HYBRID SIMULATION AND INTEGER LINEAR PROGRAMMING MODEL FOR INTERMODAL DISTRIBUTION: A CASE STUDY OF FERTILIZER COMPANY IN INDONESIA

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ABSTRACT

The company currently delivers fertilizer using trucks with a capacity of 16 tons directly from factory to distributor. In practice, trucks deliver fertilizer more than their capacity that causes frequent traffic accidents. It prompted the Indonesian government to make regulations that prohibit trucks from carrying loads that exceed their capacity. If the regulation is fully implemented, it will significantly increase the cost of distribution. Therefore, the company intensively tries to find ways to reduce delivery costs. Currently, the company considering intermodal delivery as an alternative in delivering fertilizer to distributor. In this alternative, bulk fertilizer is sent by ship, then bulk fertilizer is brought by the truck to the packing plant and after bagging, the fertilizer is sent by truck to the distributor. The company needs to determine optimal combination of direct delivery using trucks and intermodal delivery in bulk using ships and trucks. Intermodal delivery, in this case, is a complex problem. It is because there are uncertainty and interdependency between stages in the delivery. Therefore, simulation is used to estimate capacity of packing plant. The simulation model is sub-model of Integer Linear Programming (ILP) model. The output of simulation model will be used as right-hand-side (RHS) of capacity constraint in the ILP Model. In addition, sensitivity analysis has been done to explore characteristics of solution in some different ship capacity and some overload thresholds capacity in regulation. The optimal solution of the ILP model shows two important insights that are many district warehouses are still more efficient to be supplied directly by truck from factory and the farther the distributor's location, the more chance it will be supplied via intermodal delivery.

Keywords: intermodal, integer linear programming, simulation, distribution

1. INTRODUCTION

The company, currently, delivers fertilizer using trucks with a capacity of 16 tons directly from the factory to distributor. There are 30 district warehouses. In practice, trucks deliver fertilizer more than their capacity that causes frequent traffic accidents. It prompted the Indonesian government to make regulations that prohibit trucks from carrying loads that exceed their capacity. If the regulation is fully implemented, it will significantly increase the cost of distribution. The increase in costs can reach 100%. This forces companies which use trucks to distribute their products to think of ways to reduce distribution costs.

The company intensively tries to find ways to reduce delivery costs. Currently, the company considering intermodal delivery as an alternative in delivering fertilizer to district warehouses. In this alternative, bulk fertilizer is sent by ship, then bulk fertilizer is brought by the truck to the packing plant and after bagging, the fertilizer is sent by truck to the district warehouse. This strategy is the implementation of a postponement strategy. In addition to distribution costs, this strategy can also reduce inventory costs. The postponement strategy can significantly reduce end-product inventory by permitting supply chains to hold semifinished goods in inventory awaiting final assembly or customization. Evidently, this can lower inventory costs, since the space used to store finished products is usually larger than the space required to hold semi-finished products (Leung & Ng, 2007a).

The two alternative fertilizer shipments are illustrated in figure 1.

