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The Effect of Supply Disruptions on Customer Service Levels: a Case for Delivering Fertilizer Products using Maritime Transportation

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Abstract. Delivering a product to customers can have a series of activities. It starts with the production of the product and then transporting it to the customers. However, uncontrollable and undesirable chance of disruption can occur during the delivery either at the production facility/supply side or in the process of transporting the product. Many researches has been conducting in the process of delivering the product. However not many considers these disruptions, although the disruptions has negative impacts on company such as reduce the profit, produce unbalanced inventory, and affect its reputation. This research will focus on the effect of supply disruption on customer service levels in the maritime transportation problem in order to maintain inventory level both in the supply and destination warehouses during predetermined planning horizon. The system considered consists of one loading port and two discharge ports for distributing one product. By using discrete event simulation, the result showed that supply disruption affects unbalanced inventory in the destination warehouses so that it will also influence company's service level. The results show that there is a significant decreasing both in delivery service level, about 14%, and production service level, about 15% when the disruption occurs. A scenario to increase production rate is simulated to improved the service level.

1. Introduction

Delivering a product to customers can have a series of activities. It starts with the production of the product and then transporting it to the customers. When distributing the product, the company needs to manage their transportation efficiently in order to minimize the cost because this cost has the biggest proportion which almost reaches 66% of the total distribution cost [1]. In this case, this efficiency of distribution process may increase the company's profit.

A company may distribute its product by using either land, air or maritime transportation. In the case of distributing fertilizer products in Indonesia, the producer uses both land and maritime transportation. The company uses trucks wherever the customer warehouse are in the same island with the factories. On the other hand, the company manages ships to deliver the products wherever the warehouses are in the different islands.

This research focus on distributing one particular fertilizer products by using maritime transportation. The product needs to be loaded from supply port to two discharge ports as seen in Figure 1. Three heteregenous (in term of capacity) time charter ships move around to serve these three ports to maintain the warehouses at those ports at minimum and maximum levels during the planning horizon. To select which demand port needs to be selected for the next destination after loading the product at supply port, the company is assumed to use the minimum coverage day criteria. Coverage day is defined as the number of days that a warehouse can cover the demand of a product from its storage before it runs out [2][3]. By using this definition, the smallest number will show that the warehouse at discharge port is very critical and needs to be visited in order not to stock out. Thus, a port which has a warehouse with smallest number coverage days will be chosen for the next destination of a ship from supply port. After arriving at demand port, a ship will unload the products into warehouse. The ship, then, sails back to the supply port for the next assignment. The ship will travel back and forth during predefined planning horizon so that the problem can be categorised as inventory routing problem (IRP). According to Al-Khayal and Hwang [4], inventory routing problem is concerned with the status inventory at each demand node and route selection in order to to find the least total cost of inventory and distribution. This problem integrates two concepts: inventory control and vehicle routing problem, where the route selection and inventory policy are simultaneously determined. The IRP that used ships as transportation mode is called as maritime inventory routing problem (mIRP) or ship inventory routing problem (sIRP).

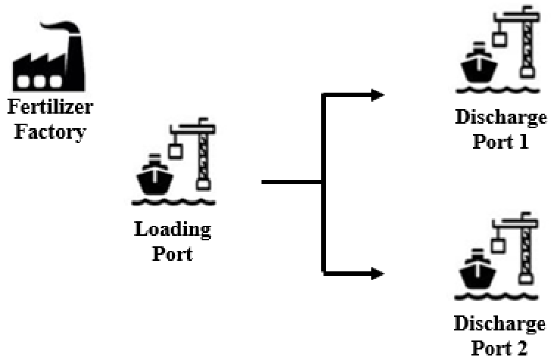

Figure 1. Distribution process of fertilizer products using ships

During distribution process, it may occur not only uncontrollable and undesirable events but also schedule events called as disruptions [5]. Disruption is defined as everything that may disrupt the system [6]. This also can happen in the maritime trtansportation. Brouer et al. [7] states that a journey of a ship to a port may about 70% - 80% not arrive on time. The delay may be caused by weather, port regulation, congestion either for shift in or shift out, and ship's machine or facility breakdown. Disruption may also occur at the production facility such as either schedule maintenance or unschedule factory breakdown. These breakdowns are influenced by the age of factory which has been operated for more than twenty years and also are caused by the late arrival of raw materials. These facility disruptions which called also as supply disruptions can affect distribution line. This supply disruption becomes the focus of this paper. The transportation disruption will be discussed in other our paper.

