JJMIE

Volume 18, Number 1, March. 2024
ISSN 1995-6665
Pages 59- 73
https://doi.org/10.59038/jjmie/180105
Editor-in-Chief: Prof. Ali M. Jawarneh

Jordan Journal of Mechanical and Industrial Engineering

Container Terminal Performance: System Dynamic Approach with Port Capacity Constraints and ESG Integration

Fajar Kurniawan[a,e], Siti Nurmaya Musa[b*], Bambang Nurfauzi[c], RendiyatnaFerdian[d], Fauzi Khair[e]

[a]*PhD student, Department of Mechanical Engineering, Faculty of Engineering, Universiti Malaya, Kuala Lumpur, Malaysia.*
[b]*Senior Lecturer, Department of Mechanical Engineering, Faculty of Engineering, Universiti Malaya, Kuala Lumpur, Malaysia.*
[c]*Senior Lecturer, Department of Electrical Engineering, Faculty of Engineering, Universitas Muhammadiyah Tangerang, Tangerang, Banten, Indonesia.*
[d]*Lecturer, Department of Industrial Engineering, Faculty of Engineering, Widyatama University, Bandung, West Java, Indonesia.*
[e]*Lecturer, Department of Industrial Engineering, Faculty of Engineering, Bina Nusantara University, Jakarta, Indonesia.*

Received 8 Aug 2023 *Accepted 23 Jan 2024*

Abstract

Each container terminal has attempted to improve its performance through effective strategic and tactical management. Therefore, performance measurement is needed due to the long waiting time of the service process within container terminal operations. We have utilized the system dynamics methodology to assess container terminal performance. Container port enterprises have been influenced by governance, environmental and social components, therefore, the management of those components has significant impacts on the service port's performance. Therefore, the objective of the research is to model the dynamic performance of the container terminal with consideration of environmental, social, and governance components. Furthermore, this dynamic model has presented practical value for increasing the performance of the container terminal operation under capacity constraints. The case study focused on the Indonesia Port Corporation of Jakarta, Indonesia. As a result, the research has identified the influence of container terminal decision variables, such as emissions, employee satisfaction, and good corporate governance, on container terminals, implying their significance in reducing berthing time as the main indicator of container terminal performance. The novelty of this research is to provide a system dynamic model which combines tactical and strategic levels for container terminal operation.

Keywords: container terminal; system dynamics; berthing time; performance; emission; social; governance.

1. Introduction

Due to the growth of international trade, there is an amplification of export-import activities, which gives significant prominence to maritime logistics. Container terminals as a logistic chain, especially in developing countries, are dealing with difficulty complying with global trade requirements. Sea freight**,** whether in containers or bulk, is generally a slow but cheap option for the transportation of mainly low-value, high-volume goods [1]. In the last 30 years, the revolutionary development of container handling has increased the efficiency of worldwide trade (by about 9.5% per year) and will continue to do so at an 8% growth rate in the coming years [2]. Port terminals are an essential facility for seaborne trade and worldwide exchange because more than 80 percent of international trade by volume is carried out through the sea [3]. Considering these facts, port is one of the primary factors influencing the logistical performance of the country.

Ports with limited equipment and capacity must deal with the build-up of container stacks in the stacking yard, which influences the fluidity of container flow. Furthermore, capacity limitations determined all operation and cost parameters [4]. The main problems of ports especially in developing countries are the absence of international hub ports, low capacity, and poor port performance services[5]. Those problems can be solved by optimizing utilization facilities through process improvement. Ports and terminals can improve their services through work optimization [6]. Process improvement has been intensively studied in the literature of operations management and industrial organization, including process improvement decisions in supply chains [7]. Process improvement enables implementation at several stages of container movement operations.

Current growth in container traffic has created strong competition among container terminals [8]. Each port terminal is trying to give excellent service to satisfy the customer and survive the global market competition. In this circumstance, port governance is important in

* Corresponding author e-mail: nurmaya@um.edu.my.

constructing excellent services by reducing berthing time and the quantity of imported stacked containers. The Environmental Social Governance (ESG) study has developed into one of the most interesting areas in the port paradigm, focusing on environmental goals, social value, and the quality of port governance. The ESG concept can be defined as a method of evaluating a company's sustainability attributes through ESG performance indicators[9]. Enterprises in the maritime sector have been persuaded by ESG changes driven by financiers, insurers, regulators, and customers[10]**.** Every intention of ESG components is to perform a fundamental function in completing container terminal excellent service requirements. Moreover, most of the important benefit processes have taken place at the strategic and tactical levels. Hence, operational management and port policies have a substantially influence ESG implementation for increasing port performance. So, container terminal operation systems are continuously measured to reduce berthing time by considering ESG factors.

Container terminals in developing countries are confronting the complexity to give excellent services to customers due to the constraints of capacity, longer berthing times, and the accumulation of containers in stacking yards. Furthermore, developing countries in general must meet the energy challenges to achieve the requirements of the government strategy for comprehensive and sustainable social and economic development[11]. Those goals are in line with the ESG concept implementation, especially for container terminals in developing countries.

The berthing process is one of the main performance metrics because if terminals maintain a rapid berthing process, they can fulfill customer demand immediately. Likewise, a faster container relocation process flow intends to reduce the service time. Hence, the container terminal management strategy performs a major task to satisfy customer requirements in the container terminal system. Therefore, port operators are continuously making strategy adjustments based on the dynamic behavior of information related to the positioning of containers in vessels and stacking yards. In this circumstance, there is a requirement to elaborate on the behavior of yield measures like capacity arrangement, information sharing, maintenance, berthing time, and the quantity of stacked containers. Furthermore, top management is pivotal in improving collaboration involving information sharing for better sustainability performance[12]. A lot of researchers have done a lot of work on the optimization of container terminal capacity. However, few researchers have revealed the affiliation between strategy and tactical operational components. Hence, this article research aims to model the dynamic performance of the container terminal operation system under the constraint of port limited capacity with consideration of ESG components. Furthermore, the connections among the operational and strategic variables have been exposed in this article. Furthermore, the connections between the operational and strategic variables have been exposed in this research article for making significant contributions to container terminal management so that they can improve their performance through efforts to accelerate service processes by utilizing limited capacity and paying attention to ESG components.

2. Literature Review

Sea transportation has always been the most important mode of transportation in world trade[13].Approximately 70.1% of goods shipped by sea transportation have a value of $70 [14]. Data showed that more than 80 percent of freight is carried out using sea transport, and of these, 80 percent is done using a container [15]. Container terminals are a type of facility that is widely used in ports for export-import activities involving specific object box containers. Port operation is an essential element in a supply chain distribution system. The speed of service time is an indicator for assessing the performance of the port. Berthing time is the key variable of the container terminal operation.

The focus of the researcher is gradually increasing on the issues that are discussed about ESG. Emissions are an indicator used in discussing environmental issues [16].Employee services are part of the representation of port service quality, which will influence overall customer satisfaction[17]. The services provided are greatly influenced by employee satisfaction, which is a social issue in the ESG component. Prosperous application of the strategy to improve port performance has emphasized the significance of effective ESG. Ports are important catalysts for social change and governance reform in sustainable transport contexts[18].Overall variables involving ESD for sustainability are the key strategic variables.

Supply chain management has moved to the integration of supply chains system with sustainability growth[19]. Many container terminals have problems recognizing environmental, social, and governance dynamics. A substantial quantity of research articles connected to the ESG have been gathered since the concept of port sustainability began to be studied. For example, Almaz, Altiok [20]have implemented a simulation modeling approach to model the performance of the port. Romeike [21]has applied simulation methods for ESG risk. Wiegmans and Janic [22]have implemented a modelling approach for assessing the infrastructural capability of freight transport and operational performance. They deliberated on the modelling methods based on the concepts of measuring performance at the strategic level.

System dynamics are able to trace the behavior of systems in container terminal operation and simulate the potential applications of process improvement. Furthermore, System dynamics could explore systems on a range of different scales [23]. According to [24], authors Cheng et.al., (2010) built a System Dynamics (SD) model to understand the mechanism of container terminal operation, considering the sub-system of the berthing process that influences port performance. Meanwhile, authors Hou and Geerlings (2016) have applied the SD simulation to model the environment of port governance[25]. Similarly, Middleton, Bernholdt [26]practiced the SD approach to modelling the ESG for the metric performance of the enterprise. In accordance with [27], authors Mei and Xin developed a SDmodel to study port operation systems based on time quality, which involved berthing time as an influencing variable of the system. Ports are important catalysts for social change and governance reform in sustainable transport contexts[18]. In connection with ESG components, Li, Li [28]used SD simulation to analyze green cooperative development as an environmental factor in the growth of port activity. Van den Houten [29]also used the SD model to investigate port construction labor as a social component for improving port capacity. Meanwhile, Xu, Li [30]developed an SD model to determine governance policies through a conceptual framework and simulation of congestion control. Another researcher studied port governance performance assessment of the berthing process through policy intervention, which contributes to the improvement of service levels within port terminals[31].

