An integrated analysis of port and coal storage development plan in a mining company with a simulation approach

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Abstract. Managing inbound logistics activities requires an integrated and comprehensive perspective to understand the operations complexity that affects inbound performance. This study proposes an integrated analysis in port and coal storage development plan in a mining company. The main goal of the analysis is creating a cost-effective plan. A discrete event simulation (DES) approach is used to model the complexity, and the model is applied to analyse the number of barge slip, port loading and unloading equipment, the number and the type of material transport equipment. It also analyses how storage capacity can achieve particular service levels. The model considers the actual restriction and uncertainties, such as tidal time, barge sailing and berthing time, loading and unloading time, material transportation time, availability of barge slip, material transportation, loading and unloading equipment. The simulation using 2020 data as the baseline of demand and 2027 data as the highest demand until 2030, this demand led to high queues at barge slip, making stockpile capacity insufficient, and high utility on trucks followed by long queues. Based on the simulation results, increasing the number of resources can be able to solve the overcome problems.

1. Introduction
Management of inbound logistics activities requires an integrated and comprehensive perspective between one process and another. This is caused by the complexity in understanding the effect of facility changes or process changes on the performance of inbound logistics. One issue that requires a holistic perspective in the scope of inbound logistics is port and warehouse development planning, where port performance and warehouse performance are interrelated. This case-based report (CBR) will discuss the importance of integrated analysis for port development plans and storage capacity (warehouses) by raising a case at PT. X which supporting the project requires the development of the company’s port facilities and infrastructures to support operational needs. Therefore, integrated planning is needed. Planning to develop port facilities and infrastructures that must be carried out include coal storage in the port; barge slip area used to transport coal, sulfur, silica sand from suppliers, nickel products produced by the company, and material handling equipment used for loading and unloading at the ports.

The business process flow at the port starting from shipping, loading & unloading, and storage at the port must be integrated with one another so that it can support the sustainability of the company's production processes at the most efficient, reliable, and safe costs. If there is a disruption in the business process at the port, it will be able to stop the nickel processing production process. In actual conditions, there are internal and external factors that greatly affect the sustainability of port operations. Internal factors include productivity and availability of port facilities and infrastructure, while external factors include tides, weather conditions, width, and depth of river channels. These factors add complexity to the operation of the port.
The objectives of this research are to develop a model that integrates all shipping in and out of barges, loading & unloading, transportation to storage, and bulk material storage capacity, especially coal at the company's port.

The problem constraints used in this research are the width of the river channel is 50 meters with a depth of 3 meters LAT (low astronomical tide) so that the size of the barges that can be used is 240 feet and 270 feet with a capacity of 4,100 tons and 5,000 tons respectively. Barges can only cross the river channel when the river reaches a minimum of 4.9 meters, which is the average in the range of 09:00 a.m. - 12:00 p.m. and 18:00 p.m. - 22:00 p.m., the river channel can only be crossed by 1 (one) barge at one time. Material handling in the form of e-crane has a bucket capacity of 10 tons and trucks carrying it from barge slip to bulk storage have a maximum capacity of 20 tons and cannot use a larger capacity due to safety reasons during operation. Increasing coal storage capacity can only be done in the port area and cannot be planted site areas due to limited space available.

The benefit of this research is supporting the company in optimally developing the port in terms of cost efficiency spent on developing and operating ports. Furthermore, this research could provide an additional reference regarding the need for integrated analysis for investment decisions in companies that have similar characteristics of inbound logistics activities.

The remaining of this paper is organized as follows. Section 2 discusses the literature used in this research. Sections 3 show the model development which includes the conceptual model and computer model. Section 4 presents the model results and analysis. Finally, the conclusion of this research is presented in section 5.

2. Literature Review

2.1. Logistics system

Logistics is a collection of goods, materials, and tools and facilities used by an organization in achieving its objectives. Logistics management is management related to the planning, implementation, and supervision of the distribution of goods, services, and information from the place of origin and ends at the point of consumption to meet the needs of consumers effectively and efficiently. The purpose of managing logistics is to move the right finished goods or materials, in the right amount at the right time and at the right location where it is needed at the lowest total cost. The logistical role has now expanded not only to move finished products and raw materials but also to create a competitive advantage by providing the best service to meet consumer demand. Logistics management functions according to Prihantono, C.R. (2012) is a series of processes consisting of planning and determining functions, budgeting functions, procurement functions, storage and distribution functions, maintenance functions, elimination functions, and control functions.