Table 1. Total downtime days for one particular production facility in year 2015

Downtime	Actual (days)
Scheduled downtime	61.2
Unscheduled downtime	19.28

Tabel 1 shows that the production facility had a total of scheduled downtime 61.2 days and unschedule downtime 19.28 days in 2015. However, these disruptions did not occur in once time, but several times. The time between downtime was distributed exponential with mean 27 days, while the length of downtime had the value minimum one hour, average 17 hours and maximum 15.75 days. These supply disruptions may decrease the quantity of product distributed and may delay the departure of a ship if the level of warehouse is less than the compartment capacity of the ship. This delay called as demurrage may decrease the utility of the ship as well as increase the ship's operational cost. If the ship is departed with the quantity loaded less than the ship's capacity, the shipment cost per weight of product will also increase.

Disruption needs to be taken attention seriously because of the severe affects to the company, such as increase cost, unmet demand, customer loss, unbalance inventory, and decrease company's reputation [5]. Because of those previously stated, this paper try to minimize the effect of disruption on customer satisfaction.

To model this disruption system, we build a discrete event simulation. This method is used because it can handle complex system [8]. The complexity can be seen from the variablity and interdependency of the elements, such as ships, warehouse, production facility, and others. The variability elements are the time between disruptions and the length of disruptions, the product loading time, the sailing time, congestion time before shift in and shift out to/from port, unconstant demand and other factors. Maritime transportation is shown to have a high degree of uncertainty [9]. The interdependency in this system can be seen from the interaction of activities, such as the length of supply disruption will affect sailing time and congestion time. To solve this system, there are several scenarios will be generated and tested to find the best recovery scenario in order to increase the preformance of the system.

2. Model Development

In this section, the steps for developing the model are described and explained as follow:

2.1 The system elements

System elements include entity, activities, resource and control of the system. The entities of the system are the ships which distribute the product and the product itself. The observed activity is maritime line distribution system as seen in the Figure 2 below. Resources of this system are the facilities at port, such as berth and cranes. The system is controlled by some rules or directions, such as ship's assignment to a discharge port with the least coverage days, port operational hours, and loading/unloading procedures.

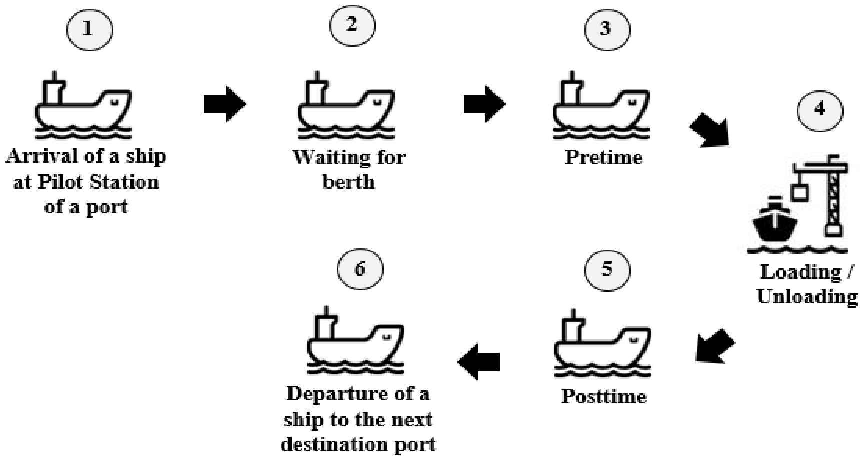

Figure 2. Maritime distribution activities

2.2 System variables

In simulation, the variables consist of decision variables, respond variables and status variables. In this maritime transportation system, the decision variables are the number of ships and mitigation schema used. The respond variables are inventory levels at the warehouses both in supply and discharge ports and total cost. Finally, the status variables are the status of the ships: idle or busy, loaded or unloaded; the status of the ports: empty or occupied. Tabel 2 shows the summary of these system variables.

