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System Dynamics Model to Improve Logistics Cost Efficiency in Fertilizer Distribution Outside Java (Gresik - Medan)

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Abstract. Within the vast development of globalization, companies are encouraged to increase competitiveness level, in order to survive in the market. One certain way to stay competitive and retain customers is to provide such products with reasonable selling prices. Supply chain costs have a great influence upon the cost of the final product; therefore, companies are suggested to continuously improve supply chain processes regarding reducing overall costs. One industry indicated with high supply chain costs is the fertilizer industry, referring to the fact that it has a nationwide distribution system. For countries which regulate fertilizer as a subsidized product, companies must be able to provide fertilizer at an efficient price to maintain prevalence in the market. Currently, the problem faced by one of the fertilizer companies is an indication of expensive logistics costs for fertilizer distribution outside Java. The most expensive logistics costs are owned by the Medan area with variations in bulk transportation. This problem can be solved if there are alternative economic scenario designs in accordance with capabilities. The purpose of this research is to provide alternative scenarios, simulate those scenarios, and choose the most efficient scenario. The method used in this research is system dynamics and 12 scenarios were generated in this paper. Selection of the appropriate ship size and type of heavy equipment for loading and unloading cargo from those scenarios can impact in energy saving/fuel consumption and minimize operational costs. Beside cost, fertilizer deficit is also a consideration in scenario selection. From the result, scenario 3 has the lowest distribution costs with a total cost is Rp. 241,513 and the total fertilizer deficit is 0 tons, so scenario 3 is the selected alternative scenario to minimize operational cost.

Introduction

A low-cost strategy and a fast response to market fulfillment are very important challenges in today's world of goods and services industry. In general, all companies aim to increase profits as many as possible and minimize expenses, but many expenditure problems are often encountered. And often the biggest expenses lie in the distribution process to customers [1]. This is commonly known as logistics management which is part of Supply Chain Management (SCM).

SCM is a series of planning, coordinating, and controlling all business processes and activities in the Supply Chain to create the best consumer value at an efficient cost while still meeting all the needs of other stakeholders in the Supply Chain [2]. Meanwhile, logistics management is part of SCM which is focused on the flow of finished goods that are connected to the place of origin and destination to meet the needs of customers [3]. Both of these are very important elements to improve cost efficiency, and to minimize a company's expenses [3, 4].

PT. X is a company engaged in the fertilizer sector. Products from PT. X are exported abroad, and some are also marketed domestically and will be distributed to several regions. Many new competitors from abroad have started to enter Indonesia. In 2019, fertilizer imports reached 6.134 million tons from more than 19 countries [5]. Fertilizer producers from abroad dare to compete with local fertilizer producers at competitive prices. This makes domestic fertilizer producers have to improve to be able to compete. All activities carried out by PT. X to meet customer needs still cannot be separated from costs. Starting from the initial arrival of the ship's raw materials, then processed into finished fertilizer, to delivery using ships and trucks to meet the needs in an area.

Recently, PT. X wanted to reduce logistics costs because it indicated that there was an expensive cost of transporting fertilizer to marketing warehouses where the fertilizer was transported by ship. In terms of quantity, PT. X had a higher share in Java Island to distribute fertilizers when compared to the total distribution outside Java. However, there was a problem that the logistics costs of distributing fertilizer to Outside Java are much higher. From the data owned by PT. X, it appears that the highest logistics costs lay in the cost of distributing fertilizer from PT. X warehouses to Distribution Center (DC) warehouses outside Java which reached 731.5 billion rupiah or equivalent to 43% of the total cost [6]. The following is data on logistics expenditures owned by PT. X. The delivery of fertilizer to areas outside Java is divided into 3 variations of shipments consisting of bulk, in-bag, and container. In the delivery demand data, four regions have large quantities listed in tons, and the Medan area is the area which obtains the highest demand by having all three variations of the demand for fertilizers. Of the three variations of delivery which are requested from the Medan Region, the Bulk variation is the largest demand from that area. This problem can be solved by designing an alternative fertilizer distribution design that is economical and following the capabilities.

The objective of this work is to explore the application of System Dynamics Modelling in logistic and supply chain management. System Dynamics methodology was introduced by Forrester as a modelling and simulation for long – term decision making in dynamic industrial management cases [7]. Since then, SD has been used to address numerous issues with business strategy and policy [8–10]. Various researchers have been documented publications using SDM in supply chain modelling, but most of them refer to forward logistics [11].

In this paper, several designed an alternative fertilizer distribution were proposed to solve the problem of inefficiency in distributing fertilizer from origin warehouse to destination warehouse. Therefore, twelve alternative scenarios of fertilizer distribution are generated in this paper so that they can be analyzed and simulated using system dynamics.

Methodology

In this paper, System Dynamics Model (SDM) are used to evaluate the potential reduction in fertilizer distribution cost in PT. X and in order to help management PT. X make effective strategic decisions. SDM is one widely used modelling tools to develop models that are based on historical data and several sub systems to reflect the dynamic relationship between important variables in each system [12,13]. In general, SDM consists of concept of development step, modelling step, simulation model step, and validation & verification of simulation results [14]. The proposed methodological procedure is presented by the diagram in Figure 1. After problem identification and literature study, data will be collected, and several alternative scenarios will be generated. Then, several scenarios simulated in Powersim Studio 8. At the end, validation and analysis will be carried out as well as compiling conclusions and suggestions for this research.