Christopher (1998) logistics is the process of managing the procurement, movement, and storage of materials, parts, and finished inventory and related information flow through the organization and its marketing channels. Stock and Lambert (2011) stated that logistics no longer solely implemented handling or transportation but do such activities, such as communication, customer service, site localization, reverse logistics, and planning, that were related to trade and production. A logistics system includes supply, transport, servicing, production, warehousing, distribution, and the relationships between them.

2.2. Simulation

Simulation is modeling the process of a system using computer software that is used to evaluate and improve the performance of the system. The reason for using simulations is that the system to be evaluated and upgraded is complex and the trial and error approach requires a large cost, a lot of time, and interferes with the operation of the system. The conceptual model of the simulation contains 5 key activities. These activities are understanding the problem of the situation/system, setting goals, defining inputs, defining outputs, and identifying assumptions and simulations. A system has 4 components, that is entities, activities, queues, and resources (Robinson et al., 2011).
Based on the purpose of the simulation, the simulation can be divided into continuous and discrete events. A system can be represented as a continuous and discrete event. One of the determinants is the discrete-event looks at a certain time unit while continuously considering the changing time or system dynamics (Harrel et al., 2004). A dynamic system can be described as an agent-based simulation (ABM). The agent-based simulation considers all individuals (agents) in a complex and dynamic system. ABM is heterogeneous and autonomous so that they can interact between agents and interact with one another. ABM adds individual components in the system besides the system variables. While in discrete event simulation, one of the software to calculate is Arena. Arena simulation software is a flexible tool in analysis to create animated simulation models that accurately represent virtually all systems.

3. Model development
This section explains the research methodology & model development process. It includes a conceptual model and a computer model to represent the simulation model. Several preliminary results are also presented here. The research methodology in this paper is conducted with discrete event simulation and using Arena Software, the software is used to model a system that takes into account a certain time unit. The variables used in this study are divided into 3 parts, namely the decision variable, the control variable, and the response variable. After determining the variables used, the next step is to collect data. The data collected consists of 2 types, namely primary data and secondary data. The decision variables in the simulation model use the number of trucks 2 units according to the existing number of trucks, the simulation also uses 5 units of trucks to realize the average waiting times of trucks from barge slips to coal, sulfur, and silica stockpiles. The coal stockpiles capacity used in this simulation is the current stockpile capacity of 61,000 tons and the stockpiles capacity of 160,000 tons in 2027 following the demand for coal in that year. The decision variables and data collected in this study is shown in Table 1.

| No | Decision variables                           | Quantity         | Units |
|----|----------------------------------------------|------------------|-------|
| 1  | Barge capacity                               | 4,100 and 5,000  | ton   |
| 2  | Trucks from barge slip to stock pile         | 2 and 5          | unit  |
| 3  | Stock pile capacity                          | 61,000 and 160,000 | ton   |

The control variables used in the simulation model are coal, sulfur, and silica consumption and nickel production in 2020 and 2027. The number of barges that can pass through the river channel is only one (1) unit of a barge at the same time and can only be passed by barges at a minimum depth of 4.9 meters, where the depth of the river is only in a few hours in 1 (one) day according to tides. Shipments of nickel products are carried out every 2 weeks to the buyer and this shipment is the main priority over coal, sulfur, and silica. The flow process of loading and unloading in barge slip until the stockpile uses the existing sequence of processes. The maximum loading and unloading time for coal, coal, and silica is 3 days, meanwhile for nickel product is 4 days, the loading and unloading time is determined by contractual agreement with the suppliers of coal, sulfur, silica, and nickel buyers. The maximum coal inventory used is 4-6 weeks according to the company’s policy. The control variables and data collected in this study is shown in Table 2.

| No | Control Variables                           | Units       |
|----|---------------------------------------------|-------------|
| 1  | Consumption rate of coal, sulphur & silica  | ton         |
| 2  | Nickel production rate                      | ton         |
| 3  | The number of barges could be passing thru the river at the same time | unit |
| 4  | The river depth of at least 4.9 m           | meter       |
| 5  | Nickel is the first or main priority commodity | types of commodity |
Nickel shipment every 2 weeks  
Flow process of loading and unloading in barge slip until stockpile  
Maximum loading and unloading time of coal, sulfur, and silica  
Maximum loading and unloading time of nickel  
Maximum inventory level for coal

The response variables in this simulation model are the loading and unloading queues of barges at anchorage points both for coal, silica and sulfur barges, by increasing the capacity of the barge, it is expected to reduce barge waiting time and the number of barges waiting in barge slip. Barge slip, e-crane, and truck utilization are also used as variable responses in this simulation model. The response variables and data collected in this study is shown in Table 3.