Table 2. System variables for maritime transportation

Decision Variables	Variabel Respon	State Variabel
The number of ships	Delivery lead time	Ship status
Disruption mitigation scheme	Service level	Port available status
	Total cost	

2.3 Key performance indicator
Key Performance Indicator is a quantitative indicator which is used to measure the performance of the system. The criteria for this system is service level for fulfilling the demand of the customers which has formulation as below:

$$\textit{Service Level} = \frac{\text{The number of delivery}}{\text{total of target delivery}} \tag{1}$$

2.4 Data collection
In this subsection, the data as the input of the simulation model is collected. The first step is to identify and explore data which is needed. In simulation, there are three kind of data: structural, operational and numerical. The structural data is the data to indicate the structure of the system, such as delivery line, loading port location, and discharge port location. The second, operational data is the data to demonstrate the way of system works, such as delivery route. Lastly, the numerical data is the quantitative data in the system. Table 3 shows the data needs to be collected for the system as below.

Table 3. Types of data for the maritime transportation

	Structural Data	
Ship:	**Loading Port:**	**Discharge Port:**
Type of ships	Loading port location	Discharge port location
The number of ship	Type of loading port	Type of discharge port
	Operational Data	
Ship:	**Loading Port:**	**Discharge Port:**
Schedulling	Time Windows	Time Windows
	Numerical Data	
Ship:	**Loading Port:**	**Discharge Port:**
Ship's capacity	Warehouse capacity	Warehouse capacity
Fuel consumption	Production rate (normal and recovery condition)	Demand rate
Operational cost	Loading rate	Unloading rate
	Shift in time, shift out time	Shift in time, shift out time
	Distance	
Charter cost	Breakdown Data / Supply facility disruption	Port congestion data

2.5 Data processing
In this step, the data that collected from the previous step is processed which is called fitting distribution. The objective of this process is to have what kind of distributions of the data and their parameters. The processed data are production rates either at normal or recovery conditions, demand rates at destination warehouses, loading and unloading rates at every ports, pre-loading and post-loading times both at loading port and discharge ports, time between facility breakdown and its repair duration.

2.6 Building simulation

There are two steps to build the simulation model. The first is to make the conceptual model which the logic flow diagram is used. There are five conceptual submodels developed: the arrival of facility downtime submodels, the update of facility inventory level submodel, the selection of discharge port destination submodel, the shipment of product submodel, and lastly, the sail of ships to the loading port submodel. Based on these submodels, simulation model is developed by entering the input data that has been fitted of distribution.

2.7 Generating scenarios

When the existing model has been verified and validated, scenario needs to be generated based on the results of decision variables. There are two scenarios are generated. The first scenario is without increasing the production rate, and the second one is increasing the production rate by 106% after occuring facility downtime.

3. Result and Discussion

In this section, the simulation experiment is conducted which can be divided into three conditions: no supply disruption model, supply disruption model with normal production rate, and finally supply disruption model with recovery production rate. All of these models used three ships with the shipment rule full ship load. The detail of these three models are described below.

3.1 No disruption Model

The objective of building this model is to verify and validate the model developed. The result of this simulation model shows that warehouse inventory levels of this model can be seen in Figure 3 as below. The delivery service level by using equation (1) has a value 98%. It means that the delivery performance is about 2% under target. On the other hand, the production service level has a value 100% which means that the production facility has achieved its target. Without any disruption, the average round trip days of a ship to deliver a product to the demand port 1 is 21.47 days, while to demand port 2 is 17.3 days.