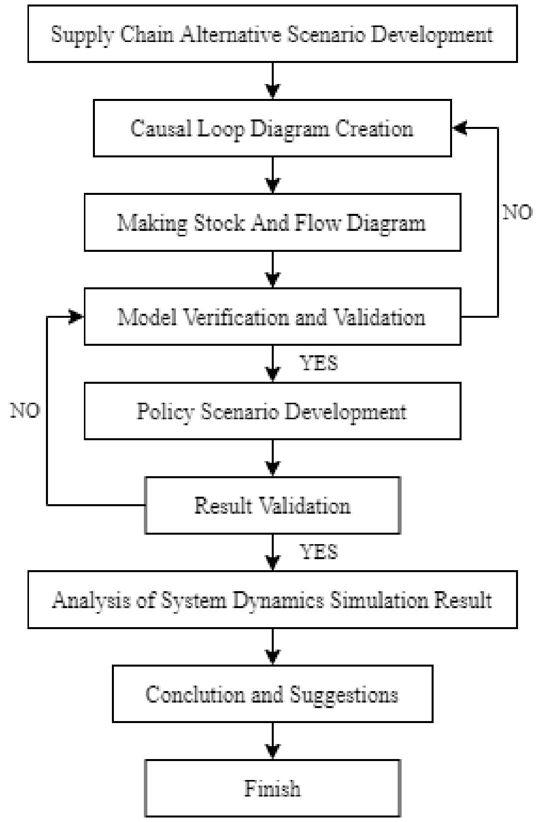


Fig. 1. Methodology

A. Supply Chain Alternatif Scenario Development

In the process of simulation, it takes several scenarios of fertilizer distribution which will be compared, so that it will emerge which scenario is the most efficient in terms of cost. The scenario made is an alternative scenario that adapts to real done by PT. X except in the aspect of ships. The ship is chosen randomly to find which ship capacity is the most efficient in terms of cost. The cost aspect of the ship will be determined from the operational cost of selected ship.

B. Causal Loop Diagram

Causal Loop Diagram (CLD) in dynamic system modeling is part of systems thinking that is used to review several types of systems and the same perspective, thus forming a diagram. According to [9] the Causal Loop Diagram (CLD) is a representation of the conceptualization of the system dynamics model to be built. Through CLD the system dynamics model to be developed is explained by showing the causal relationship between the variables entered the model before next to the model development stage. By showing each relationship between variables in the system, CLD can show the hypothetical results of a system modeled with system dynamics.
In a CLD, the relationship between two variables is represented by an arrow that marks the relationship between the two variables. In addition, there is also a positive sign (+) and a negative sign (-) which refer to how the two variables are related. The positive sign shows a positive effect, meaning that if there is a change in a certain variable, it will affect the other variables which are associated with a positive arrow and will change in the same direction. On the other hand, the negative sign indicates a negative effect where if there is a change in a certain variable it will affect other variables but in a different direction of change [15].

C. Stock And Flow Diagram

The stock flow diagram is a concept of a system dynamics model that serves to represent the stock and flow of a particular system [9]. Stock and flow diagrams can be described as a container where the flow of water enters through the valve and the volume of water can be reduced by opening the valve in the container. The container is represented as a 'stock' in a stock flow diagram whereas the flow of water flowing either in or out of a tube distorted by a valve is a 'flow' in a stock flow diagram.

D. Model Verification and Validation

Verification indicates that the developed model produced is a conceptual model, and validation is a step to determine one of the successful models with its implementation representing real conditions or not [16]. In this study, 3 (three) methods would be used to validate the simulation:

1. Structural Scoring Test
   This test aims to determine whether the structural model has represented the conceptual model by containing all the same elements, relations, and events or not [16]. The conceptual model refers to the Causal Loop Diagram.
2. Dimensional Consistency Test
   It is important that the units of measurement for the variables on both sides of the equation are the same. This test also checks whether the dimensions of the variables in the model correspond to the units in which they can correctly express the real variables that exist in the company [17].
3. Extreme Condition Test
   This test is intended to test the model that has been made with predetermined limits on the causal loop. When the simulation takes place, a variable will be entered in an extreme value to see the attachment between one variable and another [17].

E. Result Verification and Validation

At this stage, validation of the results that have been obtained will be carried out. The simulation results will be matched with the results from real data so that the actual system output that occurs in real conditions also occurs in the simulation conditions that have been made. When the output of the simulation and the real conditions are the same, the results of the alternative scenarios in the simulation can be declared valid.

Results and Discussion

After the required data is obtained, the next step is to create several alternative scenarios that adjust the real conditions of PT. X and develop it on aspects of ships that have different variations in cargo to compare which of each scenario has the most efficient cost. This aspect of the cost of the ship will be determined from the cost of fuel incurred to move variations in shiploads. The following are 12 forms of logistics scenarios that will be simulated using system dynamics to see which scenario is the most cost- effective. Alternative scenarios can be seen in Table 1.