Table 3. The response variables.

| No | Response variables                           | Units |
|----|---------------------------------------------|-------|
| 1  | Queues in loading and unloading barge system| Days  |
| 2  | Barge slip utility                          | %     |
| 3  | E-Crane utility                             | %     |
| 4  | Truck utility                               | %     |

The coal, sulfur and silica barges queue at the anchorage point before berthing at the barge slip and unloading processes is carried out, the anchorage point is approximately 9 nautical miles from the company’s barge slip. After ensuring that barge slip, unloading equipment, hauling equipment and stock piles are available, barges are allowed to enter the barge slip through the river channel, this river channel can only be passed by one (1) barge at the same time and at a minimum river depth of 4.9 meters, after the barges are berthed at the company’s barge slip, then the unloading process will be carried out using e-crane and transported to the stock pile using trucks.

Figure 1. The conceptual model for the process of inbound coal, sulfur, and silica & outbound nickel.
The nickel shipment process is carried out when a mother vessel is available at the anchorage point, the nickel will be loaded onto the barge using an e-crane from a storage warehouse next to the barge slip, after the nickel has been loaded into the barge then the barge sails to the anchorage point and the transshipment process is carried out to the mother vessel, the nickel shipments are carried out every 2 weeks. The conceptual model for the inbound and outbound logistics process is used for existing and improvement conditions in 2027. A conceptual model used for the process of inbound coal, sulfur, and silica and the process of outbound nickel is shown in Figure 1.

The existing conditions using 4,100 tons of barges capacity for coal, stockpile capacity is 61,000 tons, and the number of trucks 2 units, meanwhile the condition of improvement using 5,000 tons of barges capacity for coal, stockpile capacity is 160,000 tons and the number of trucks is 5 units. The number and capacity of barge slip and e-crane are remaining the same between existing and improve conditions in 2027. The capacity of barges and stockpile for sulfur, silica, and nickel are using the same capacity between the existing and improvements condition in 2027. Flow process including the existing and improvement conditions is shown in Figure 2.

![Figure 2](image-url)

**Figure 2.** The flow process including the existing and improvement conditions for coal, sulfur, silica and nickel barges, equipment and stock pile.

The average number of waiting in barge slip is the average waiting time of each barge waits in the barge slip for one year. The average waiting time in barge slip is the total average waiting time of all barges waiting at barge slip for one year. The average waiting time in trucks processing is the total average waiting time of trucks during the loading process of barges using e-cranes in one year. The number of barges waiting in barge slips is the total number of barges waiting in a queue at barge slip.
due to unpreparedness or unavailability of unloading equipment, coal storage, or barge slip itself within one year. The number of supplies that cannot be stored in the stockpile is the amount of coal that cannot be stored in the coal storage area. This result is a one-year simulation process. The simulation process is carried out every day with a replication length of 365 days. The following Table 4 and Table 5 are the simulation results obtained with existing and improved conditions of coal storage capacity, barge capacity and number of trucks in 2027.

Table 4. The simulation results obtained with existing conditions of coal storage capacity, barge capacity and number of trucks in 2027.

| No | Year                                           | 2027                      |
|----|------------------------------------------------|---------------------------|
| 1  | Average number of waiting in barge slip        | 19.879 hours              |
| 2  | Average waiting time in barge slip             | 84.93 hours               |
| 3  | Average waiting time in trucks processing      | 12.08 hours               |
| 4  | Number of barges waiting in barge slip         | 44 units                  |
| 5  | Number of supplies that cannot be stored in stock pile | 99,000 tons (coal) |

Table 5. The simulation results obtained with improvement conditions of coal storage capacity, barge capacity and number of trucks in 2027.

| No | Year                                           | 2027                      |
|----|------------------------------------------------|---------------------------|
| 1  | Average number of waiting in barge slip        | 0.47 hours                |
| 2  | Average waiting time in Barge Slip             | 56.88 hours               |
| 3  | Average waiting time in trucks processing      | 3.85 hours                |
| 4  | Number of barges waiting in barge slip         | 16 units                  |
| 5  | Number of supplies that cannot be stored in stock pile | 0 tons (coal) |

4. Analysis
The reason for using the year 2027 is that in that year the highest demand occurred between 2020 and 2030. This demand led to high queues at barge slip, making stockpile capacity insufficient, and high utility on trucks followed by long queues. The long queue will put this company at risk of getting a penalty because it is not following the contract and will not be able to meet the supply of coal to the processing plant to produce nickel because of the unavailability of coal and inadequate coal storage.