ESG performance goals play a substantial function in the success of ESG for this purpose. Nõmmela and Kõrbe Kaare [10]developed an ESD framework to design the maritime policy framework and evaluate the components of ESG goals. Saif-Alyousfi, Saha [32]have utilized this method to analyze the dynamic behavior of ESG to embrace sustainable finance within enterprises. The ESG concept recommends companies develop and implement management methods and tools that allow them to measure ESG performance goals[33].Additionally, they have examined the ESG managerial level using the measuring tools to achieve the expected result in port performance to increase service quality. Most of the literature examines port performance, which reflects ESG factors at the strategic level.

Despite the significant advancements in system dynamics methodology, a discernible research gap requires further exploration. One notable gap lies in the limited attention given to the application of the SD model at the tactical level of management. Furthermore, it is observed that there is a nascent focus on port ESG, which combines strategic and tactical levels through the SD simulation model. The novelty of this research is to provide a model that integrates the strategic and tactical operation of container ports through system dynamics, which contributes to increasing container terminal performance.

3. System Dynamics Modeling

System Dynamics (SD) is an influential approach for scrutinizing the complexity of the system through the evaluation of system behavior and information feedback. The objective of SD is to recognize the formation of causes that carry out the system's behavior and to increase a valuable understanding of dynamic complexity [34]. In system dynamics, description leads to equations of a model, simulation to understand dynamic behavior, evaluation of alternative policies, education and choice of a better policy, and implementation [35].

In the research, system dynamics also explored port terminals. It was used to develop the port economy model from the perspective of the sustainable development of dynamic mechanisms[36]. The dynamic model shows connectivity between port variables consisting of equipment capacity, stacking, berthing time, idle time, accurate information, discharge, and loading activity. It is also able to solve the problem by updating parameter variables, which provide feedback to the indicator variable that represents the success of a system. The arrangement of variables, flow direction, and interaction among elements in the system can be illustrated in a chart known as a causal loop diagram, which is the initial stage of model development in system dynamics. Based on the causal loop diagram, the model development continued to the next stage, known as the stock flow diagram. This stage is utilized to examine the data and equations designed based on the current state of system activity through computer simulation. Recently, the system dynamics method has been implemented in many disciplines. It includes research in the agriculture system [37], Manufacture performance [38], supply chain management [39], agriculture modelling [40, 41], container marine model [42], banking [43, 44], port sustainability [45], health governance [46], environmental system [47], social development [48], software development [49], politics [50], public management [51], sustainable transportation [52, 53], economic [54], defense system [55], risk management [56], production management [57], environmental social governance (ESG) [58] and Covid context [59, 60].

4. Methodology

This research used System Dynamics methodology for developing container terminal operation model. A system dynamics model was utilized to assess the dynamic behavior of various variables involved in the container terminal operation with consideration of ESG components. This model captured the variables of vessels, container movement, equipment capacity, and time of service, considering environment, social, and governance factors. The relationship among the various variables was determined by making the causal loop diagram (CLD), and continuing to the stock Flow Diagram (SFD) using system dynamics software [61].

Simulation model development is shown in Figure 1. The first few stages involve process mapping and variable identification. This process will elaborate on the existing condition of the port operation and identify the influencing variables to the port performance. The Research is conducted in Indonesia Port Corporation (IPC) Container Terminal Jakarta, Indonesia. The next step is designing a causal loop diagram, through understanding the relationship between factors for minimizing berthing time. This step involved overall variables of import, export, vessel movement, environment, social, governance, idle time, information, and maintenance. Then the research steps continue with interpreting the causal loop diagram into a stock flow diagram. The causal loop diagram and stock flow diagram was processed using simulation software of Anylogic 8.8.0. The stage continues to the simulation process through running the model. System dynamics can solve complex problems faced by container terminals. Basically, the design of container terminal operations is complex because manifold factors shake the operational performance [62]. The last stage is the sensitivity test, which will assess the quantity of error when the simulation is running. The last stage is the validity test using the Welch t-test method.

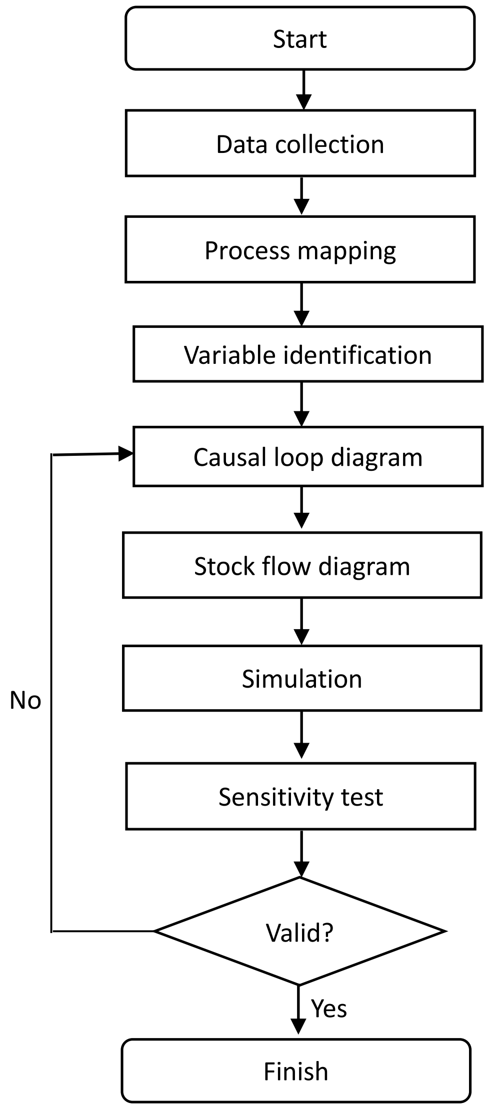

Figure 1. Flow chart of system dynamics model development

4.1. Problem Description

Port ESG is an integration of diverse activities within the system. So, the decision to do one activity influences another's performance. ESG decisions are especially having a greater impact on container terminal performance. In container terminals, excellent service, which represents the performance of berthing time, plays an important function in the accomplishment of the ESG target, and because of having a faster berthing time, this leads to higher customer satisfaction[63]. Equipment capacity plays a vital role in the berthing time management of container terminals[64]. Capacity constraints on containers consist of the presence of outdated facilities, a limited stacking yard area, and the absence of a platform that supports more effective information sharing between stakeholders. Another component of port performance influence is the environmental issue. Most countries worry about the recent increase in air pollution from emissions, which causes environmental degradation [65].Developing countries concentrate their effort to minimize pollutants that come from the internal emissions of combustion engines[66].Thus, the authors had simulated the impact of environmental, social, and governance metrics on the performance of the container terminal, and these impacts had been analyzed under different simulation scenarios of ESG variables.

4.2. Data Collection

Data utilized for developing the simulation model were primary and secondary data. Primary data were collected through interviews or verbal surveys. The questions for interview design included open-ended survey questions. Implementing face-to-face interviews was preferable in this research. This study utilized qualitative method through semi structured in-depth interview. Meanwhile, secondary data collection was carried out with survey activities for obtaining data records from container terminal operation platform namely OPUS terminal. Data recognized as secondary included spreadsheet data records of container terminal activities, annual company report, periodically report, press release, container terminal layouts, container flow and system introduction report. Those data were used to develop system dynamics simulation model for observing leverage and interaction among sub-systems. These activities were conducted to obtain facts and empowering a significant level of secondary data and rational reason for all phenomena in the system. This step took six months, as it required thorough consideration of the research goals.

4.3. Data Initialization

The simulation was built based on the data obtained from the IPC container terminal's daily data records. The data was recorded in software called ITOS and OPUS. The results were converted to Microsoft Excel. The data obtained records container terminal activities from 2018 to 2022. Those daily recorded data were extracted into average weekly and monthly data for each variable. Finally, data was obtained, which was the average result of the entire daily container terminal operation activities for five years. A summary of the recorded data can be seen in Table 1.

Table 1. Container terminal data record

No	Variables	Min	Max	Average	Daily Units
1	Discharge Rate (DR)	126	923	347	Units
2	Gate Out Rate (GOR)	180	834	377	Units
3	Gate In Rate (GIR)	249	853	552	Units
4	Loading Rate (LR)	143	744	449	Units
5	Gross Crane Rate (GCR)	346	559	408	Units
6	Working Time (WT)	12	24	20	Hours
7	Idle Time (IT)	1	15	2	Hours
8	Berth Time (BT)	13	39	22	Hours

The data in Table 1 was based on the average value of each variable that was important in determining the continuity of operation of a container terminal. Based on those data, a simulation was built. The average discharge rate value was 10 points less than the Gate Out Rate (GOR) value. The berthing time value showed the berthing time was 22 hours. Meanwhile, in export activities, the average Gate in Rate (GIR) value was greater than Loading Rate (LR) by 3 points.

Model development was based on a set of data obtained from container movement records at the IPC Container Terminal for Ocean Going from 2018 to 2022. Experiments were carried out by observing container movements for 1,487 vessels and 1,060,372 containers. Every year, container terminals serviced an average of 294 vessels and 213,710 units of containers. The terminal's container capacity was 7 vessels per week and was able to relocate 30 containers per hour. The container terminal had two dock facilities and 85 handling equipment.