Table 1. Alternative Scenarios

Scenario	Loading	Ships Payload	Unloading	Warehouse
1	Conveyor	16.800	Truck and Crane	DC warehouse
2	Conveyor	26.100	Truck and Crane	DC warehouse
3	Conveyor	34.300	Truck and Crane	DC warehouse
4	Conveyor	52.200	Truck and Crane	DC warehouse
5	Conveyor	41.400	Truck and Crane	DC warehouse
6	Conveyor	25.200	Truck and Crane	DC warehouse
7	Truck and Crane	16.800	Truck and Crane	DC warehouse
8	Truck and Crane	26.100	Truck and Crane	DC warehouse
9	Truck and Crane	34.300	Truck and Crane	DC warehouse
10	Truck and Crane	52.200	Truck and Crane	DC warehouse
11	Truck and Crane	41.400	Truck and Crane	DC warehouse
12	Truck and Crane	25.200	Truck and Crane	DC warehouse

After the alternative scenario has been created, the next step is to model the condition of the existing using the variables shown by the causal loop diagram. These variables must be determined in advance because they are needed to formulate the diagram. Then the causal loop diagram will serve as a guide for creating the basic model. The basic model is a model that already represents the existing system in fertilizer distribution. The causal loop diagram that will be made is a diagram that shows the growth of fertilizer distribution costs carried out. The conceptual model of fertilizer distribution costs can be seen in Figure 2.

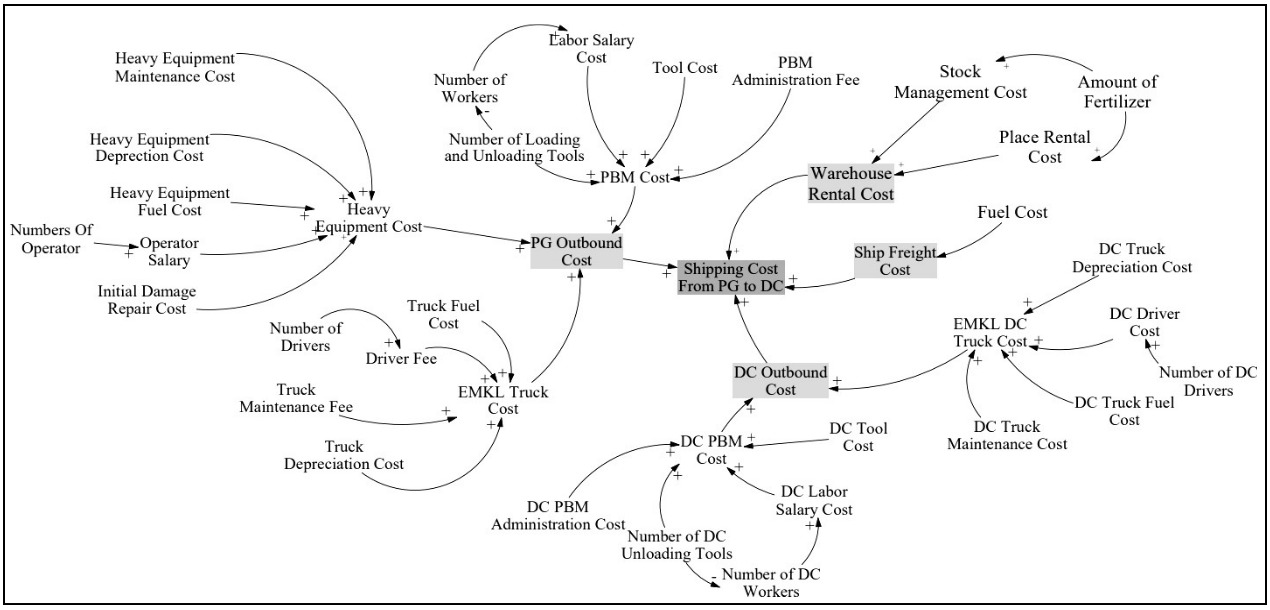


Fig. 2. Causal Loop Fertilizer Distribution Diagram

In the causal loop modeling the cost of sending fertilizer from PT. X to Medan Distribution Centre, there are 4 main variables, namely PT. X outbound costs, Ship freight costs, warehouse rental costs, and DC outbound costs. In the main variable, there are also sub-variables that influence each other as follows.

1. PT. X Outbond Cost

   PT. X outbound costs are costs incurred to transport PT. X to Medan port. Aspects in this cost include heavy equipment costs, which are heavy equipment operational costs such as pay loader costs to lift bulk fertilizer to trucks, and also conveyor operating costs, trucking costs, which are costs for transporting bulk fertilizer from the PT. X warehouse to the port using trucks, and PBM costs, which are the costs of transporting fertilizer from the truck or dock to the ship.

$$Outbond\ Cost = Heavy\ Equipment\ Cost + PBM\ Cost + Trucking\ Cost \tag{1}$$

2. Ship Freight Cost

   Ship freight costs are costs that will be incurred to send fertilizer from PT. X port to Medan port. Aspects that include ship freight include the cost of fuel oil to move the main engine and auxiliary engine when the ship is sailing. In addition to this, fuel costs also include lubricants used by the main engine and auxiliary engines on the selected ship.

$$FOC = \frac{BHP\ Engine\ \times SFOC\ Engine \times\ Unit}{1000} \times t \tag{2}$$

3. Warehouse Rental Cost

   Warehouse rental costs are costs that will be incurred to rent a place according to the required fertilizer capacity. In addition to capacity, other costs that need to be incurred are for managing the stock of fertilizer in the warehouse so that it does not get damaged quickly.

$$Warehouse\ Rental\ Cost = Rental\ Cost + Stock\ Management\ Cost \quad (3)$$

4. DC Outbond Cost
   Outbound DC costs are costs incurred to transport fertilizer products from PT. X from DC port to DC warehouse. Aspects in this cost include PBM costs, which are costs for transporting fertilizer from ships or docks to trucks using shore cranes or vessel cranes, and trucking costs, which are costs for transporting bulk fertilizer from DC port to DC warehouse using trucks.

$$DC\ Outbond\ Cost = PBM\ Cost + Trucking\ Cost \quad (4)$$

After making a Causal Loop Diagram and knowing all its relationships with all variables, the next step is to make a Stock and Flow Diagram. In each scenario, there are 2 (two) kinds of Stock and Flow Diagrams. First, Stock and Flow Diagram discuss the flow process of fertilizer distribution in PT. X and the second Stock and Flow Diagram discuss the estimation cost from this scenario. From the existing data, 12 Stock and Flow Diagrams were generated in this paper. Stock and Flow Diagrams are presented in Figure 3 and Figure 4.