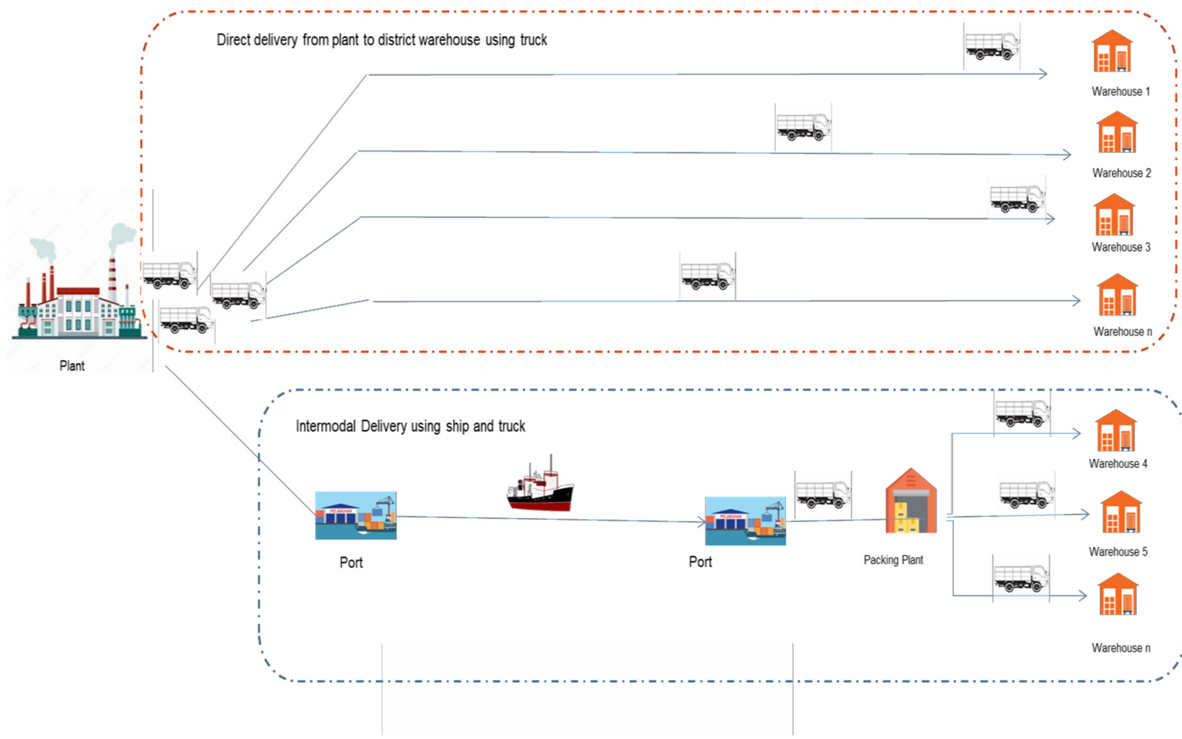

Figure 1. Direct Delivery and Intermodal Delivery Using Truck and Ship.

Fertilizers need to be distributed to a wide and spread area so that there will be some district warehouses that are more efficient if the delivery is done directly from the factory and there are some district warehouses that will be more efficient if the shipments are done by intermodal ships and trucks. The company needs to determine which district warehouse should be supplied with the two delivery alternatives.

2. METHOD

The problem is solved by a combination of optimization and simulation methods. The optimization method used is integer linear programming (ILP) and the simulation method used is discrete event simulation (DES). Optimization method has advantages to provide optimal solutions. However, this method cannot properly model the uncertainties and interdependencies between system elements. in addition, optimization methods are also difficult to use for large scale problems. Conversely, the simulation method can properly model the uncertainty and interdependence of system elements but this method cannot provide an optimal solution. The simulation method can only determine the best alternative solution among the several alternative solutions tried. In this problem, the simulation model is a submodel of the optimization model.

The integration of optimization and simulation methods has been carried out in many studies and on various problems.Viera et al (2019) developed a model of production planning and detailed scheduling. In this study, the production plan is prepared with an optimization model. Simulation is used to test whether the plan can be done or not. If this cannot be done, the parameters in the optimization model are corrected based on the output of the simulation model. Linnéusson, G., et al (2019) investigated the maintenance strategic plan to improve production performance using goal programming, dynamics system simulation and discrete event simulation (DES). The use of agent based simulation and optimization is carried out by Cabrera (2012) to determine the allocation of medical personnel in emergency departments in hospitals. Oliviera (2019) discusses the integration of simulation and optimization methods in supply chain risk management. There are still many other studies about the integration of the two methods.

In this case, simulation is used to estimate capacity of packing plant. The simulation model is sub-model of Integer Linear Programming (ILP) model. The output of simulation model will be used as right-hand-side (RHS) of capacity constraint in the ILP Model. In addition, sensitivity analysis has been done to explore characteristics of solution in some different ship capacity and some overload thresholds capacity in regulation.