4.4. Assumptions

The authors had deliberated on the following assumptions to develop the model:

- The cost of port operation is not considered
- Discharge rate and gate rate are counted as inflow containers
- Gate out rate and loading rate are counted as outflow container
- Berthing time is considered the main indicator of port performance
- Emissions volume is considered the metric for environment metrics within the ESG framework
- Employee satisfaction is reflected as the social metric within the ESG concept
- A good corporate governance index is measured as the metric of governance aspects of ESG
- The identification of variables in SD was made according to the data recording of the import-export container movement from each position within the container terminal through Opus terminal software.

4.5. Variables of the Model

The dynamic model is a group of variables that influence each other over a certain period. The SD model consists of stock and flow variables. The stock variable is depicted as a rectangle, which illustrates the stock as a variable that enters the system flow and exits the flow, which is used to represent the accumulation of the system (i.e., import arrival, import stack container, import departed container). Flow variables are represented as an arrow with the lever representing the flow of a system between stocks and the amounts of variation in stocks (i.e., discharge rate, gate in rate, loading rate). Table 2 shows the initial circumstances of variables within the model.

Table 2. Model variables

Variable	Initial values	Units
Discharge rate	347	Boxes/day
Loading rate	449	Boxes/day
Gross crane rate	450	Boxes/day
Emission (environment)	1,8	Tons/day
Employee satisfaction index (social)	0,0115	Daily index
Governance score	0,264	Daily score

4.6. Causal Loop Diagram

The causal relationship between variables within the container terminal operation system and the feedback loop’s structure is visually represented in Causal Loop Diagram (CLD). It was necessary to highlight the relationship among the various variables within the dynamics system [61]. The process involves several steps. First, the system boundaries within port must be defined to concentrate on involved variables. Next, the important variables that are significantly influenced by other system elements must be identified. Third, cause-and-effect relationships between selected variables must be established to comprehend how changes in one affect other variables.

The next step which includes feedback loops, whether reinforcing (positive) or balancing (negative), must be identified by examining interconnected causal relationships. Regarding physics comparison, negative and positive feedback loops are equivalent to stable and unstable equilibrium, respectively [38]. In this model, berthing time, idle time, and working time are dynamic variables and are represented by circles. The relationship between two variables can be classified into positive and negative relations. The symbol appears at the end of the link arrows. Stock (level) is a state variable of the system used to represent accumulation, which is denoted by a rectangle. Positive means the enlargement of a target variable impacted by the increased value of initial variables. Meanwhile, negative indicates the decrease of a destination variable influenced by the value reduction of the previous variable. The CLD of the container terminal operation system is presented in Figure 2. Finally, choose variables based on their relevance, influence, and significance as drivers within defined system boundaries.

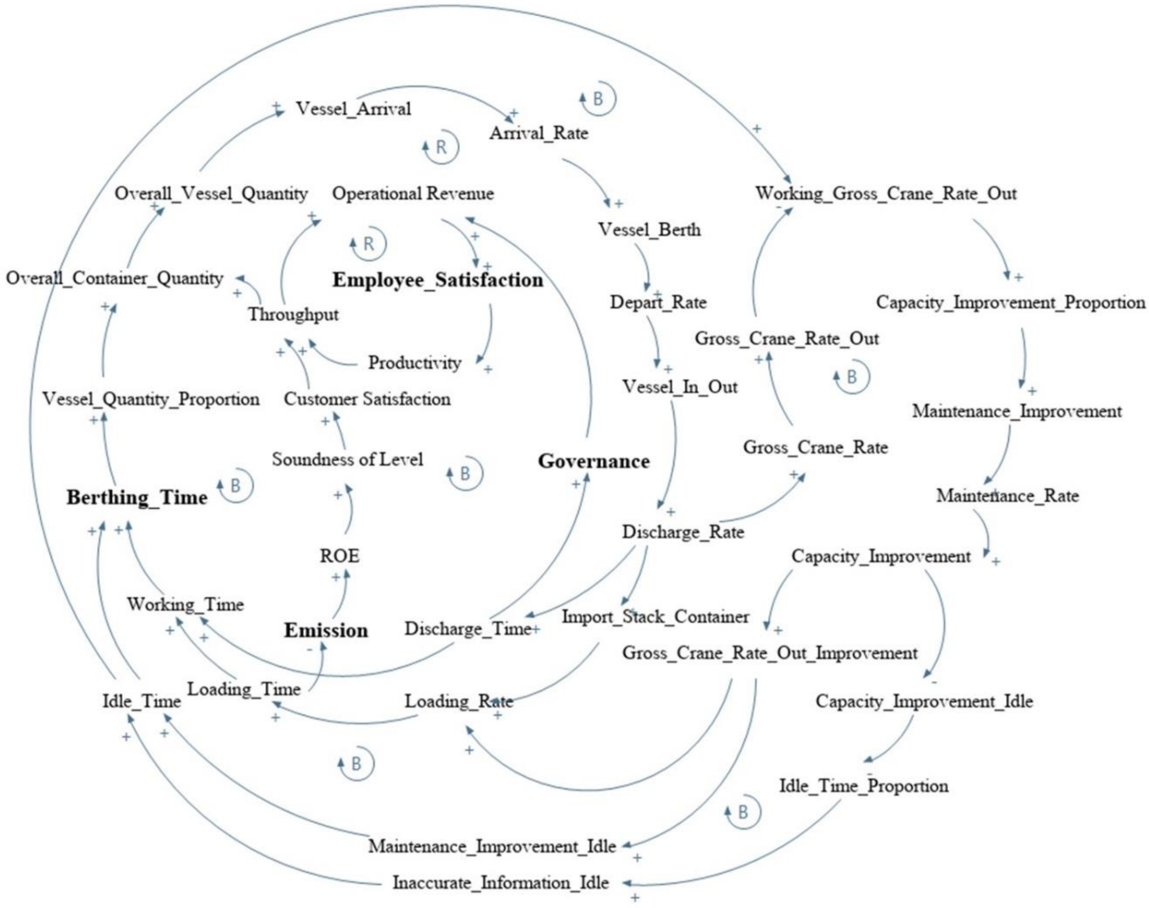

Figure 2. Causal Loop Diagram

4.7. Model Development

4.7.1. Stock Flow Diagram

Model development of container terminal considering ESD components continues to the construction of a Stock Flow Diagram (SFD) which describes the relationship among variables represented by a certain symbol. A Stock-Flow Diagram (SFD) is a visual representation of the accumulation and flow of stocks, flow, dynamic, and parameter variables. Berthing time, emission, and governance are the dynamic variables that always change at a certain time and are described as a circle. The variables are chosen according to how important they are in expressing the fundamental dynamics of the system. Meanwhile, the parameter indicates a fixed fraction, which limits the dynamic variables (i.e., export rate, import rate). Parameters are determined by the result of container terminal activities recorded by the ITOS system in container terminal, which is supported by expert judgment through interviews conducted. These parameters can develop depending on the desired research scope, considering that the data obtained varies greatly. The simulation experiment was set up in Anylogic software, and the output was downloaded in Microsoft Excel 2016. Origin's software was used for plotting the graphs[61].

Flow variables shown in SFD are the rate of change in stocks that are organized by a decision-maker. These variables are important components that impact the behavior of the system, and it is imperative to include them to fully comprehend how stocks grow or decrease in the system that is being represented.

The ESG component is divided into three large groups of variables that influence each other. The environment is represented by emission variables, Return on Equity (ROE), soundness of the level, customer satisfaction and throughput. These components relate to the loading time by quay crane, revenue, and the variable of container movement vessel. Effective scheduling of quay cranes can increase throughput and lead to higher revenues for container terminals [67].