In the Stock and Flow Diagram, the distribution is divided into several parts which indicate that the fertilizer distribution runs from the PT. X warehouse to DC Medan. Starting from the stock in the warehouse, loading fertilizer to the ship using a conveyor, ships with varying payloads, unloading fertilizer using a shore crane and expedition to the DC warehouse using a truck. The formula used from the Stock and Flow Diagram above is the "IF", "AND" and "OR" formulas.

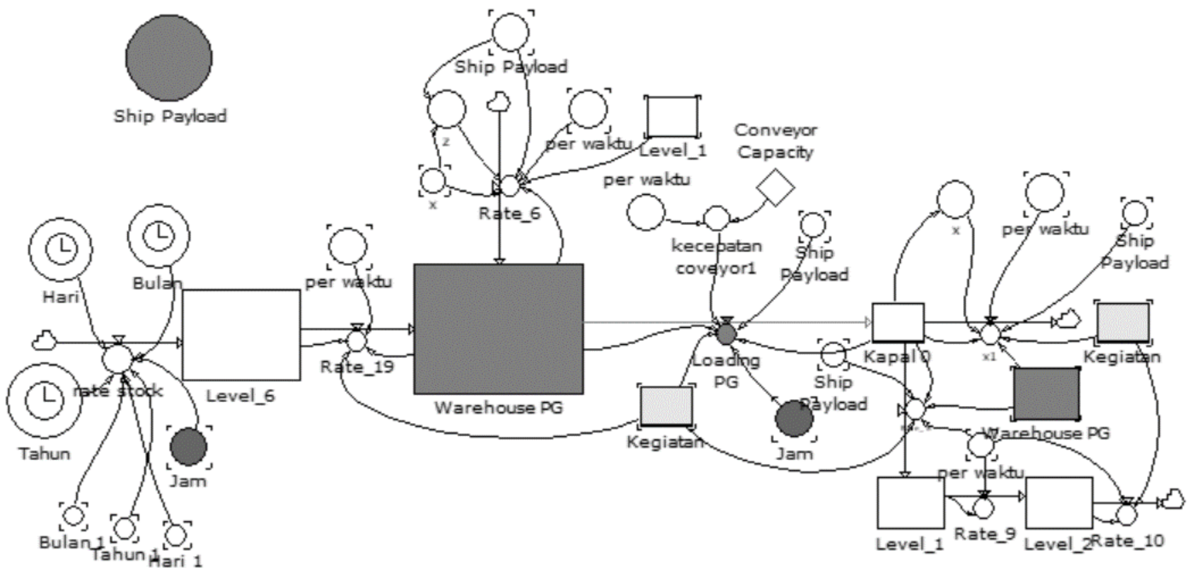


Fig. 3. Stock and Flow Diagram of Loading Fertilizer

To run the distribution simulation, activities will be carried out in the system dynamics simulation. The activities in this simulation are divided into four activities. The first activity is loading from the PT. X warehouse to the ship using a conveyor. The second activity is that after the ship is fully loaded according to the specified payload, the ship will sail according to the distance and speed of the ship. The third activity is that after the ship arrives at its destination, the fertilizer will be unloaded by Shore Crane DC and will be carried by truck to the DC Medan warehouse.

