry. Using Tecnomatix Plant Simulation software, the study aimed to develop alternative machine layouts that are better aligned with the current product types and more efficient in terms of material handling distance, transportation time, and production output. The results indicated that the integration of SLP and DES successfully reduced material handling distances by 32 % annually, decreased transportation time by 27 % annually, and increased production output by 6 % per year.

3 Theoretical Framework

3.1 Layout

Apple (1990) [1] defines factory layout as the arrangement of physical facilities, including equipment, personnel, buildings, and other facilities. This arrangement is intended to optimize the relationship between personnel, the flow of goods, information, and procedures. The objective is to ensure that the process functions effectively, efficiently, economically, and safely. The layout design process necessitates strategic deliberation concerning the sequence of work, the allocation of materials, and the transmission of information. This is done to minimize distance and process time, while ensuring the safety and comfort of the labor force. Muther (1955) [11] underscores that an optimal layout is predicated on a comprehensive comprehension of operations and workflow, encompassing the distinct requirements of each work domain and the interrelationship between these domains. This facilitates a rational and efficient process flow.

3.2 Layout Design Method

The layout design of facilities is a critical component in the planning of production and service systems. A plethora of methodologies are employed in the design of layouts, including BLOCPLAN, Computerized Relationship Layout Planning (CORELAP), Computerized Relative Allocation of Facilities Technique (CRAFT), and Systematic Layout Planning (SLP). Each method has its own approach and advantages in optimizing facility placement.

BLOCPLAN is a layout design tool that relies on a hybrid algorithm, which is a combination of a constructive algorithm and an improvement algorithm. This approach aims to produce an optimal layout by minimizing the distance between facilities or, alternatively, maximizing the proximity relationship between facilities. In its implementation, BLOCPLAN produces an initial layout solution and subsequently implements enhancements to achieve enhanced efficiency. BLOCPLAN is capable of generating alternative layouts based on adjacency scores, its application is limited due to the requirement for predefined block shapes, which are often rigid and lack the flexibility needed to accommodate actual field conditions.

CORELAP is a method designed to organize layouts based on proximity relationships between departments. This method utilizes a Total Closeness Rating (TCR) approach, which calculates the sum of the numerical values of the proximity relationships between departments, with the numerical values weighted based on their respective levels of importance. This TCR value is employed to ascertain the sequence of department placement by prioritizing departments that have the highest interaction or proximity relationship with other departments. Consequently, CORELAP is capable of ascertaining the relative position of a facility within the comprehensive layout framework based on the intensity of the relationship between facility elements. CORELAP is efficient for arranging departments within structured manufacturing systems. However, it lacks flexibility when applied to open spaces such as port staging areas and operates under the assumption of relatively fixed material flow patterns.

CRAFT is a methodology that facilitates the enhancement of layout through a systematic approach involving the gradual exchange of positions between departments. This process is undertaken to identify a more optimal solution compared to previous iterations. The evaluation is based on changes in material handling costs and distance efficiency between facilities. A notable benefit of this approach is its flexibility in accommodating departmental shapes that may not conform to a uniform, box-like structure. This flexibility allows for the placement of these units in a variety of positions as required. Furthermore, the CRAFT model has been expanded to prioritize material handling cost reduction, and it has gained widespread popularity due to its simplicity, rapid computation time, and capacity to provide a mathematical solution to the problem of minimizing material handling costs and facility spacing. The utilization of these methodologies enables a more systematic, efficient, and operational layout design that aligns with the specific needs of the company or organization in question. CRAFT is more appropriate for improving existing layouts, primarily focusing on the optimization of load-distance. However, it is less suitable for initial layout planning stages, as it does not explicitly incorporate qualitative factors such as safety, accessibility, or functional compatibility.

3.3 Systematic Layout Planning (SLP)

Muther (1955) [11] mentions the steps of layout design using the Systematic Layout Planning approach using material flow analysis, activity relationship chart, activity relationship diagram.

Material flow analysis uses two main approaches: conventional techniques and quantitative techniques, both of which help to understand and optimize material flow in a production or operational environment. An Activity Relationship Chart (ARC) is an analytical tool used to map and understand how closely various areas or parts of an organization or workspace are. To help determine the activities, a grouping of degrees of relationship has been established with a mark for each degree.

An Activity Relationship Diagram (ARD) is a visual tool used to map and assess how various activities or areas should be placed relative to each other in a workspace or facility. This diagram has the degree of proximity between facilities expressed by letter and line codes. This diagram serves as a preliminary foundation for generating layout alternatives, which are further evaluated through simulation and performance analysis. Through this approach, the decision-making process in layout redesign moves beyond intuition, adopting a systematic and scientifically accountable methodology that integrates both qualitative and quantitative considerations.