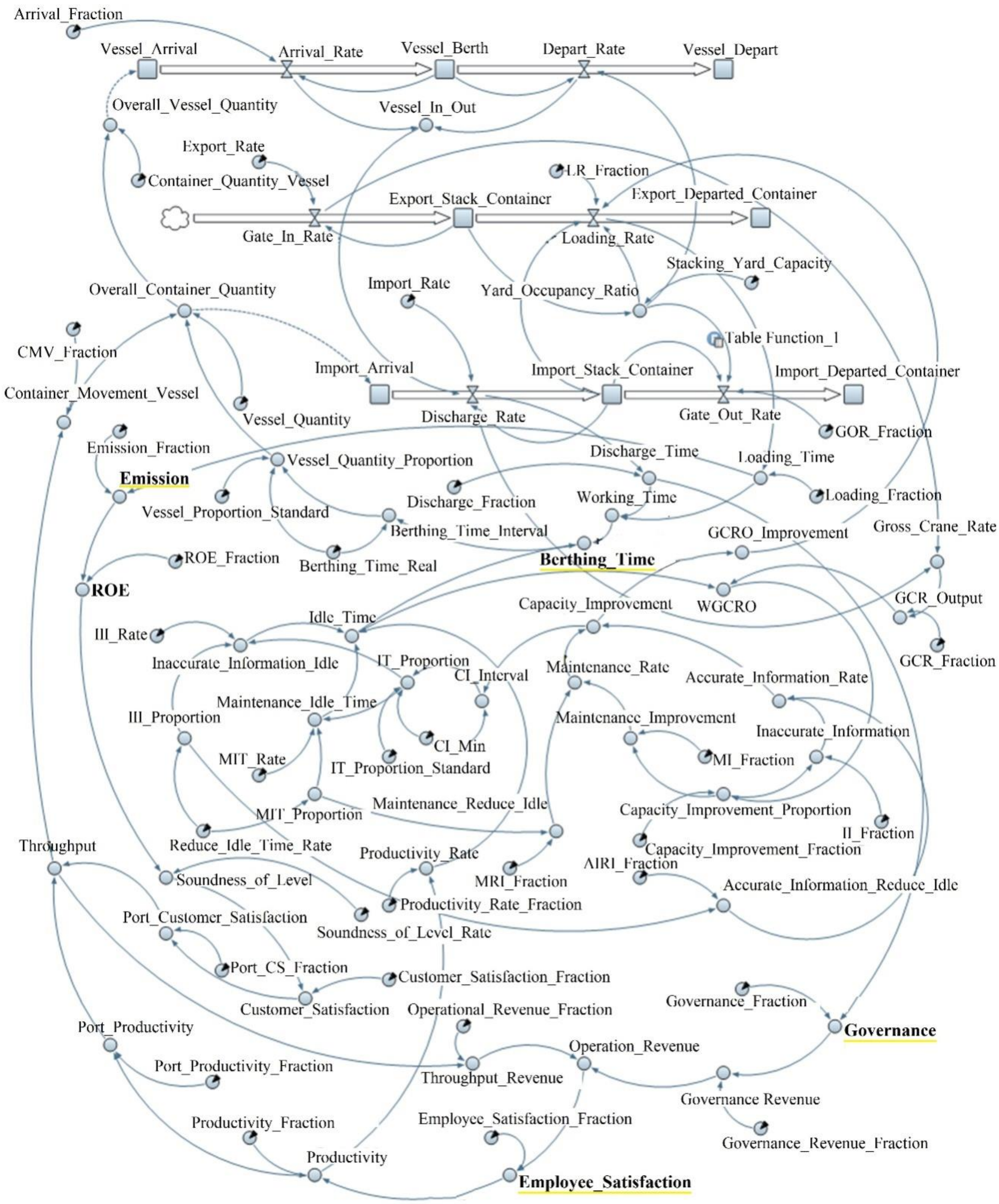

Figure 3. Stock flow diagram

The second group presents social components, where the variables involved are employee satisfaction, operational revenue, throughput revenue, and throughput. Those variables are continuation of environment group, and lead to the quantity of container movement vessel variable. Finally, the last group represents governance, which involved governance and governance revenue. This group is associated with discharge time and environment components. SFD of the dynamic model is represented in Figure 3.

4.7.2. Capacity Improvement Variables

The ability of cranes to relocate containers within container terminals every hour represents in Gross Crane Rate (GCR). Effective crane movement can reduce the container operation slowdown [68]. This variable is the summation of Gate in Rate (GIR) and Discharge Rate (DR). and DR each hour. The relationship between variables especially involved Gross Crane Rate (GCR) in the container terminal operation system is described in the following equation.

$$GCR = \frac{GIR + DR}{24} \quad (1)$$

$$GCRO = GCR \,.\, GCRF \quad (2)$$

$$WGCRO = GCRO - (GCRO \,.\, IT) \quad (3)$$

$$IT = \frac{WGCRO}{CIP} \quad (4)$$

Gross Crane Rate Out (*GCRO*) is a dynamic variable that represents the capacity of crane equipment for relocating containers out of port every hour. *GCRO* is related to the fraction of *GCR* (*GCRF*) and idle Time (IT), which are given in the eq. 2 and eq. 3. Container terminals, which were able to improve *GCR*, impacted the Capacity Improvement Proportion (*CIP*) of the port. Working Gross Crane Rate Out (*WGCRO*) is the continuity of the *GCR* formula that represents the working capacity of the crane. The division between *WGCRO* and *CIP* will result in IT. Idle time variable will be used in the calculation of Berthing Time (*BT*).

4.7.3. Berthing Time and ESG Components

The basic formula to determine Berthing Time (*BT*) in this model development is the sum of Discharge Rate (*DR*), Loading Rate (*LR*) and Idle Time (*IT*) which is represented in the following equation.

$$BT = 0.0288\, DR + 0.0264\, LR + 24\, IT \quad (5)$$

$$CI = MR + AIR \quad (6)$$

$$AIR = 0.28\, CIP + AIRI \quad (7)$$

$$MR = 0.713\, CIP + MRI \quad (8)$$

$$IT = (1-PR)(III + MIT) \quad (9)$$

Capacity Improvement (CI) is the sum of Accurate Information Rate (*AIR*) and Maintenance Rate (*MR*). AIR influenced by the Accurate Information Reduce Idle (AIRI) and Capacity Improvement Proportion (CIP). The equation for determining MR is represented in eq. 8, which is deliberate *CIP*, Maintenance Reduce Idle (*MRI*). Meanwhile, the formula for determining Idle Time is represented in eq. 9, which is considered Productivity Rate (*PR*), Maintenance Idle Time (*MIT*), and Inaccurate Information Idle (*III*). *CIP* regulates the formula for inaccurate information and maintenance improvement.

$$DR = 0.530\, ISC \frac{VB + YOR}{AR} \quad (10)$$

$$GR = GF\,(0.0012\, DR) \quad (11)$$

$$VB = \frac{0.272\,.((0.82\,.TR + 34.8\,.GR) + (57.26\,.ER))\,(VQ(1 + VQP))}{CQV} \quad (12)$$

Container terminal operation performance, which is represented by Berthing Time (*BT*), is connected to the ESG component through the Discharge Rate (*DR*). This variable is also used in the *BT* determination formula. Governance Rate (*GR*) is a multiplication of Governance Fraction (*GF*) with discharge rate, which is represented in eq. 11. The DR formulation can be seen in eq. 11 which involves the variables Import Stack Container (*ISC*), Yard Occupancy Ratio (*YOR*) and Arrival Rate (*AR*). *AR* describes the flow of the vessel quantities that started to berth, while *ISC* is the quantity of containers stacked in stacking yards in units. *YOR* is the ratio of the utilization of stacking yards compared with stacking yard capacity, which is expressed in percent. Social and environmental variables, which are part of the ESG component, are included in the formula for determining the number of vessels that dock at the container terminal. This variable is referred to as Vessel Berth (VB). The determination of VB is influenced by the Emission Rate (ER) variable as a representation of the environment component. A vessel and head truck within the container terminal is an engine that uses fuels,contributing to the temperature and pressure in the port environment. Engines and cars largely contribute to total pollutant emissions [69].

Throughput Revenue (TR) also plays a role in determining VB, as a variable that represents employee satisfaction which represents the social component. Apart from that, VB is also influenced by the variables Vessel Quantity (VQ), Vessel Quantity Proportion (VQP) and the number of containers in the vessel, which is known as the Container Quantity Vessel (CQV).

4.7.4. Validation and Sensitivity Evaluation of Model

Verification of the simulation model was also conducted in this CTO system, considering ESG components. The results show that the implementation of a running model simulation to run well without any errors in the system. Validation has also been conducted on this sub-system using the hypothesis test and the Welch T-test. The results of the validation are shown in Table 3.

Table 3. Validation result of model

	Real Data	Simulation
Mean	18.45	21.02
Variance	126.64	41.30
Observations	46	46
Hypothesized Mean Difference	0	
Df	72	
t Stat	1.346	
P(T<=t) one-tail	0.091	
t Critical one-tail	1.666	
P(T<=t) two-tail	0.183	
t Critical two-tail	1.993	

The t stat value for the validation process is 1.346, and the t critical two-tail is 1.993. The T stat value is less than the t-critical two-tail, which means both data are considered the same. Meanwhile, P(T<=t) two-tail is 0.183. The value is greater than t-stat, which means there is no significant difference between the simulation result and real data. Furthermore, this vessel movement model was evaluated for sensitivity to see the model's response to the scenario implementation, and the results show that if a parameter variable has changed, it will automatically change all the existing variable outputs. This shows that this model is sensitive.

5. Results and Discussion

Marine ports play an important role in logistical activities by serving as a link between suppliers and manufacturers. The Port of Tanjung Priok (PTP) is Indonesia's main port and is in the north of Jakarta, the capital city of Indonesia. This port was chosen because of its strategic position and significant role in transportation routes. PTP provides a wide range of logistical services for import and export operations, particularly in the west region of Indonesia. This port has a volume of more than 50% container freight transport access[5]. The strategic location with a hinterland, which is the area with the activity of trade and industry, makes the Port of Tanjung Priok the main port on the island of Java[70]. This port also has two functions, namely as a destination port and a transit port that connects two continents, namely Asia and

Australia. Export-import process of container terminal within PTP area is operated by Indonesia Port Corporation (IPC). This company is a government-owned company that first served container transport in the region.

Research conducts the modeling process because the modeling makes it possible to handle experiments by providing solutions at the model level with minimum risks. There are six types of modeling such as mental models, boxes connected with line models, physical models, formula models, excel spreadsheets, and simulation models[71]. Mental models, formulas, and spreadsheets can be the best alternatives for simple model, because they usually have a small quantity of parameters with linear dependability characteristics. Simple models involved two or three parameters which indicate small quantity of parameters. Meanwhile, this container terminal model involved ten parameters, which indicates big quantity of parameters. Variables involved in this model was 74 variables. The quantity of variables indicates that the operation in container terminal is a complex system. The relationship among each variable is non-linear. Furthermore, there is an indication that some variables have uncertain conditions, such as idle time, break down maintenance and arrangement of stacking process. In such a case, simulation modeling is the right choice, because all the characteristics of the system are well-matched with the characteristics of the container terminal operation. Furthermore, system dynamics simulation is compatible method for a case with a complex system [72].