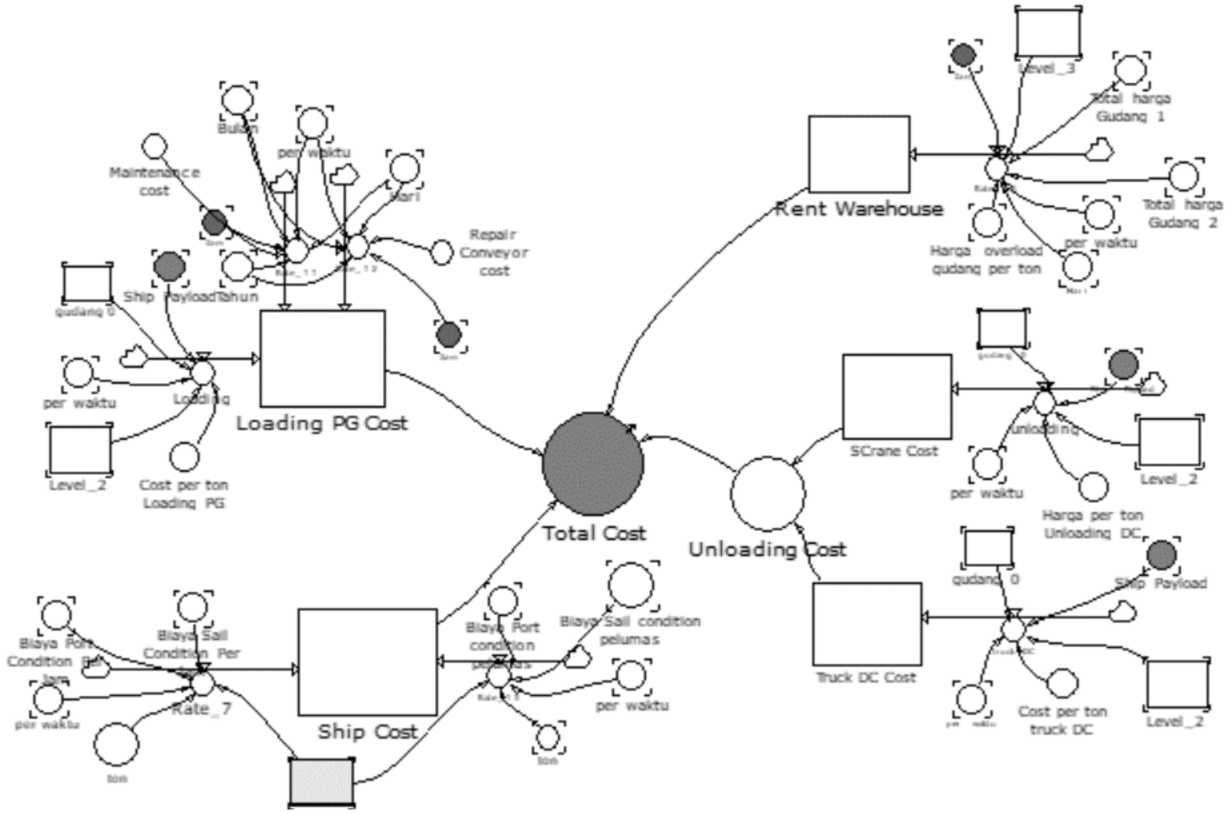


Fig. 4. Stock and Flow Diagram of Logistic Costs

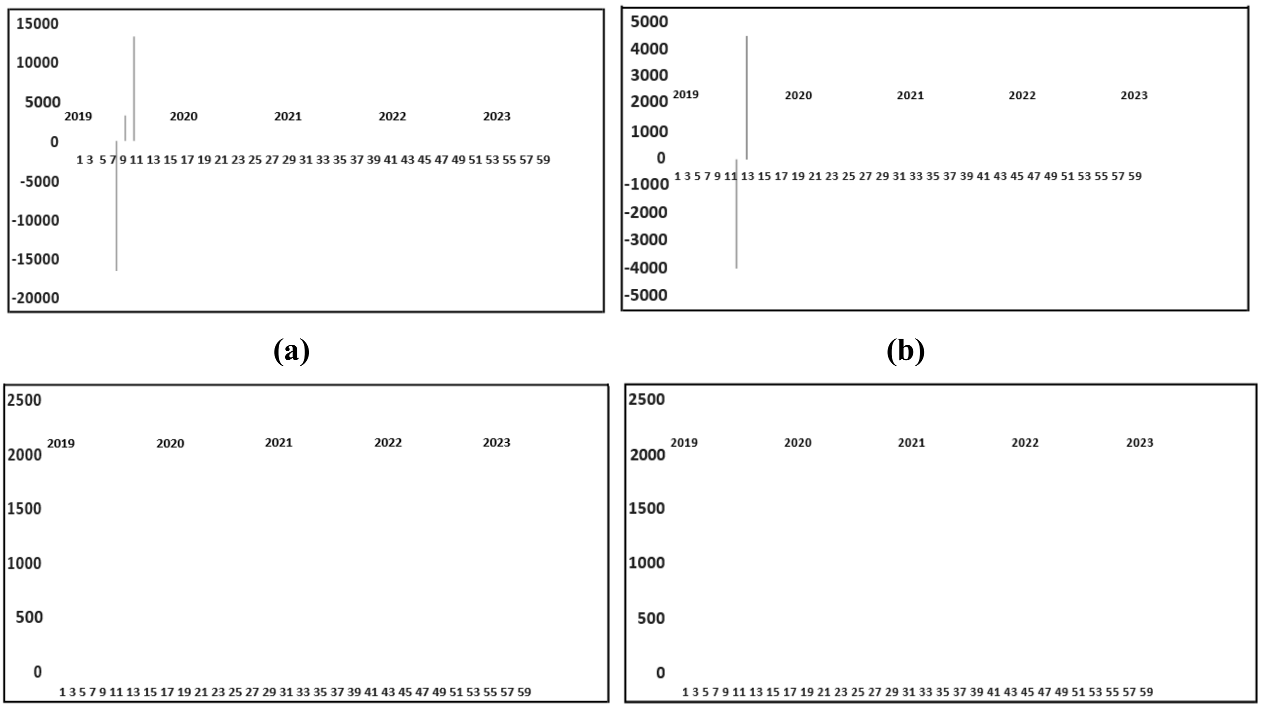
To calculate the fuel requirements, there are 6 different ships whose fuel requirements will be calculated according to the specifications of the Main Engine and Auxiliary Engine of the ship. In this simulation, two ship conditions will be calculated, when sailing and unloading at the port. For fertilizer loading simulation, fertilizer will be moved from the PT. X warehouse using a conveyor or truck and crane to the selected ship until the ship's payload is full. For shipping, the ship will run according to the speed and distance that adjusts the real conditions of the ship and the berth distance so that the time can automatically adjust. For the flow of fertilizer, unloading using a shore crane and later it will be loaded in a truck so that the truck can move and distribute it to the DC warehouse. For Stock and Flow Diagrams this cost is the same model as the causal loop diagram which is the initial benchmark for running this simulation. In the Stock and Flow Diagram, the logistics costs are divided into several parts that indicate different cost aspects. Stock and Flow Diagram refers to the movement of the Stock and Flow Diagram distribution. These aspects include conveyor costs, which are loading costs, shore crane costs, and DC truck costs, which are unloading costs, ship costs which are FO and LO costs, as well as DC warehouse rental costs located in Medan.