SLP offers a distinct advantage due to its capacity to address the complexity of interdepartmental relationships, which are influenced not only by material flow volumes but also by non-quantitative factors such as occupational safety, physical space constraints, ease of access, and functional proximity between zones. These considerations are particularly critical in port operations, where various functional areas—such as temporary storage zones and loading/unloading points—are interconnected and must operate cohesively.

Moreover, SLP adopts a structured and participatory planning approach that encourages the involvement of multiple stakeholders, including port authorities, logistics personnel, and stevedoring service providers, particularly during the development of the Activity Relationship Chart (ARC). This collaborative process contributes to the design of a facility layout that better aligns with on-site operational requirements. To facilitate this process, the Activity Linkage Map employs a set of standardized symbols to indicate the strength and importance of relationships between activities, as summarized in Table 1. These symbols provide a visual framework for analyzing interdependence among functions and operations.

Table 1. Symbols of Activity Linkage Map.

Symbol	Color	Description
A	Red	**A**bsolutely Necessary
E	Orange	**E**specially Important
I	Green	**I**mportant
O	Blue	**O**rdinary
U	Colorless	**U**nnecessary
X	Brown	Une**x**pected

Furthermore, Fig. 1 illustrates the degree of proximity between facilities, offering a graphical representation of how closely related activities should be positioned in the layout. Together, Table 1 and Fig. 1 support the systematic evaluation of spatial relationships, ensuring that the final facility design effectively reflects both operational priorities and functional connectivity.

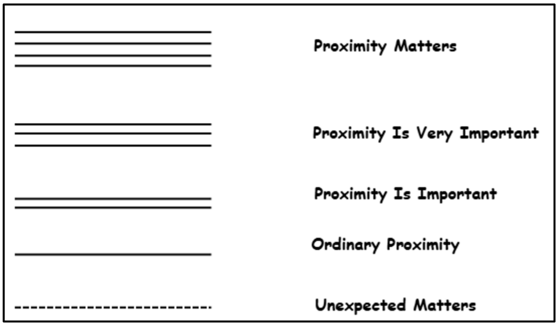


Fig. 1. Code Degree of Proximity between Facilities.

3.4 Simulation

Simulation is defined as a method of replicating the behavior of a system, frequently utilizing computer software [10]. This method has proven effective in the management of complex systems, particularly those characterized by variability and interdependence. Variability is indicative of changes in simulation results due to differences in input parameters, while interdependence is indicative of the interrelationship between components or variables in the system that affect each other.

3.5 Queuing Theory

Queuing is a prevalent situation in which one or more customers await service [9], typically resulting from demand that surpasses service capacity and variations in arrival and service times. Heizer et al. (2014) [7] posit that queuing theory is a mathematical study of waiting lines employed in operations management to analyze and manage customer flow. The objective of this management is to reduce waiting times and improve service efficiency. There are three components of queuing system characteristics, namely the first arrival characteristics are the nature and pattern of arrival of entities (customers, orders, or data) into the queuing system, the second is queuing characteristics are a set of rules that determine how customers or objects in the queue get service, and the third is service characteristics which have important aspects including service system design and service time distribution.

There are four basic queuing structure models, namely the first single channel single phase describes a queuing system with one entry line and one service station, where customers leave the system immediately after receiving service, the second is single channel multi-phase has one entry line but involves two or more service stages that must be passed sequentially before customers leave the system, the third is multi-channel single phase consists of several parallel service channels serving a single queue, where each customer only undergoes one service stage, and the fourth is multi-channel multi-phase involves more than one service facility at each stage, allowing simultaneous service to several customers and usually requires advanced analysis methods due to its complexity. As illustrated in Fig. 2, these four queuing structures differ in the number of service channels and phases, providing visual clarification of how customer flow and service interactions vary across different queuing system configurations.