This model had been simulated based on the daily time motion units for 365 days through the Anylogic 8.8.0 simulation software. This study implemented several experiment simulation scenarios by considering emission, employee satisfaction, and governance, which enlarge linearly. As shown in Figure 4, berthing time was affected by the variation of emission. When emissions were decreased from 3.32 to 2.95 tons/day. The berthing time was reduced from 27 to 20 hours per vessel. Variations in the Emission Rate (*ER*) reduction percentage values are due to changes in Capacity Improvements (*CI*), which have an impact on increasing throughput values. The import stack container value will also increase in line with increasing throughput. The throughput rate will affect the Discharge Time (*DT*), so it has a direct impact on reducing the Berthing Time (*BT*) value. The average *BT* rate will be 10% faster if the *ER* value is reduced by 20%. Faster berthing times indicate better service performance.

Similarly, Figure 5 shows the effect of employee satisfaction on berthing time. Average berthing time was 5% and getting faster due to an increasing rate of employee satisfaction of 20% as a social metric. Variations in social values were due to improvements in capacity, which had an impact on productivity because of changes in the value of employee satisfaction. This is also in line with the decrease in idle time caused by maintenance activities. Breakdown maintenance is often carried out, considering the condition of old equipment. Berthing time will reach 19.12 hours per vessel if it has an employee satisfaction rate of 0.145. Berthing time is getting shorter due to an increasing rate of employee satisfaction as a social metric. Finally, Figure 6 represents the influence of governance on berthing time. The increasing governance index leads to a decrease in berthing time.

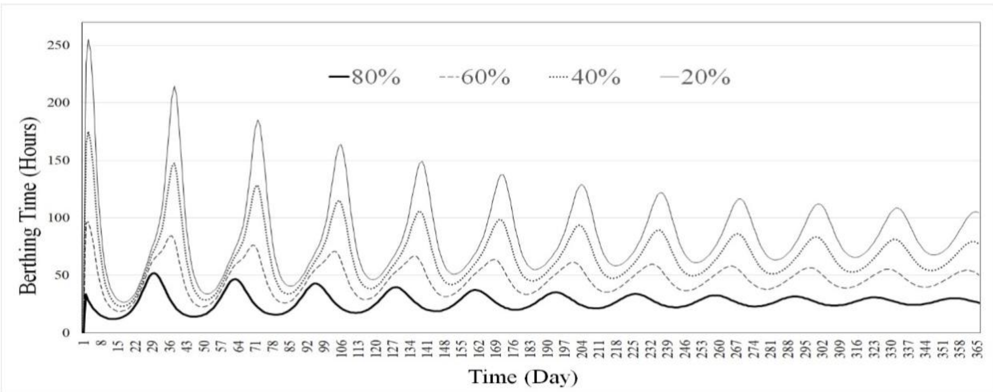

Figure 4. Effect of emissions on berthing time

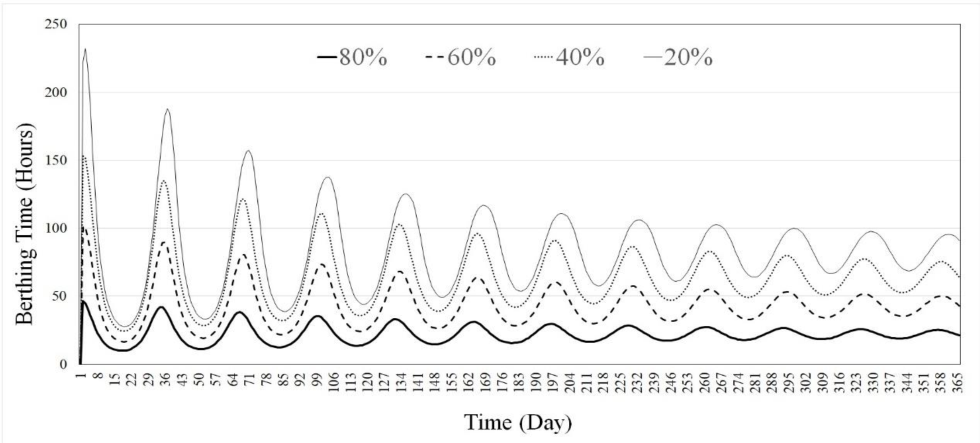

Figure 5. Effect of employee satisfaction on berthing time

Finally, Figure 6 represents the influence of governance on berthing time. The 20% increase in governance index rate led to an average change in berthing time 11% faster than before. The percentage variation that resulted in a decrease in governance values was caused by an acceleration of discharge time, which directly impacts increasing employee satisfaction rate. An increase in this rate will cause an increase in productivity figures, thus affecting the throughput and overall container terminal. Berthing time will reach 19.12 hours per vessel if it has a rate of governance of 0.345.

Berthing time, as the main indicator of port performance, was used as the basis for the ideal output, which describes the results of the combined rate derived from emission, employee satisfaction, and governance variables. For evaluating various berthing times, 12 scenarios were selected. The scenarios created must be based on the dynamic scenario planning system which consider the assumption and limitations of model[23]. The parameters of scenarios were based on the difference in import rate and capacity improvement rate, which will change the values of ESG components that affect the berthing time. The number of scenarios was determined based on changes in the value of ESG components, where each component (environment, social, governance) had 4 scenarios, bringing the total to 12 scenarios. The value change level for each parameter component was 20%, 40%, 60%, and 80%. These four levels represent changes in scenarios based on low, medium, high, and extremely high levels. The plan was prepared based on scalable scenario simulation planning [73]. Simulations based on the selected scenario were based on testing the model by changing parameters by trial and error, which produced the main output variables in accordance with the main target of model development. This was done because system dynamics modeling is a participatory activity in which one learns by trial and error and practice[35].

The simulation result of the container terminal operation considering ESG components is shown in Table 3. Simulation result showed that the 12thscenario was the best scenario because it has the smallest berthing time value. This value can be obtained if emission is 2.21 tons per day, social is 0.145, and governance is 0.345.

This system dynamics model evaluated for sensitivity to see the model's response to the scenario implementation, and the results show that if a parameter variable has changed, it will automatically change all the existing variable outputs. This shows that this system dynamics model is sensitive. Furthermore, simulation model verification was also conducted in this container terminal operation considering ESG components. The results showed that implementation of running model simulation was able to run well without any error of the system. Validation also has been conducted on this sub-system using hypothesis test and Welch T-test. The t stat value for the validation process was 1.346, and the t critical two-tail was 1.993. T stat value was less than t critical two-tail, which means that both data are considered the same. Meanwhile, P(T<=t) two-tail was 0.183. The value was more than t stat, which means there was no significant difference between simulation result and real data. Those results indicate that the model was valid.

Table 3. Simulation scenario results (mean)

Scenario	Berthing Time Hours / vessel	Emission (Environment) Tons/day	Employee Satisfaction (Social) Daily index score	Governance Daily Index score
1	26.83	3.32	0.073	0.201
2	19.77	2.95	0.128	0.251
3	19.99	2.26	0.149	0.343
4	19.12	2.21	0.145	0.345
5	21.97	2.61	0.097	0.282
6	20.58	2.73	0.113	0.261
7	19.77	2.94	0.129	0.250
8	19.12	2.21	0.145	0.345
9	26.83	2.61	0.085	0.268
10	22.12	2.61	0.085	0.268
11	21.09	2.23	0.112	0.307
12	19.12	2.21	0.145	0.345

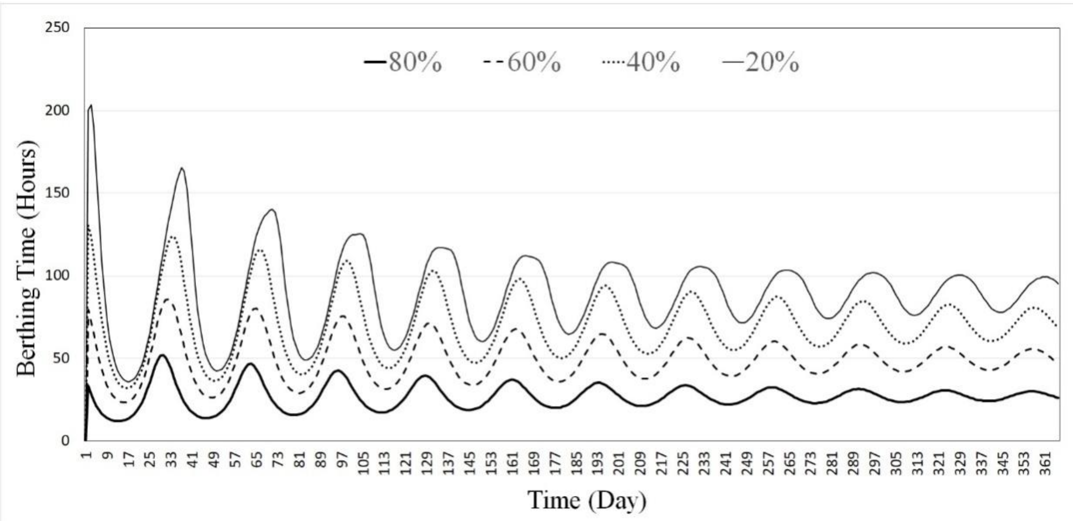

Figure 6. Effect of governance on berthing time

There is a research gap in developing berth allocation system dynamics models for the port capacity constraint that explicitly incorporates environmental, social, and governance (ESG) components. Existing literature primarily focuses on operational efficiency, with limited attention to how berth allocation strategies can be aligned with sustainability goals, social responsibility, and governance principles. The SD model designed for the container operation system combines strategic and tactical management levels. The strategic level includes the ESG component as a variable that affects container terminal performance. The environmental component focuses on emission measurements as a basis for achieving pollution reduction. The resulting emissions are highly dependent on the length of the operating process. The longer the operating process lasts, the greater the emissions produced. According to the scenario result in Table 3, the higher the emission value, the longer the berthing time. The faster the container relocation service was able to reduce emission. Therefore, the berthing speed certainly affects the emissions generated from port activities.