The simulation was carried out for 5 years, and Table. 2 shows a summary of the total cost of fertilizer distribution results. In addition to simulating the flow process of distribution and estimating cost, this paper also simulated the deficit between supply and demand in each scenario. The result from simulation of deficit of supply and demand in each scenario was taken into consideration for selecting the most efficient scenario.

Table 2. Total Costs in All Scenarios

Scenario	Total Cost	Total Cost per Ton
Scenario 1	Rp221.334.233.586	Rp264.172
Scenario 2	Rp205.929.357.116	Rp245.786
Scenario 3	Rp202.349.574.658	Rp241.513
Scenario 4	Rp231.082.903.420	Rp275.808
Scenario 5	Rp209.814.390.200	Rp250.423
Scenario 6	Rp200.088.981.642	Rp238.815
Scenario 7	Rp257.995.339.192	Rp307.929
Scenario 8	Rp242.517.850.297	Rp289.456
Scenario 9	Rp239.013.127.874	Rp285.273
Scenario 10	Rp267.748.292.343	Rp319.569
Scenario 11	Rp246.462.348.627	Rp294.164
Scenario 12	Rp236.743.605.977	Rp282.564

Scenario 1 is a distribution model scenario using a conveyor when loading from PT. X and using a ship that has a payload of 16,800 tons. The total cost obtained from the simulation of scenario 1 for five years reached Rp221,334,233,586 and Rp264,172 per ton. The number of ship trips in scenario 1 reach 70 trips. In Figure 5a**,** there are 3 months in 2019 that are found to have a fertilizer difference, May, June, and July. In May the fertilizer data submitted was less than 16,513 tons of fertilizer from the existing demand. In June there was an excess of 3,225 tons of fertilizer and in July there was also an excess of 13,258 tons. This happened because the selected ship payload is relatively small.



(a) **(b)**

(c) **(d)**

Fig. 5. Deficit between Supply and Demand in a) Scenario 1; b) Scenario 2; c) Scenario 3; d) Scenario 4.

Scenario 2 is a distribution model scenario using a conveyor when loading from PT. X and using a ship that has a payload of 26,100 tons of fertilizer. The total cost obtained from the simulation of scenario 2 for five years reached Rp205,929,357,116 and Rp245,786 per ton. The price is quite expensive because the payload is still relatively small and the number of ship trips in scenario 2 reached 52 trips. However, the higher payload, the lower the number of trips, so that the operational cost of ship can decrease. The number of trips is one of the important aspects of the total distribution price. In Figure 5b, there are 2 months in 2019 were found to have a fertilizer difference, June, and July. In June the fertilizer data submitted was less than 3,958 tons of fertilizer from the existing demand and in July there was an excess of 3,958 tons of fertilizer.

Scenario 3 is a distribution model scenario using a conveyor when loading from PT. X and using a ship that has a payload of 34,300 tons of fertilizer. The total cost obtained from the simulation of scenario 3 for five years reached Rp202,349,574,658 and the price per ton reached Rp241,513. The price is relatively low because the large payload can carry more cargo, the more tonnage of fertilizer carried in one trip then the number of trips can be less. The number of ship trips in scenario 3 reached 48 trips. In Figure 5c, there is no fertilizer deficit resulting from this scenario. This is due to the fertilizer that is brought according to the amount of demand from each month that is available.

Scenario 4 is a distribution model scenario using a conveyor when loading from PT. X and using a ship that has a payload of 52,200 tons. The total cost obtained from the simulation of scenario 4 for five years reached Rp231,082,903,420 and Rp275,808 per ton. The number of ship trips in scenario 4 is 47 trips. In Figure 5d, there is no fertilizer deficit resulting from scenario 4. This happened because the supply of fertilizer carried by ship followed the monthly demand.