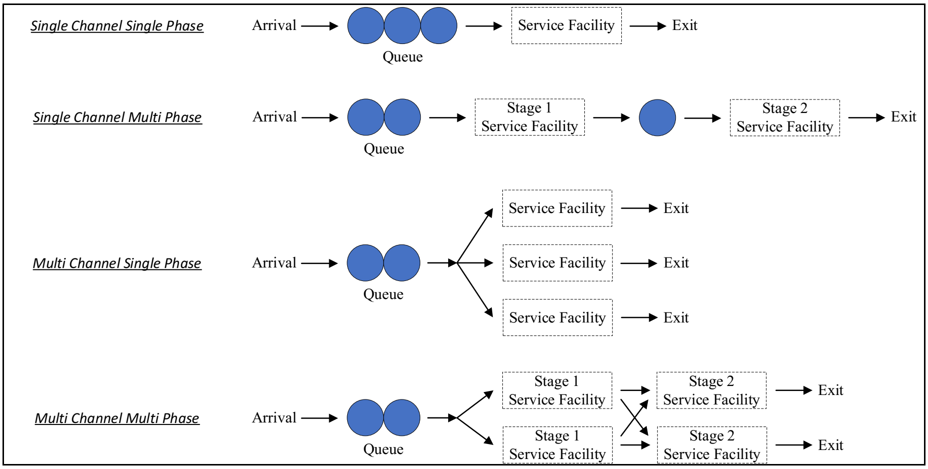


Fig. 2. Basic Queue Structure.

4 Methodology

The objective of this study is to implement the Systematic Layout Planning (SLP) method in the redesign of the layout of the staging area at Marunda Port. Furthermore, a comprehensive evaluation of the efficacy of ship loading and unloading services was conducted, encompassing a pre- and post-application of SLP analysis. The results of the analysis form the foundation for the development of improvement recommendations, with a focus on enhancing loading and unloading service efficiency, reducing ship waiting times, and minimizing material transfer distances. The present research was conducted through six primary stages, which are outlined below:

4.1 Data Collection

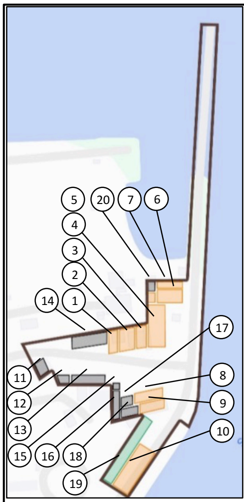
The data collection process in this study employed a mixed-method approach, combining both primary and secondary data to obtain a comprehensive understanding of the actual field conditions and the functional requirements for the redesign of the staging area layout.

Primary data were obtained through in-depth interviews with five key stakeholders who hold strategic roles in port operations. The interviewees included Port Operations Supervisor, Cargo Handling Coordinator, Cargo Handling Senior Staff, Marine Operations Staff, and Port Services Supervisor. The interviews were conducted using a semi-structured format, allowing for flexibility in exploring critical insights related to process flows, operational bottlenecks, and technical preferences for an efficient layout design. This approach enabled the identification of specific needs grounded in the practical experiences of frontline personnel.

To complement the primary data, secondary data were utilized, consisting of initial layout data, data on heavy equipment utilized, ship data, ship activity logs, loading and unloading records over a three-month period. These data were compiled from official port operational documents and internal company information systems.

The compiled data served as the basis for quantitative analysis through simulation modelling, enabling the assessment of system performance under different layout scenarios.

To ensure the accuracy and consistency of the information used, data triangulation was conducted by cross-referencing findings from stakeholder interviews, on-site observations, and secondary documentation. Observations were carried out in multiple sessions at different times to capture consistent actual conditions and to minimize potential bias. This validation technique strengthens the reliability of the findings and ensures that the proposed layout design is not only data-driven but also reflects real operational conditions. As shown in Fig. 3, the initial layout of Marunda Port illustrates the existing spatial configuration and facility arrangement observed during the study. Fig. 4 and Fig. 5 further depict the initial cargo handling processes, specifically the loading and unloading operations, respectively. These visual representations provide essential contextual understanding of the current operational flow, which serves as the foundation for identifying inefficiencies and proposing layout improvements.



No.	Owner	Description
1	XYZ	Maintenance Shelter
2	XYZ	CCU Yard
3	XYZ	Outgoing Yard
4	XYZ	Backload Yard
5	XYZ	Cutting Pod Area
6	XYZ	Chemical Yard
7	XYZ	Silo Tank Area
8	XYZ	Car Parking Area
9	XYZ	Office
10	XYZ	Stacking Yard
11	ABC	Organic Waste Storage
12	ABC	Unorganic Waste Storage
13	ABC	Parking Area
14	ABC	Truck Parking Area
15	ABC	Mushola
16	ABC	Canteen
17	ABC	Car Parking Area
18	ABC	Office
19	ABC	Green Area
20	ABC	Electrical Building