The social component focuses on employee satisfaction measurements as a basis for supporting labor rights and achieving human well-being goals. Increasing employee satisfaction will have an impact on productivity, which will improve the performance of the port. According to the scenario result in Table 3, the higher the social rate score impacted, the faster the berthing time is.

The last component is governance. This ESG component was taken from the good corporate governance index, which represents operational performance for achieving the goals of a strong institution. The scenario result in Table 3 shows that the higher governance daily index score was influenced by the faster berthing time. An increase in the score index of the social components, which are represented by employee satisfaction and governance index, will be able to reduce the quantity of berthing time. Improvement to the governance score will influence better performance of container terminal.

Observations made during the COVID-19 pandemic showed that the pandemic did not have a significant effect on the performance of the container terminal. Throughput was only reduced to 6%. Related to the governance, which has a lot of influence on performance, is the contractual relationship with the shipping line. The company should boost the performance of the commercial department so that it can reopen cooperation with large shipping lines and improve the company's operational performance. Good performance will attract the attention of the shipping line and have an impact on the smooth process of opening charter contracts between container terminals and large shipping lines.

We use the Welch T-test in the validation process because, in principle, this test can compare the output parameters between the existing condition variables and the results from the simulation so that we can see the level of relationship between the two variables. A small loss in statistical power can occur, depending on the shape of the distributions. Welch's t-test provides better control of type 1 error rates when the assumptions are met [74].

The speed of service from the container terminal is the result of a tactical decision strategy, where the faster berthing time is affected by the increase in the flow of container movement leaving the port to the consignee. Regarding the tactical management level for the SD model. Lu and Park [75]revealed that the most sensitive factors designated as critical for container terminals are terminal cranes, yard trucks, quay cranes, and yard areas. Fast service for vessel berthing indicates that the container is stacked in the yard for a short period of berthing time. This condition allows the container terminal to accept new vessels for berthing. Venturini, et. al [76] observed that the minimization of time spent at ports by prompt berthing of vessels can offer a counterbalance to negative economic consequences for shipping companies.

The large amount of berthing time caused by the piling up of containers in the stacking yards boils down to regulations set by the government that regulate the length of the container storage process in the port area. If the government reduces the time interval for placing containers in stacking yards, it will certainly have an impact on consignee awareness and port governance management's compliance with these regulations. Therefore, tactical decision management for increasing the volume of containers leaving the stacking yard to the consignee will improve the performance of port services.

This research was limited to container terminals, which have three berths for ships with a limited stacking yard area. Apart from that, this research also did not consider aspects of the costs incurred when the operation is carried out. Another limitation is the existence of old facilities, so there was a lot of maintenance activity and limited information exchange platforms between stakeholders. Those facts are supported by research results, which revealed that the main idea behind maintenance was to make the parts and machines ready to do what was required within the time and sizes allocated with fewer amounts of resources[77].

Efficient berthing time is an essential factor in enhancing the container terminal's operational efficiency. By minimizing turnaround times for ships, the terminal can handle a greater volume of vessels, resulting in increased throughput and revenue. Furthermore, reducing berthing time also reduces idle time for both vessels and terminal resources, leading to significant cost savings. Faster berthing times improve customer satisfaction as shipping lines and clients experience a quicker turnaround for their vessels, fostering enhanced relationships. Container terminals with minimized berthing times gain a competitive advantage in the industry, attracting more shipping lines and alliances.

Effective maintenance is a crucial activity to ensure the longevity of terminal equipment and infrastructure. This approach can extend the lifespan of equipment and reduce the frequency of breakdowns and unplanned downtime. Furthermore, it will minimize disruptions to operations. The simulation represents the influence of maintenance on idle time, which is the main variable in determining berthing time. Observation results showed that a large amount of idle time was caused by machine breakdowns for maintenance activities. This is in line with other studies, which interpret maintenance as an effort to anticipate the failure of the machine [78]. One of the maintenance goals in the operation process is the system's accomplishment of the environment, safety, and efficiency of utilizing the resources [79]. Moreover, effective maintenance practices play a key role in ensuring environmental compliance and promoting sustainability within the container terminal.

Improved information sharing within the container terminal fosters collaboration among different departments and stakeholders, leading to better decision-making. Information sharing between chain actors plays a pivotal role in supply chain management for enhancing sustainable performance relationships [12].Timely and accurate information sharing facilitates real-time decision support, enabling managers to respond more effectively to changes in demand, vessel schedules, and other operational factors. Enhanced information sharing also enables better risk assessment and management, as managers have a comprehensive view of operational data, allowing them to identify potential challenges early on and to implement proactive measures to mitigate risks.

The impact of minimizing berthing time, maximizing maintenance activity, and increasing information sharing results in a more efficient, and competitive container terminal operation. The results of this research can be applied practically and managerially to container terminals with limited capacity in developing countries. This is in line with the increasing number of seaport development projects in the Southeast Asia region, where countries compete to secure the leading position in the container transport system[80]. These countries include Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand, Timor-Leste, and Viet Nam.

The problems faced are related to service and berthing processes [81]. This can be done by increasing crane capacity through improvements in maintenance management and providing an effective information sharing platform. Furthermore, improvements carried out at this port will also have an impact on operational activities and scheduling at ports that are directly connected, such as Singapore Port and Klang Port in Malaysia, which are geographically close to the port of Tanjung Priok.

The connectivity between environmental, social, and governance factors creates a framework for a container terminal to achieve sustainable and high-performance operations through the performance improvement activities. By considering those factors, container terminals can navigate challenges, enhance stakeholder relationships, and driving positive outcomes for its overall performance and sustainability.

6. Conclusions

The article proposed a systematic SD model of container terminals to analyse the influence of ESD components on port performance, which was represented by a change in the berthing time value as a dynamic variable. The simulation was carried out using Anylogic 8.7.7 software, followed by validation through the sensitivity analysis. The system approach can identify significant variables that play a role in accelerating performance improvements from container terminals, where container ports are complex systems that are compatible with system dynamic methods.

This model can discover the strategy for reducing berthing time as the main indicator of port performance and evaluate the fluency of container movement within the port, with the limitations of not considering cost factors, having old equipment facilities, and a limited stacking yard area. Reducing berthing time within a container terminal involves a combination of computer simulations to test different scenarios and identify potential improvements, collaboration through synchronizing information sharing, equipment efficiency, and environmental consideration.

The ESG component influences strategic decisions in management. The environment component indicates that a faster service process can reduce emissions. The integration of the environmental approach in the industries has become more essential in the last years[19].Meanwhile, an increase in the score index of the social components, represented by employee satisfaction and governance index, will reduce the quantity of berthing time. The speed of service from the container terminal is the result of a tactical decision strategy, where the faster berthing time is affected by the increase in the flow of container movement leaving the port to the consignee. The novelty of this research is to provide a model for improving complex port system that associates operational and strategic levels through system dynamic modelling.

Container terminal operation models are effective for maritime ports with limited capacity. In advance, the SD model can be extended for further study in increasing gross crane rate through the strategy of preventive maintenance assignment. Moreover, this model can be extended to various container terminals by considering the variables of sharing information and innovation to speed up port services.

7. Acknowledgements

The authors of this article are thankful to the reviewers for their observations, comments, and endorsements to improve the article’s content. Furthermore, the authors also acknowledge the infrastructure support provided by UniversitiMalaya, Kuala Lumpur, Malaysia, for this research.