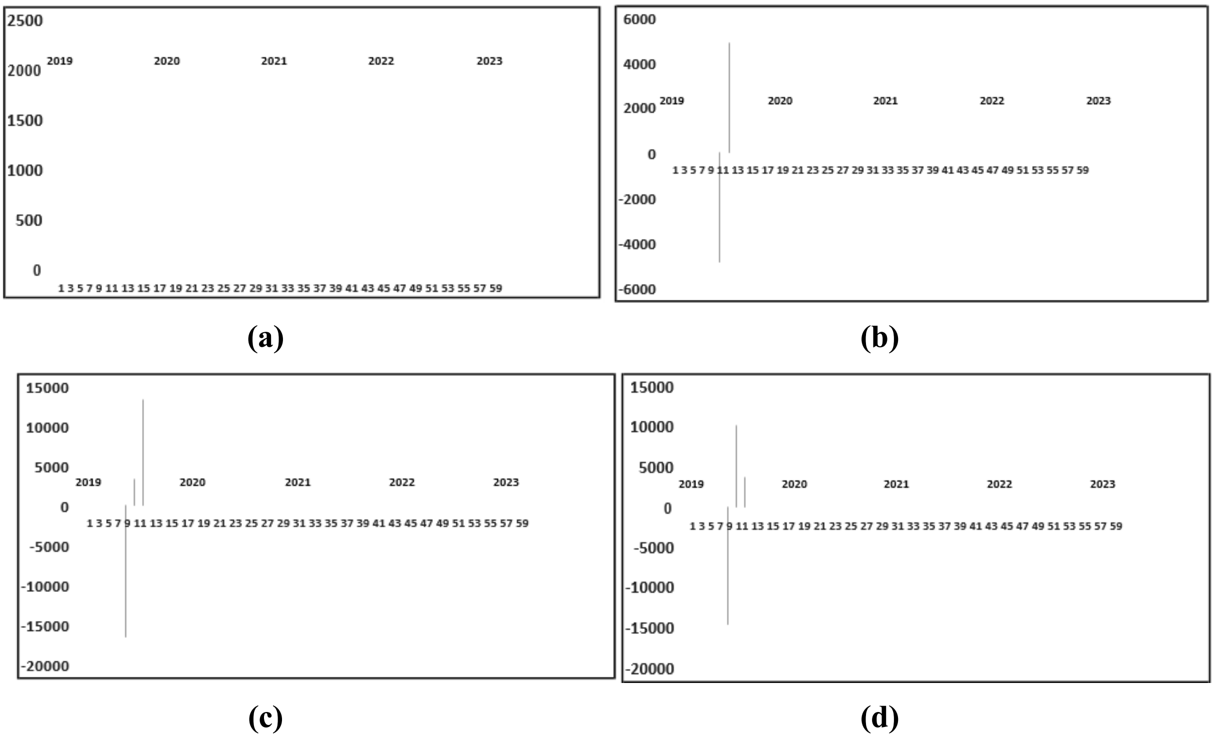


Fig. 6. Deficit between Supply and Demand in a) Scenario 5; b) Scenario 6; c) Scenario 7; d) Scenario 8.

Scenario 5 is a distribution model scenario using a conveyor when loading from PT. X and using a ship that has a payload of 41,400 tons. The total cost obtained from the simulation of scenario 5 for five years reached Rp209,814,390,200 and in price per ton, it reached Rp250,423. The number of ship trips in scenario 5 reached 48 trips. In Figure 6a above, there is no fertilizer deficit resulting from scenario 5. This happened because the supply of fertilizer carried by ship followed the monthly demand.

Scenario 6 is a distribution model scenario using a conveyor when loading from PT. X and using a ship that has a payload of 25,200 tons. The total cost obtained from the simulation of scenario 6 for five years reached Rp200,088,981,642 and Rp238,815 per ton. The number of ship trips in scenario 6 reached 55 trips. In June 2019 the fertilizer data submitted was less than 4,858 tons of fertilizer from the existing demand. In July there was an excess of 4,858 tons of fertilizer, this is because the fertilizer deficit in June was distributed in the following month. The result can be seen in Figure 6b.

Scenario 7 is a distribution model scenario using trucks and cranes when loading from PT. X and using a ship that has a payload of 16,800 tons. The total cost obtained from the simulation of scenario 7 for five years reached Rp 257,995,339,192 and Rp307,929 per ton. The number of ship trips in this scenario reached 70 trips. In Figure 6c above, 3 months in 2019 were found to have a fertilizer difference, May, June, and July. In May the fertilizer data submitted was less than 16,513 tons of fertilizer from the existing demand. In June there was an excess of 3,225 tons of fertilizer and in July there was also an excess of 13,255 tons. This was because the fertilizer deficit in May was distributed in the following month.

Scenario 8 is a distribution model scenario using trucks and cranes when loading from PT. X and using a ship that has a payload of 26,100 tons of fertilizer. The total cost obtained from the simulation of scenario 8 for five years reached Rp242,517,850,297 and Rp289,456 per ton. The number of ship trips in this scenario reached 52 trips. In Figure 6d, 3 months in 2019 were found to have a fertilizer difference, May, June, and July. In May the fertilizer data submitted was less than 14,653 tons from the existing demand. In June there was an excess of 10,095 tons and in July there was an excess of 3,718 tons, this was because the fertilizer deficit in May was distributed in the following month.

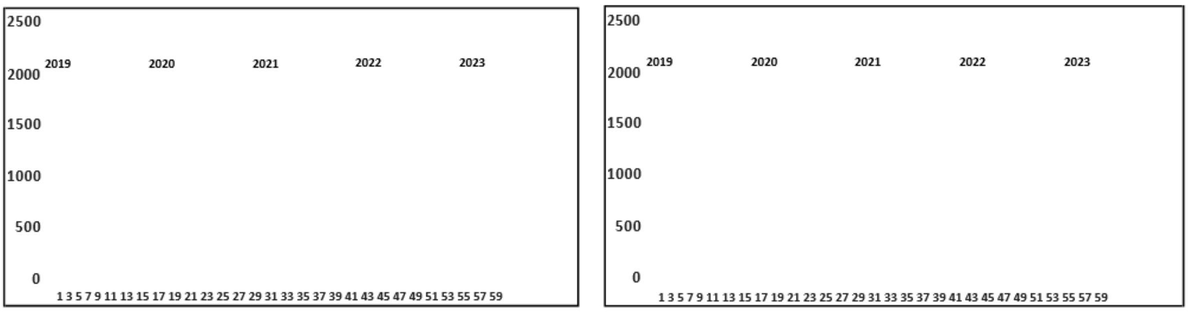


Fig. 7. Deficit between Supply and Demand in a) Scenario 9; b) Scenario 10.