Based on the simulation results, the amount of coal that cannot be stored in coal storage in 2027 is 99,000 tons, therefore, the company must increase its coal storage capacity to 160,000 tons from the existing capacity of 61,000 tons. Increasing coal storage capacity from 61,000 tons to 160,000 tons, coal barging capacity from 4,100 tons to 5,000 tons and also increasing the number of trucks in the process of unloading from 2 units to 5 units will reduce the average number of waiting in barge slips from 19,879 hours in 2020 to 0.47 hours in 2027, it will also reduce the average waiting time in Barge Slips from 84.93 hours to 56.88 hours. The improvement also reduces the average waiting time in trucks processing from 12.08 hours in 2020 to 3.85 hours in 2027 and will reduce the number of barges waiting in barge slip from 44 units in 2020 to 16 units in 2027.

Testing results from this arena cannot be directly applied in existing conditions. Implementation in the existing conditions will directly disrupt the ongoing operation process. This application also requires other analyses such as sensitivity analysis and financial analysis and more importantly, it requires considerable effort, time, and cost. However, the results of this paper will greatly assist the company in determining the amount of additional stockpile capacity, barge capacity, and the optimal number of trucks. The optimal amount referred to in this paper is the amount that can produce the most significant queue reduction times, can meet the highest demand in the next 10 years, and can eliminate the risk of companies getting penalized for delays.
5. Conclusions & future research
The existing condition of the company cannot meet future demand and is at risk of being penalized because it cannot fulfill the agreed of maximum loading and unloading time. Improvement conditions by increasing the capacity of barges from 4,100 tons to 5,000 tons, adding stockpile capacity from 61,000 tons to 160,000 tons, and increasing the number of trucks from 2 units to 5 units can overcome this problem.

The contribution of this paper for the company is to help the company develop port optimally following the production plan, generate objective and optimal decisions by considering the decrease in queue time. The contribution of this paper to science is to be a reference material for other companies that have a similar business process flow to determine the optimal addition of resources.

The recommendation for further research is to add cost and financial analysis calculations to get the most optimal and economic addition, and add other scenarios such as increasing the number of e-crane, the number of barge slip. Sensitivity analysis is also a useful tool to react inconsistency from price. Financial analysis, sensitivity analysis, and adding more scenarios from increasing resources will make this research better.

References
[1] Daellenbach HG, McNickle DC. J Classif. Macmillan Education UK; 2005;10–20. doi.org/10.1007/978-0-230-80203-2_2
[2] Daellenbach HG, McNickle DC. Systems thinking. Manag. Sci. Macmillan Education UK; 2005;10–20. doi.org/10.1007/978-0-230-80203-2_2
[3] Law, A. M., & Kelton, W. D. 2000. Simulation Modeling and Analysis. New York: Mcgraw Hill.
[4] Husnan dan Suad. 1982. Teori Antrian. Yogyakarta: BPFE.
[5] Rosetti. 2016. Simulation modeling & Arena 2nd edition, Wiley.
[6] Taha, H.A. 1997. Riset Operasi : Suatu Pengantar. Terjemahan Daniel Wirajaya, Jakarta: Binarupa Angkasa.
[7] Hasan dan M.Iqba. 2002. Teori Pengambilan Keputusan. Jakarta: Ghalia Indonesia.
[8] Dundovic, Cedomir and Hess, Svjetlana. 2005. Exploitability of the Port Container Terminal Stacking Area Capacity in the Circumstances of Increased Turnover. ISEP 2005.
[9] Gurning, Raja Oloan Saut, Budiyanto, dan Eko Hariyadi. 2007. Manajemen Bisnis Pelabuhan. Jakarta: PT Andhika Prasetya Ekawahana.
[10] Jinca dan Yamin N. 2011. Transportasi Laut Indonesia, Analisis Sistem dan Studi Kasus. Surabaya: Brilian Internasional.
[11] Musso E, Ferrari C, Benacchio M. Port Investment: Profitability, Economic Impact and Financing. Res. Transp. Econ. Elsevier BV; 2006 Jan;16:171–218. doi.org/10.1016/s0739-8859(06)16008-4
[12] Triatmodjo, B. 2009. Perencanaan Pelabuhan. Yogyakarta : Beta Offset.