References

1. Grant, D.B., C.Y. Wong, and A. Trautrims, Sustainable logistics and supply chain management: principles and practices for sustainable operations and management. Kogan Page Publishers. 2017.
2. Steenken, D., S. Voß, and R. Stahlbock, Container terminal operation and operations research-a classification and literature review. OR spectrum, **26**(1): 2004, p. 3-49. DOI: https://doi.org/10.1007/s00291-003-0157-z.
3. Mokhtari, K., et al., Application of a generic bow-tie based risk analysis framework on risk management of sea ports and offshore terminals. Journal of Hazardous Materials, **192**(2): 2011, p. 465-475. DOI: 10.1016/j.jhazmat.2011.05.035.
4. Rahimi, M., H.J.J.J.o.M. Fazlollahtabar, and I. Engineering, Optimization of a Closed Loop Green Supply Chain using Particle Swarm and Genetic Algorithms. Jordan Journal of Mechanical and Industrial Engineering, **12**(2): 2018. DOI: https://jjmie.hu.edu.jo/vol12-2/JJMIE-06-18-01.pdf.
5. Suprata, F., C. Natalia, and A. Sugioko. Analysing the cause of idle time in loading and unloading operation at Indonesian

international port container terminal: Port of Tanjung Priok case study. in IOP Conference Series: Materials Science and Engineering. IOP Publishing, 2020.

6. Klopott, M. and J. Miklinska, E-Customs and Importers' Port of Choice: Experiences From Poland. Proceedings of the 16th European Conference on E-Government, ed. M. Decman and T. Jukic. 107-114. Nr Reading: Acad Conferences Ltd. 2016.
7. Mantin, B. and J. Veldman, Managing strategic inventories under investment in process improvement. European Journal of Operational Research, **279**(3): 2019, p. 782-794. DOI: 10.1016/j.ejor.2019.06.026.
8. Yoon, J., H.Y. Lee, and J. Dinwoodie, Competitiveness of container terminal operating companies in South Korea and the industry-university-government network. Transportation Research Part a-Policy and Practice, **80**: 2015, p. 1-14. DOI: 10.1016/j.tra.2015.07.009.
9. Dos Santos, M.C. and F.H.J.C.S.o.T.P. Pereira, ESG performance scoring method to support responsible investments in port operations.**10**(1): 2022, p. 664-673. DOI: https://doi.org/10.1016/j.cstp.2022.01.027.
10. Nõmmela, K. and K.J.E. Kõrbe Kaare, Maritime Policy Design Framework with ESG Performance Approach: Case of Estonia.**10**(4): 2022, p. 88. DOI: https://doi.org/10.3390/economies10040088.
11. Jawarneh, A.M., et al., Measurement and Assessment of Solar Energy in Zarqa Governorate-Jordan. Jordan Journal of Mechanical and Industrial Engineering, **17**(4): 2023. DOI: https://jjmie.hu.edu.jo/vol17/vol17-4/15-JJMIE-261-23.pdf.
12. Jreissat, M., L.J.J.J.o.M. Jraisat, and I. Engineering, Sustainable Dyads in Supply Chain Management: A Qualitative Perspective. Jordan Journal of Mechanical and Industrial Engineering, **13**(4): 2019. DOI: https://jjmie.hu.edu.jo/vol-13-4/97-19-01.pdf.
13. Jia, L., et al., Design of Quantitative Risk Assessment System for Ship Longitudinal Motion Based on Analytic Hierarchy Process. Jordan Journal of Mechanical and Industrial Engineering, **16**(1): 2022. DOI: https://jjmie.hu.edu.jo/vol16-1/16-jjmie-J677.pdf.
14. Feng, M., J. Mangan, and C. Lalwani, Comparing port performance: Western European versus Eastern Asian ports. International Journal of Physical Distribution & Logistics Management, **42**(5): 2012, p. 490-512. DOI: https://doi.org/10.1108/09600031211246537.
15. Hsu, W.-K.K., Improving the service operations of container terminals. The International Journal of Logistics Management, **24**(1): 2013, p. 101-116. DOI: https://doi.org/10.1108/IJLM-05-2013-0057.
16. Aljawabrah, A., L.J.J.J.o.M. Lovas, and I. Engineering, Dynamic Modeling of the Dog Clutch Engagement Process Using Hybrid Automata. Jordan Journal of Mechanical and Industrial Engineering **17**(1): 2023. DOI: https://jjmie.hu.edu.jo/vol17/vol17-1/10-JJMIE-278-22.pdf.
17. Al-Refaie, A., H.J.J.J.o.M. Abedalqader, and I. Engineering, Optimal Quay Crane Assignment and Scheduling in Port's Container Terminals. Jordan Journal of Mechanical and Industrial Engineering, **15**(2): 2021. DOI: https://jjmie.hu.edu.jo/vol%208-2/JJMIE-30-13-01.pdf.
18. Nursey-Bray, M.J.I.J.o.S.T., Partnerships and ports: Negotiating climate adaptive governance for sustainable transport regimes.**10**(2): 2016, p. 76-85. DOI: https://doi.org/10.1080/15568318.2013.855849.
19. Tronnebati, I., F.J.J.J.o.M. Jawab, and I. Engineering, Green and Sustainable Supply Chain Management: A Comparative Literature Review.**17**(1): 2023. DOI: https://doi.org/10.1109/LOGISTIQUA49782.2020.9353939.
20. Almaz, O.A., T.J.S.m.p. Altiok, and Theory, Simulation modeling of the vessel traffic in Delaware River: Impact of deepening on port performance.**22**: 2012, p. 146-165. DOI: https://doi.org/10.1016/j.simpat.2011.12.004.
21. Romeike, F.J.B.J.o.A.S., Simulation methods for quantifying ESG risks. 2022, p. 77-94. DOI: https://doi.org/10.25929/bjas202299.
22. Wiegmans, B. and M.J.I.J.o.S.T. Janic, Analysis, modeling, and assessing performances of supply chains served by long-distance freight transport corridors.**13**(4): 2019, p. 278-293. DOI: https://doi.org/10.1080/15568318.2018.1463419.
23. Featherston, C.R. and M. Doolan, Using system dynamics to inform scenario planning: a case study. 2013. DOI: https://openresearch-repository.anu.edu.au/bitstream/1885/23942/6/03_Featherston_Using_System_Dynamics_to_2013.pdf.
24. Cheng, J.K., R.M. Tahar, and C.L. Ang, Understanding the complexity of container terminal operation through the development of system dynamics model. International Journal of Shipping and Transport Logistics, **2**(4): 2010, p. 429-443. DOI: 10.1504/IJSTL.2010.035503.
25. Hou, L. and H.J.J.o.C.P. Geerlings, Dynamics in sustainable port and hinterland operations: A conceptual framework and simulation of sustainability measures and their effectiveness, based on an application to the Port of Shanghai.**135**: 2016, p. 449-456. DOI: https://doi.org/10.1016/j.jclepro.2016.06.134.
26. Middleton, D., et al. Enabling worldwide access to climate simulation data: the earth system grid (ESG). in Journal of Physics: Conference Series. IOP Publishing, 2006.
27. Mei, S. and H. Xin. A system dynamics model for port operation system based on time, quality and profit. 2010.
28. Li, B., et al., Modeling and Simulation of Yard Trailer Dispatching at Container Terminals. 2009 Ieee International Conference on Automation and Logistics. 29-34. 2009.
29. van den Houten, J., A system dynamics exploration of port-city development: the case of Tema, Ghana. 2017. DOI: https://repository.tudelft.nl/islandora/object/uuid:317d30a7-cdfa-4130-a82f-0cf9fdded486.
30. Xu, B., et al., System dynamics analysis for the governance measures against container port congestion.**9**: 2021, p. 13612-13623. DOI: 10.1109/ACCESS.2021.3049967.
31. Onwuegbuchunam, D.J.L., Assessing port governance, devolution and terminal performance in Nigeria.**2**(1): 2018, p. 6. DOI: https://doi.org/10.3390/logistics2010006.
32. Saif-Alyousfi, A.Y., A. Saha, and T.R.J.E.S. Alshammari, Bank diversification and ESG activities: A global perspective. 2023, p. 101094. DOI: https://doi.org/10.1016/j.ecosys.2023.101094.
33. Egorova, A.A., S.V. Grishunin, and A.M.J.P.C.S. Karminsky, The Impact of ESG factors on the performance of Information Technology Companies.**199**: 2022, p. 339-345.
34. Sweeney, L.B. and J.D. Sterman, Bathtub dynamics: initial results of a systems thinking inventory. System Dynamics Review: The Journal of the System Dynamics Society, **16**(4): 2000, p. 249-286. DOI: 10.1002/sdr.198.
35. Forrester, J.W., System dynamics, systems thinking, and soft OR. System dynamics review, **10**(2-3): 1994, p. 245-256.
36. Hou, J.J.S.E.T.P., Sustainable development of port economics based on system dynamics.**1**: 2010, p. 56-61.
37. Li, F.J., S.C. Dong, and F.J.E.M. Li, A system dynamics model for analyzing the eco-agriculture system with policy recommendations.**227**: 2012, p. 34-45.
38. Reddy, K.J.M., A.N. Rao, and L. Krishnanand, Manufacturer performance modelling using system dynamics approach. Materials Today: Proceedings: 2020. DOI: 10.1016/j.matpr.2020.03.563.
39. Oliva, F. and R. Revetria. A system dynamic model to support cold chain management in food supply chain. in WSEAS International Conference. Proceedings. Mathematics and Computers in Science and Engineering. WSEAS, 2008.
40. Aminudin, M., Simulasi model sistem dinamis rantai pasok kentang dalam upaya ketahanan pangan nasional. 2014.