Scenario 9 is a distribution model scenario using trucks and cranes when loading from PT. X and using a ship that has a payload of 34,300 tons. The total cost obtained from the simulation of scenario 9 for five years reached Rp239,013,127,874 and Rp285,273 per ton. In Figure 7a, there is no fertilizer deficit resulting from this scenario 9. This happened because the supply of fertilizer carried by ship followed the monthly demand.

Scenario 10 is a distribution model scenario using trucks and cranes when loading from PT. X to ship and using a ship that has a payload of 52,200 tons. The total cost obtained from the simulation of scenario 10 for five years reached Rp 267,748,292,343 and Rp319,569 per ton. The number of ship trips reached 47 trips. In Figure 7b, no fertilizer deficit results from this scenario.

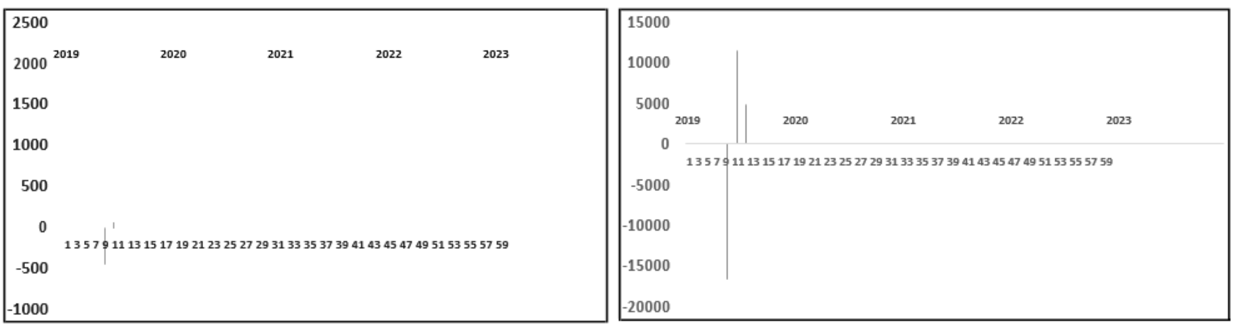


Fig. 8. Deficit between Supply and Demand in a) Scenario 11; b) Scenario 12.

Scenario 11 is a distribution model scenario using trucks and cranes when loading from PT. X to ship and using a ship that has a payload of 41,400 tons. The total cost obtained from the simulation of scenario 11 for five years reached Rp246,462,348,627 and Rp294,164 per ton. In Figure 8a, two months in 2019 were found to have a fertilizer difference, May and June. In May the fertilizer data submitted was 433 tons less than the existing demand. In June there was an excess of 73 tons of fertilizer, this is because the fertilizer deficit in May was distributed in the following month.

Scenario 12 is a distribution model scenario using trucks and cranes when loading from PT. X to ship and using a ship that has a payload of 25,200 tons. The total cost obtained from the simulation of scenario 12 for five years reached Rp 236,743,605,977 and Rp 282,564 per ton. In Figure 8b, 3 months in 2019 were found to have a fertilizer difference, May, June, and July. In May the fertilizer data submitted was less than 16,663 tons of fertilizer from the existing demand. In June there was an excess of 11,415 tons of fertilizer and in July there was an excess of 4,858 tons, this was because the fertilizer deficit in May was distributed in the following month.

There are two parameters to select the best scenario: scenario with the minimum total cost and a scenario with no deficit. From the simulation results above, it can be concluded that scenarios 3 and 6 have minimal distribution costs among all existing scenarios. However in the result of scenario 6 there is a deficit, so the selected scenario is scenario 3. Scenario 3 has minimum cost because the payload on the ship was quite suitable for the demand and this factor also impacted the number of ship trips. The fewer number of ship trips resulted in decreasing fuel oil consumption of the ship. Selection of the right type of heavy equipment for loading and unloading cargo can impact in energy saving/fuel consumption and minimize operational costs.

Conclusion

From the results of research carried out in the paper, the authors summarize as follows:

1. In providing alternative forms of scenarios, 12 scenarios have been created. The scenarios consist of loading cargo, ship payload, unloading cargo, and warehouse rental. For loading cargo, two aspects will be simulated, i.e., loading using a conveyor or loading using trucks and cranes. For ships, there are about 6 ships that have different payloads. The ship's payload varies from 16,800 tons to 52,200 tons and the warehouse rental cost with the provision of data obtained from the PT. X.
2. The twelve (12) scenarios were simulated in the Powersim Studio 8 software. From the simulation results, a comparison of each cost in each scenario is obtained and scenario 3 has the lowest distribution costs.
3. There is no deficit in the scenarios 3, 4, 5, 9, and 10 because they have sufficient cargo to distribute fertilizer according to demand. Scenario 3 has the minimal distribution costs because the payload is quite large so that the number of ship trips are relatively small. Number of ship trips have a great influence on fuel oil consumption in one year. Scenario 3 is an alternative scenario that uses conveyors when loading, has a shipload of 34,300. tons, as well as loading and unloading using shore cranes and trucks. The total logistics cost is Rp202,349,574,658, the cost per ton is Rp241,513 and there is no fertilizer deficit every month.

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