2.1 Simulation Model

In this section, simulation and optimization model are described and explained as follow:

2.1.1 System Element

System elements include entity, activities, resource and control of the system. System element in this case can be seen in table 1.

Table 1. System Element

System Element	Detail
Entity	Fertilizer, Ship
Activity	Loading, Unloading, Delivery, Packing, Storing
Resources	Truck, Ship Crane, Packing Machine, Port.
Control	Unloading Procedure in Destination Port, Loading Procedure in Factory Port, Loading fertilizer with rule First in First Out (FIFO)

2.1.2 Variable

There are three types of system variables namely decision variables, state variables, and response variables. The system variables, in this case, can be seen in table 2.

Table 2. System Varible

Variable	Details
Decision variable	The Capacity of Ship, shipping frequency
Response Variable	The amount of fertilizer that can be packaged at the packing plant in a month.
State Variable	State of ship (idle, waiting for loading, waiting for unloading, shipping), state of packing machine (idle, processing bagging, maintenance), state of fertilizer (store in open yard, being delivered in ship, being processed in packing plant)

In the model, there are two decision variables namely ship capacity and shipping frequency. This factor is a relatively easy factor to be changed when compared to other factors such as the capacity of the machine to package fertilizer, port capacity, conveyor capacity, and crane capacity. These factors are relatively more difficult and require a long time to be changed. There are three alternatives of ship capacity. The simulation model is a sub-model of the ILP model. The output of the simulation model will be the right-hand-side value of constraint of the packing plant capacity on the ILP model. Therefore, the response variable is the amount of fertilizer that can be sent from the packing plant. Finally, State variables include state of ship: idle, waiting for loading, waiting for unloading, shipping, state of packing machine: idle, processing bagging, being maintenance, state of fertilizer: store in open yard, being delivered in ship, being processed in the packing plant.

2.1.3 Data

In simulation, there are three categories of data: structural, operational and numerical. The company is quite orderly in recording operational data. There is a lot of data that can be used, but this work only uses data for the past year. The reason is that only the data of the past year still illustrates the conditions of the coming periods.The data used to estimate the model parameters in the simulation have been filtered and corrected. For example, data at the time of damaged bridge is not included in data processing and was replaced by reasonable data. There are two functions of the data collected is for the development of models and perform validation of the model. Validation of the model is done by validating the output of each stage. This is because data on intermodal delivery output does not exist because the company has never done it.

2.1.4 Conceptual Model

Conceptual model of delivering bulk fertilizer to the packing plant. Can be seen in figure 2 as follow:

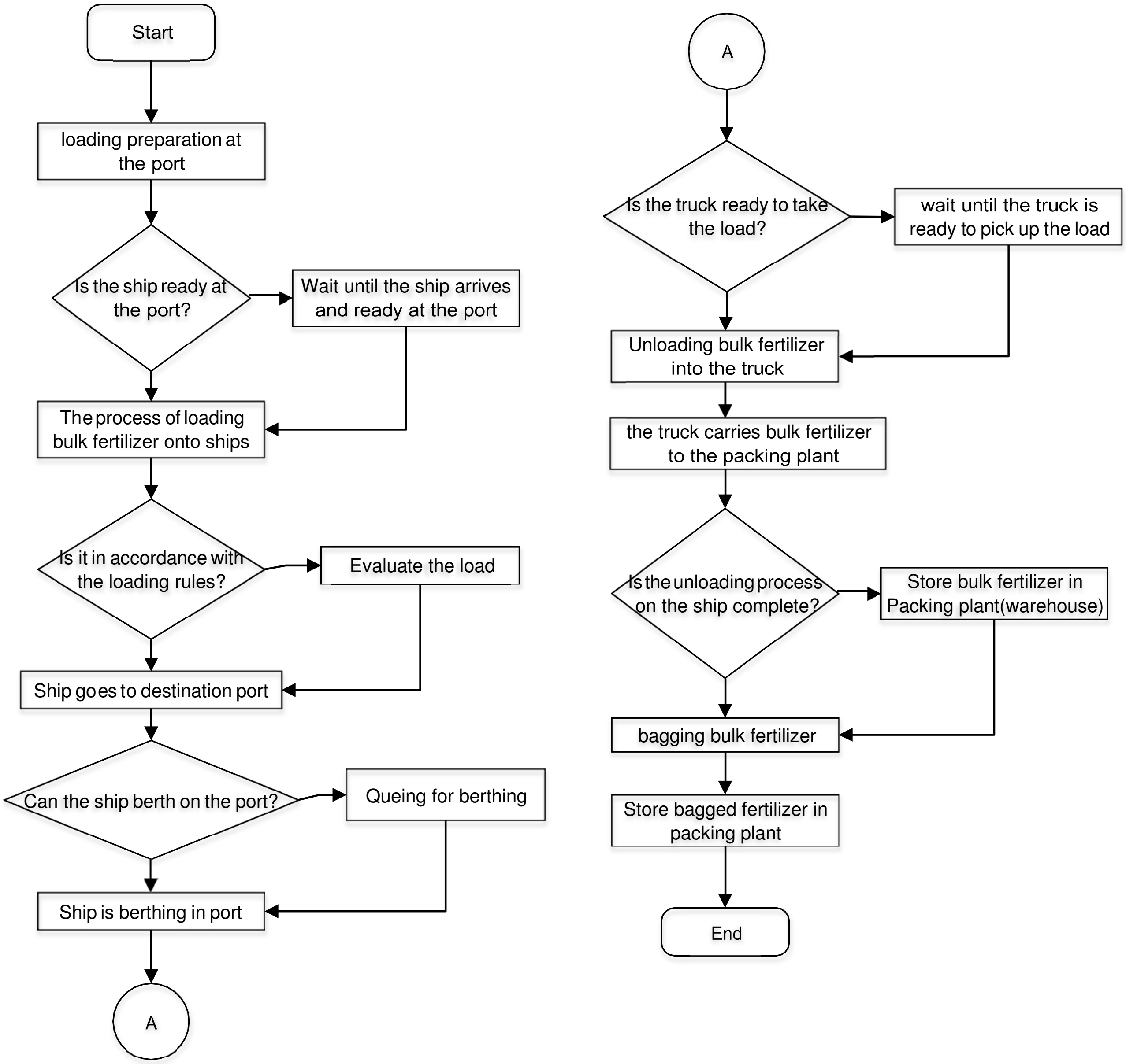

Figure 2. Conceptual Model

Loading time, queuing time at the origin and destination port, travel time, unloading time, time needed to load bulk fertilizer into the truck and truck travel time from the destination port to the packing plant are estimated using 136 historical data of shipments. before the data is used, the data is scanned first to improve and or eliminate outlier data.

2.2. Integer Linear Programming Model

The company needs to determine the optimal combination of direct delivery using trucks and intermodal delivery in bulk using ships and trucks. The optimal combination can be determined by developing an ILP model. The objective function of the model is to minimize shipping costs which include the cost of sending fertilizer directly from the factory using a truck, the cost of sending fertilizer intermodally to the packing plant and the cost of sending fertilizer from the packing plant to the distributor. Shipping costs include handing material costs.