Fig. 3. Initial Layout of Marunda Port

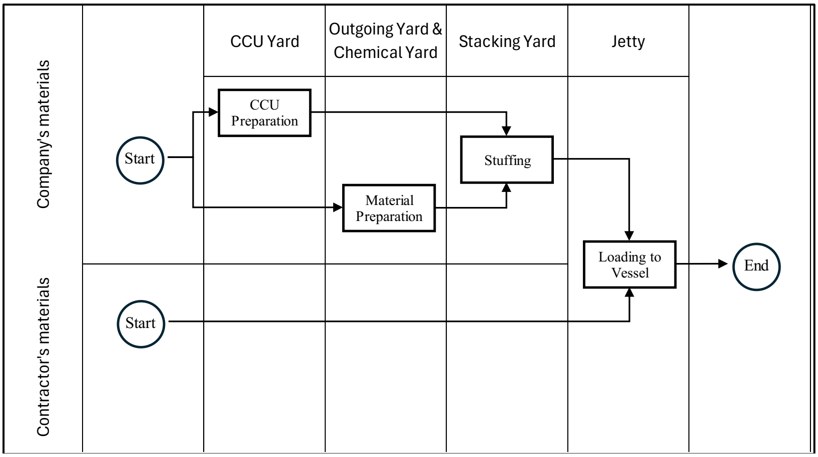


Fig. 4. Initial Process of Cargo Loading

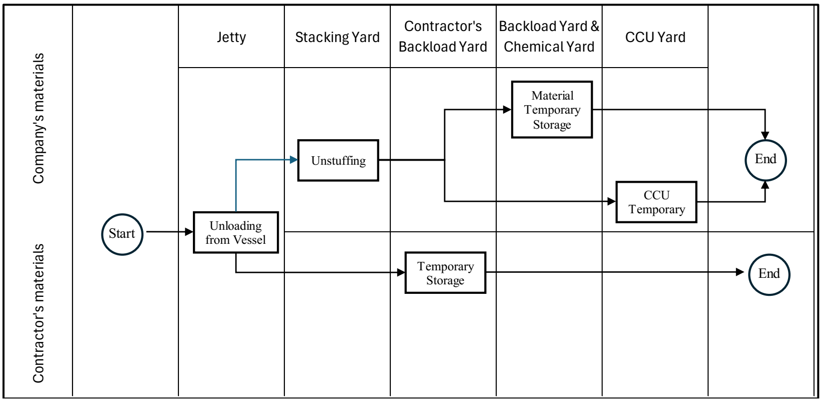


Fig. 5. Initial Process of Cargo Unloading

4.2 Drafting a New Layout Using SLP

Next, the Activity Relationship Chart (ARC) is prepared, which shows the level of closeness between areas in Marunda Port. To ensure the validity and reliability of the assigned relationship values, a consensus-based validation method was implemented through an expert panel discussion. The panel involving personels with in-depth knowledge of port operations including port operation supervisors and cargo handling personels with extensive field experience. Through focused group discussions (FGDs), each proposed relationship value—especially those rated as critical (A and E)—was reviewed, debated, and jointly validated. Consensus is reached by considering the following criteria:

1. Frequency of interaction between activities
2. Requirements for material or vehicle flow

3. Safety and security risks
4. Physical constraints and operational regulations

This consensus-based approach aimed to mitigate individual subjectivity, align the scoring with actual field conditions, and enhance the credibility of the resulting layout configuration.

By combining a systematic methodology, technical and practical considerations, and expert validation, the ARC results serve as a robust foundation for developing the proposed layout and modelling its performance through Discrete Event Simulation (DES).

Once the ARC assessment is complete, the data is translated into an Activity Relationship Diagram (ARD), which spatially visualizes the relationships between activities using connecting lines that reflect the level of closeness based on ARC scores. The results of the design process yielded key metrics, including the distance between processes and the travel time using a forklift. These metrics were then meticulously calculated and presented in the form of a distance and timetable within the new layout.

4.3 Simulation of Old Layout and New Layout Using DES

The subsequent stage involves the implementation of a Discrete Event Simulation (DES) to assess the capacity of the current layout and the proposed layout to produce a given number of products. The data utilized in both conditions remains constant; however, the discrepancy arises in the material movement time between processes. It is anticipated that the new layout will result in a reduction of this time due to the reduction in distances involved. In this study, a simulation was conducted to compare the performance between the existing staging area layout and the redesigned layout developed using the Systematic Layout Planning (SLP) method. The simulation employed a Discrete Event Simulation (DES) approach to realistically represent the dynamics of the ship loading and unloading processes.

1. Simulation Software:

   The DES-based simulation was carried out using FlexSim software. FlexSim was selected due to its capability to model logistics processes and loading/unloading activities in detail, as well as its strong 3D visualization features, which are beneficial for layout analysis.