41. Indayani¹, N.P., I.K. Satriawan, and C.A.B. Sadyasmara, Sistem Dinamis Ketersediaan Buah Pisang di Provinsi Bali. Jurnal Rekayasa dan Manajemen Agroindustri, **5**(2): 2017, p. 77-87.
42. Martín Alcalde, E., Strategies for improving import yard performance at container marine terminals. 2014. DOI: 10.5821/dissertation-2117-95403.
43. Arquitt, S. and R.J.E.E. Johnstone, Use of system dynamics modelling in design of an environmental restoration banking institution.**65**(1): 2008, p. 63-75. DOI: https://doi.org/10.1016/j.ecolecon.2007.05.013.
44. Abbasi, E., M. Bastan, and A.M. Ahmadvand. A system dynamics model for mobile banking adoption. in 2016 12th International Conference on Industrial Engineering (ICIE). IEEE, 2016.
45. Moeis, A.O., et al., Sustainability assessment of the tanjung priok port cluster. International Journal of Technology, **11**(2): 2020, p. 353-363. DOI: 10.14716/ijtech.v11i2.3894.
46. van Raak, R., Transition Policies; connecting system dynamics, governance and instruments in an application to Dutch Healthcare. 2016.
47. Ford, A. and F.A. Ford, Modeling the environment: an introduction to system dynamics models of environmental systems. Island press. 1999.
48. Lane, D.C.J.E.J.o.O.R., Social theory and system dynamics practice.**113**(3): 1999, p. 501-527. DOI: https://doi.org/10.1016/S0377-2217(98)00192-1.
49. Abdel-Hamid, T.K.J.I.T.o.S.e., The dynamics of software project staffing: a system dynamics based simulation approach.**15**(2): 1989, p. 109-119. DOI: https://doi.org/10.1109/32.21738.
50. Bazrkar, M.H., et al., System dynamic approach to hydro-politics in Hirmand transboundary river basin from sustainability perspective.**3**(4): 2013, p. 378-398. DOI: https://doi.org/10.1504/IJHST.2013.060338.
51. Bianchi, C.J.S.R. and B. Science, Improving performance and fostering accountability in the public sector through system dynamics modelling: From an 'external'to an 'internal'perspective.**27**(4): 2010, p. 361-384.
52. Sayyadi, R., A.J.I.J.o.S.S.O. Awasthi, and Logistics, An integrated approach based on system dynamics and ANP for evaluating sustainable transportation policies.**7**(2): 2020, p. 182-191.
53. Fontoura, W.B. and G.M.J.u.R.B.d.G.U. Ribeiro, System dynamics for sustainable transportation policies: A systematic literature review.**13**: 2021.
54. Cheng, J.K., R.M. Tahar, and C.L. Ang, A system dynamics approach to operational and strategic planning of a container terminal. International Journal of Logistics Systems and Management, **10**(4): 2011, p. 420-436. DOI: 10.1504/IJLSM.2011.043103.
55. Nugroho, S.H., et al., Analysis and scenario of navy performance allowance policy using system dynamic model.**8**(12): 2019, p. 1140-1147.
56. Musa, S.N., Supply chain risk management: identification, evaluation and mitigation techniques. Linköping University Electronic Press. 2012.
57. Ferdian, R., et al., Dynamic Lot Sizing Model for Retailers with Multi Supplier Quantity Discount and Capacity Constrains.**17**(5): 2020, p. 1024-1031.
58. Huang, B., et al., ESG Investment Scale Allocation of China's Power Grid Company Using System Dynamics Simulation Modeling.**20**(4): 2023, p. 3643. DOI: https://doi.org/10.3390/ijerph20043643.
59. Jia, S., Y. Li, and T. Fang, Can driving-restriction policies alleviate traffic congestion? A case study in Beijing, China. Clean Technologies and Environmental Policy, **24**(9): 2022, p. 2931-2946. DOI: 10.1007/s10098-022-02377-z.
60. Kozlovskyi, S., et al., The system dynamic model of the labor migrant policy in economic growth affected by COVID-19. 2020.
61. Shaikh, W.A., et al., A System Dynamics Costing Model for The Refurbishment of Electric Vehicle Batteries. Jordan Journal of Mechanical and Industrial Engineering **17**(1): 2023. DOI: https://jjmie.hu.edu.jo/vol17/vol17-1/02-JJMIE-218-22.pdf.
62. Roy, D., R. De Koster, and R.J.O.R. Bekker, Modeling and design of container terminal operations.**68**(3): 2020, p. 686-715. DOI: https://doi.org/10.1287/opre.2019.1920.
63. Golias, M.M., et al., Berth scheduling by customer service differentiation: A multi-objective approach.**45**(6): 2009, p. 878-892. DOI: https://doi.org/10.1016/j.tre.2009.05.006.
64. Imai, A., E. Nishimura, and S. Papadimitriou, Berthing ships at a multi-user container terminal with a limited quay capacity. Transportation Research Part E: Logistics and Transportation Review, **44**(1): 2008, p. 136-151. DOI: https://doi.org/10.1016/j.tre.2006.05.002.
65. Kapilan, N.J.J.J.o.M. and I. Engineering, Impact of Carbon Nano Tubes on the Performance and Emissions of a Diesel Engine Fuelled with Pongamia Oil Biodiesel.**15**(3): 2021.
66. Kumarappa, S., G.J.J.J.o.M. Prabhukumar, and I. Engineering, Improving the performance of two stroke spark ignition engine by direct electronic CNG injection. Jordan Journal of Mechanical and Industrial Engineering **2**(4): 2008, p. 169-174. DOI: https://jjmie.hu.edu.jo/files/JJMIE-V2-N4-press.pdf#page=8.
67. Al-Refaie, A. and H. Abedalqader, Optimal Quay Crane Assignment and Scheduling in Port's Container Terminals. Jordan Journal of Mechanical and Industrial Engineering, **15**(2): 2021, p. 153-167. DOI: https://jjmie.hu.edu.jo/vol%208-2/JJMIE-30-13-01.pdf.
68. Masoud, Z.N., M.F.J.J.J.o.M. Daqaq, and I. Engineering, A graphical design of an input-shaping controller for quay-side container cranes with large hoisting: Theory and experiments. 2007.
69. Ali, R., et al., Numerical Analysis of Combustion Characteristics and Emission of Dual and Tri-Fuel Diesel Engine under Two Engine Speeds.**14**(2): 2020.
70. Aprilianty, H. and H. Evander. Information Technology in Port Container Terminal: Automation Tally System Implemented in Port of Tanjung Priok. in Global Research on Sustainable Transport (GROST 2017). Atlantis Press, 2017.
71. Robinson, S., Simulation: the practice of model development and use. Bloomsbury Publishing. 2014.
72. Sterman, J., System Dynamics: systems thinking and modeling for a complex world. 2002. DOI: http://hdl.handle.net/1721.1/102741.
73. Casanova, H., et al., Versatile, scalable, and accurate simulation of distributed applications and platforms.**74**(10): 2014, p. 2899-2917. DOI: https://doi.org/10.1016/j.jpdc.2014.06.008.
74. Delacre, M., D. Lakens, and C.J.I.R.o.S.P. Leys, Why psychologists should by default use Welch's t-test instead of Student's t-test.**30**(1): 2017, p. 92-101.
75. Lu, B. and N.K. Park, Sensitivity Analysis for Identifying the Critical Productivity Factors of Container Terminals. Strojniski Vestnik-Journal of Mechanical Engineering, **59**(9): 2013, p. 536-546. DOI: 10.5545/sv-jme.2012.931.
76. Venturini, G., et al., The multi-port berth allocation problem with speed optimization and emission considerations. Transportation Research Part D: Transport & Environment, **54**: 2017, p. 142-159. DOI: 10.1016/j.trd.2017.05.002.
77. Almeanazel, O.T.R.J.J.J.o.M. and I. Engineering, Total productive maintenance review and overall equipment effectiveness measurement. Jordan Journal of Mechanical and Industrial Engineering **4**(4): 2010. DOI:

https://jjmie.hu.edu.jo/files/v4n4/JJMIE-129-08_Revised(11)/JJMIE-129-08_modified.pdf.

78. Al-Tahat, M.D., M. Ala'a, and I.S.J.O.J.o.S. Jalham, A Statistical Comparison of the Implementation of Concurrent Engineering in Jordanian Industry.**9**(3): 2019, p. 361-372. DOI: https://doi.org/10.4236/ojs.2019.93025.
79. Ismail, F.B., et al., Enhancement of Maintenance Efficiency for Liquefied Natural Gas Plant: Operation Factors, Workforce and Productivity Control. Jordan Journal of Mechanical and Industrial Engineering.**16**(4): 2022. DOI: https://jjmie.hu.edu.jo/vol-16-4/05-101-21.pdf.
80. Nguyen, P.N., et al., Competition, market concentration, and relative efficiency of major container ports in Southeast Asia.**83**: 2020, p. 102653. DOI: https://doi.org/10.1016/j.jtrangeo.2020.102653.
81. Kuntoji, G. and S.J.A.P. Rao, A review on development of minor ports to improvethe economy of developing country.**4**: 2015, p. 256-263. DOI: https://doi.org/10.1016/j.aqpro.2015.02.035.