This is important because, in intermodal shipments, material handling costs will be significantly higher when compared to direct shipments. Constraints include packing plant capacity, factory capacity, and the demand of each distributor. The trucks are assumed to have unlimited capacity because so far the trucks are provided by 3rd Party logistics companies and they can always meet the need of trucks. The problem, in this case, is the classic transportation problem. The ILP model is as follows:

$$Minimize : Z = \sum_{i=1}^{2} \sum_{j=1}^{30} C_{ij} X_{ij} \quad (1)$$

$Subject\ to$

$$\sum_{j=1}^{30} X_{1j} \leq T \quad (2)$$

$$\sum_{j=1}^{30} X_{2j} \leq P \quad (3)$$

$$\sum_{i=1}^{2} X_{ij} \leq D_j, \qquad for\ j=1\ to\ 30 \quad (4)$$

$$X_{ij} \geq 0\ , \qquad for\ all\ i\ and\ j \quad (5)$$

Where :
C_{ij} : Cost to deliver a ton of fertilizer from source i to j
X_{ij} : Number of fertilizer delivered from source i to j.
D : Capacity of direct delivery.
P : Capacity of packing plant (Intermodal Distribution).
D_j : Demand of Distributor j.

3. RESULTS AND DISCUSSION

There are three scenarios. This scenario is related to the delivery cycle of 15 days, 20 days and 30 days. The results of the simulation of the three scenarios can be seen in Table 4 and Figure 3.

Table 3. Scenario of Delivery Cycle

Scenario	Capacity of Ship(ton)	Delivery Cycle (Days)	Capacity of Packing Plant (ton)		
			Minimum	Average	Maximum
1	20000	15	80000	86436,12	100000
2	20000	20	60000	61101,26	80000
3	20000	30	40000	40894,21	60000

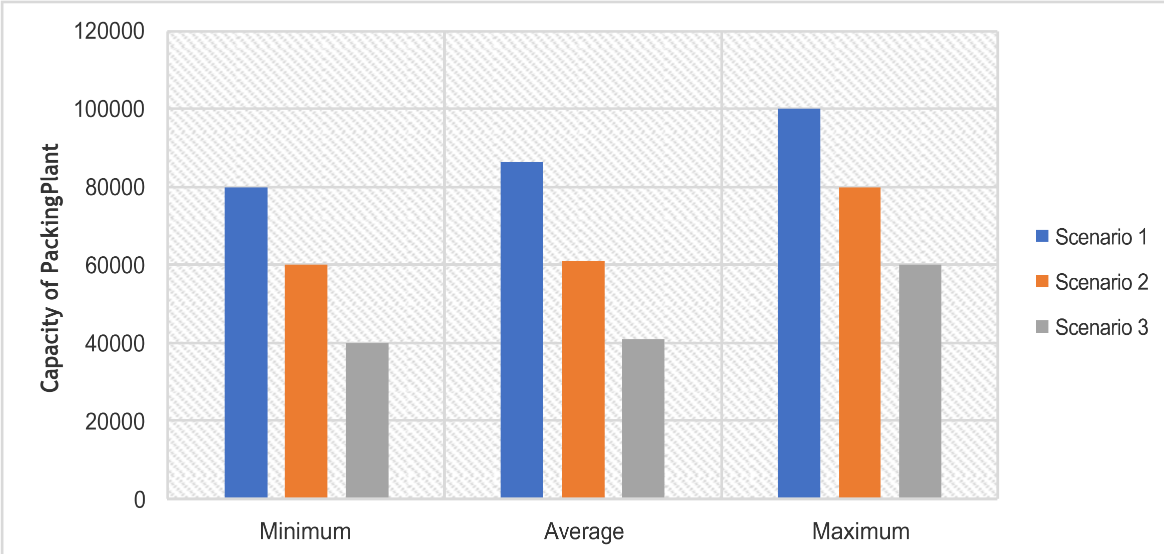

Figure 3. Capacity of Packing Plant based on Delivery Cycle

In addition, sensitivity analysis is also conducted to determine the effect of changes in trucking costs. the regulations regarding overcapacity and overdimension are not entirely clear. There is a possibility that the government still tolerates excess capacity by up to 75%. This will affect the transport rates of trucks. The increase is highly determined by the tolerance. The results of the sensitivity analysis can be seen in table 4.