2. Simulation Duration and Replications:

   The simulation was run for a duration of 30 operational working days, assuming port operations run 24 hours per day. To obtain statistically stable results and reduce random variability, 10 replications of the simulation were performed.

3. Input Distributions:

   The input distributions—such as ship arrival times and material handling durations—were derived from actual operational data collected from the port.

4.4 Modelling Assumptions and Limitations

In the simulation modeling process conducted in this study, several key limitations and assumptions were identified as follows:

1. Equipment Availability and Breakdown
   The model does not incorporate dynamic variables related to equipment failure or breakdowns (e.g., crane, forklift, or truck downtime). It is assumed that all equipment used in the loading and unloading process operates under optimal conditions and is fully available throughout the operational hours.
2. Forklift Routes and Congestion
   The simulation does not explicitly model the specific movement routes of forklifts or potential congestion that may occur due to vehicle interactions within the staging area. It is assumed that forklifts and other supporting vehicles can move freely without significant delays or queues, and that no route conflicts occur between vehicles.
3. Human Operator Variability
   The simulation model does not account for variability in human operator performance. It is assumed that all operators perform tasks at a uniform speed and efficiency, in accordance with standard time values. Factors such as fatigue, differences in operator experience, and human error are excluded from the model.
4. Weather and Environmental Conditions
   External environmental factors, such as weather conditions (e.g., rain, strong winds, or flooding), which may affect productivity and operational safety, are not modeled. The entire simulation is conducted under the assumption of normal and stable environmental conditions.
5. Fixed and Non-Flexible Operating Hours
   The model assumes fixed operating hours, without considering overtime or dynamic shift changes. This simplification is intended to allow the model to focus on spatial utilization and material flow within the staging area rather than workforce scheduling aspects.
6. Homogeneity of Cargo Types and Sizes
   The model assumes that cargo types, sizes, and handling methods are relatively homogeneous. This allows for consistency in time calculations and space utilization across different simulation cycles.

The arrival rate is measured based on the arrival of ships at the port and the arrival of cargo units at the staging area. The arrival pattern does not follow a fixed or perfectly scheduled pattern but rather occurs randomly and independently over time. This variability is influenced by ship schedules and traffic conditions—both maritime traffic and land-based cargo transport. Furthermore, the arrival of one ship or one cargo unit does not affect the arrival of others, indicating independence between arrival events.

The service time for loading and unloading operations, whether using cranes or forklifts, is obtained from actual process observations or time study data. It is assumed that the number of forklifts, cranes, and port workers remains constant throughout the simulation and is modelled as finite resources. Disturbance factors such as equipment breakdowns or maintenance activities are not included in the model.

Sensitivity analysis, which aims to evaluate how simulation results respond to changes in key parameters such as arrival rate, service time, and resource availability, will be conducted in subsequent research.

4.5 Calculation of Total Moving Distance, Total Moving Time, and Total Number of Ships Served

The following calculations were made: the total material transfer distance, the total material transfer time, and the number of ships that can be served in one year based on normal working hours. They are internally tracked and calculated within the simulation model constructed using FlexSim simulation software. The objective of this calculation is to assess the efficiency of the new layout, particularly regarding the efficiency of product movement, the distance and time involved, and the enhancement of ship service capacity. Specific numerical results will be conducted in the future studies.

4.6 Analysis, Discussion, and Conclusion

In the final stage of the research, a comparative analysis was conducted between the existing and alternative layouts. The analysis focused on the distance and time of material movement, as well as the number of ships that can be served. In addition, the discussion and conclusions presented herein aim to evaluate the significant impact of the application of Systematic Layout Planning (SLP) and Discrete Event Simulation in improving the efficiency of goods movement and ship service capacity. Although the numerical outcomes will be explored in future studies, the redesigned layout based on the Systematic Layout Planning (SLP) approach is anticipated to have a significant positive impact on the operational efficiency of the staging area. A reduction in loading and unloading time would indicate that improvements in material flow and shorter travel distances directly contribute to increased port throughput. Similarly, a decrease in vessel queuing time would reflect an overall enhancement in system capacity, which implies potential cost reductions and improved satisfaction among port service users. Furthermore, the increased utilization of the staging area suggests a more optimal and effective use of space, consistent with the principle of space efficiency in layout planning.

Several future research directions may be considered to further enhance and expand the scope of this study, such as: Cost-Benefit Analysis of Implementing the New Layout, Integration of Dynamic Scheduling and Real-Time Dispatching, or 3. Comparison with Alternative Layout Methods: CORELAP, CRAFT, and Heuristic Algorithms.

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