Table 4. Sensitivity Analysis on Cost of Deliver Directly using Truck

Percentage of Increase in Direct Delivery	The amount of fertilizer delivered from packing plant
0%	2267.87
25%	6240.79
50%	15084.27
75%	34496.78

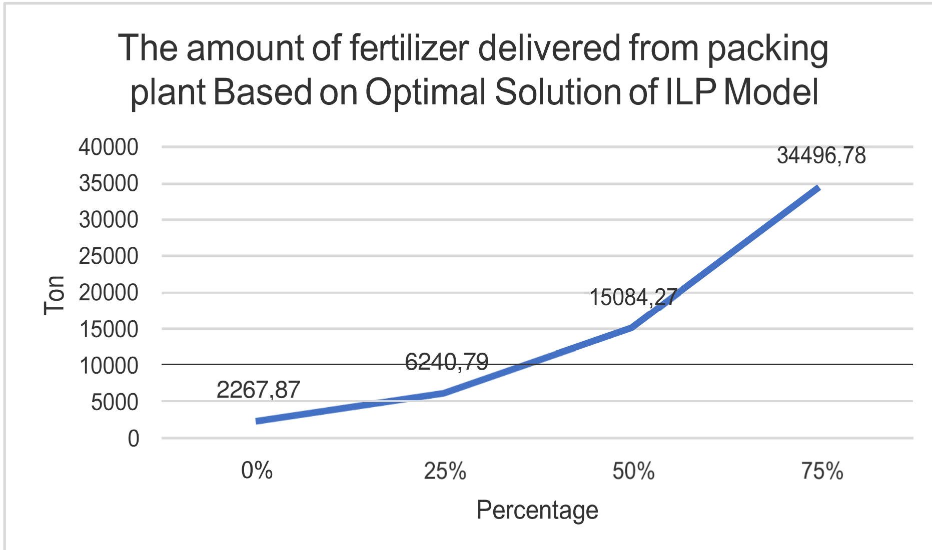

Figure 4. Sensitivity Analysis on Cost of Deliver Directly using Truck

These results indicate that the more expensive the cost of delivery directly by using the truck, the more fertilizer is delivered by intermodal distribution using ships and trucks. interestingly, even though the increase in the cost of direct delivery using trucks is quite high, reaching 75%, there are still many district warehouses which are still more economical to be supplied by truck directly from the factory.

The percentage of use of packing plant capacity based on optimal solutions in all three scenarios can be seen in table 6. The percentage is calculated based on the results of simulation replication with a minimum value, not an average. The minimum value indicates the worst condition. In the table, it can be seen that, in all scenarios, even in the worst conditions not all available capacity will be used. Therefore, these show that scenario 3, which uses smallest capacity of ship and the smallest frequency in delivery, is enough to fulfill the need to supply the demand.

Table 5. The percentage of use of packing plant capacity based on optimal solutions

Scenario	Minimum Capacity of Packing Plant	Usage of Packing Plant Capacity Based on Output of ILP			
		0%	25%	50%	75%
		2267.87	6240.79	15084.27	34496.78
1	80000	2,83%	7,80%	18,86%	43,12%
2	60000	3,78%	10,40%	25,14%	57,49%
3	40000	5,67%	15,60%	37,71%	86,24%

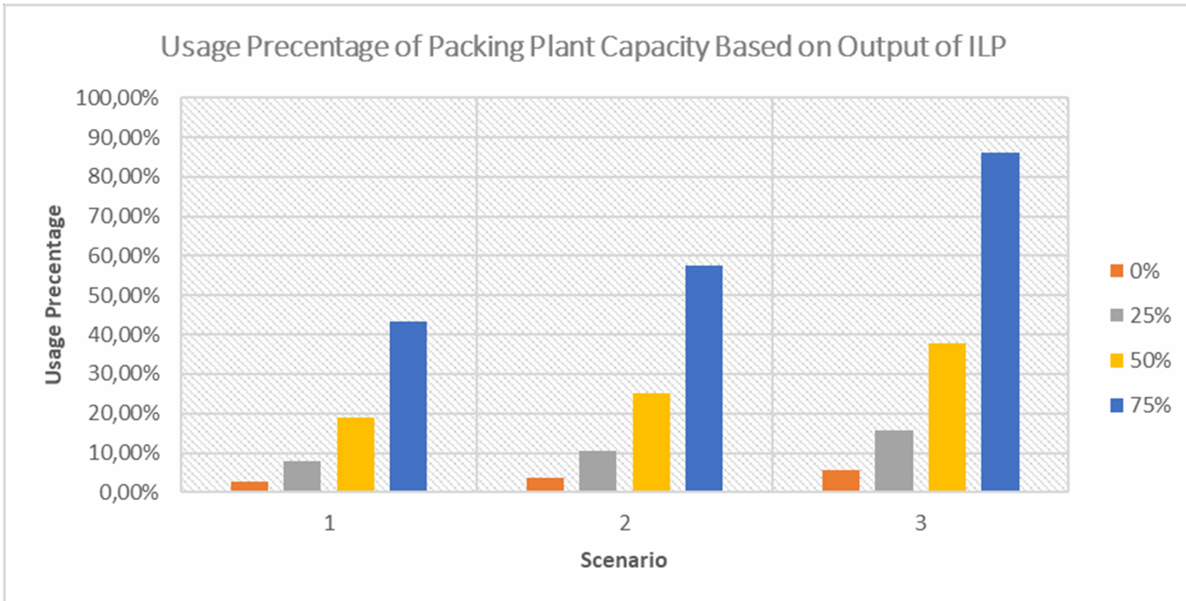

Figure 5. The percentage of use of packing plant capacity based on optimal solutions

In the table, it can be seen that only if trucking costs increase by more than 75 % then the optimal solution of the ILP model will change. This information can be interpreted that the solution can be applied with high confidence because the solution will only be inappropriate if the truck costs increase by 75 %.

4. CONCLUSION

The model solution shows that not all capacity available at the packing plant will be used to supply fertilizer demand. The use of alternative intermodal shipping is very dependent on the cost of delivering directly from the factory using trucks. The higher delivery costs as a result of enforcement regulation on overcapacity, the more packing plant capacity will be used. Sensitivity analysis shows that at an increase in the cost of direct shipping using trucks by 75%, the best scenario is still to use the smallest ship and the least frequent delivery. The optimal solution of the ILP model shows two important insights that are many district warehouses are still more efficient to be supplied directly by truck from factory and the farther the distributor's location, the more chance it will be supplied via intermodal delivery

5. REFERENCES

Cabrera, E., Taboada, M., Iglesias, M., Epelde, F. and Luque, E. (2012). Simulation Optimization for Healthcare Emergency Departments. *Procedia Computer Science*, 9, 1464-1473.

Daniel Budiman, S. and Rau, H. (2019). A mixed-integer model for the implementation of postponement strategies in the globalized green supply chain network. *Computers & Industrial Engineering*, p.106054.

Leung, S. C. 2007. A goal programming model for production planning of perishable products with postponement. *Computers & Industrial Engineering*, 53, 531-541.

Linnéusson, G., Ng, A. and Aslam, T. (2019). A hybrid simulation-based optimization framework supporting strategic maintenance development to improve production performance. *European Journal of Operational Research*.

Oliveira, J., Jin, M., Lima, R., Kobza, J. and Montevechi, J. (2019). The role of simulation and optimization methods in supply chain risk management: Performance and review standpoints. *Simulation Modelling Practice and Theory*, 92, 17-44.

Vieira, M., Moniz, S., Gonçalves, B., Pinto-Varela, T. and Barbosa-Póvoa, A. (2019). Integrating Simulation and Optimization for Process Planning and Scheduling Problems. *Computer Aided Chemical Engineering*, pp.1441-1446.