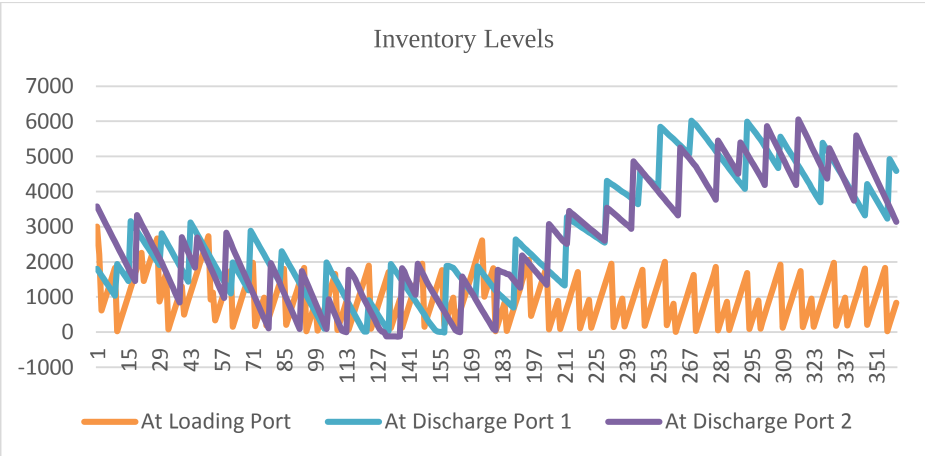

Figure 3. Inventory levels at three warehouses for no disruption model

From Figure 3, the inventory levels at discharge port 1 and discharge port 2 are relatively stable. There exist stockout at discharge port in about day 130, however this stockout quantity is only 2% from the delivery target. After day 180, the Inventory levels at discharge ports are increasing for about six months due to low demands (because it is not in the plant season). The inventory levels reach about 6000 tons in about day 270.

3.2 Supply disruption model with normal production rate

For this model, there exist facility disruptions called as supply disruptions in the form of factory breakdowns. These breakdowns are influenced by two factors: the age of factory which has been operated for more than twenty years and the late arrival of raw materials. When the disruption occur, factory cannot produce the product so there is loss of production. After the disruption occur, the production is back to the normal condition. Based on the experiment of this simulation model, the delivery service level is 84.5%, below about 14% from the model of without any disruption as in the first model. The production service level decrease to 84,93% from 100% if without any disruptions. It means that supply disruptions will affect the loss of production by about 15% from the target. With supply disruption, the average round trip days of a ship to deliver a product to the demand port 1 is 25,8 days, longer than the first model which is 21.47 days, while to demand port 2 is 19.95 days, longer about 3 days from the first model. 17.3 days. Figure 4 depicts the warehouse levels of the case supply disruption without recovery scenario as below.

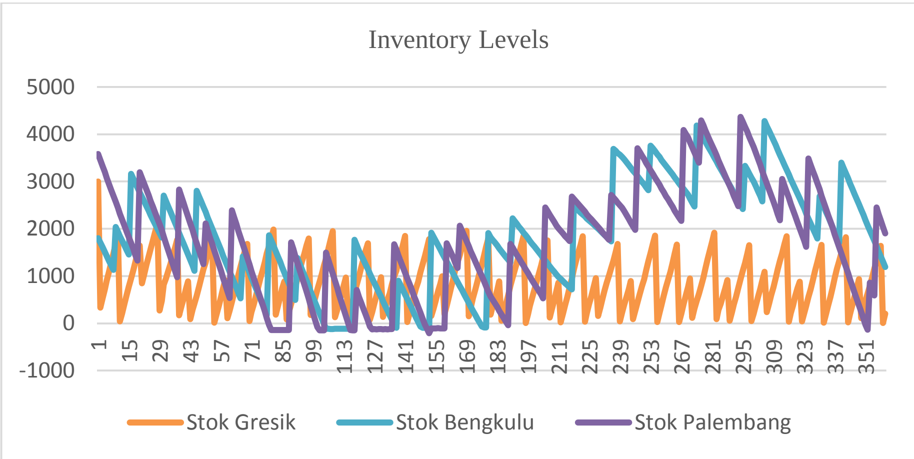

Figure 4. Inventory levels at three warehouses for supply disruption model with normal production rate

From Figure 4, the inventory levels at discharge port 1 and discharge port 2 seems not stable at the beginning period. There are plenty of stockout condition at discharge port 1 and dicharge port 2. This stockout condition is higher than the model without any disruptions. The Inventory levels at discharge ports for the six month and so on is relatively high due to the dry season and not in plant season. Compared to model without any disruption, the inventory level reach 4000 tons when entered the nineth and tenth months, below 2000 tons compared to the first model.

3.3 Model with supply disruption combine with recovery rate

This model also consiederd facility disruptions. When the disruption occur, factory cannot produce the product so there is loss of production. However, there exists recovery option to increase the production rate by 106% whenever after breaking down occurred. This recovery rate has been done to compensate the loss of production. Based on the experiment of this model, the delivery service level can be increased 7% to 91.5%. The production service level also increase to 92,3%, above also 7% compared without recovery scenario. With additional production rate, the average round trip days of a ship to the demand port 1 is 24,2 days, shorter than without recovery with 1,5 days, while to demand port 2 is 19.03 days, shorter about 1 days from the scenario without recovery. Figure 5 depicts the warehouse levels of the case supply disruption with recovery scenario as below.

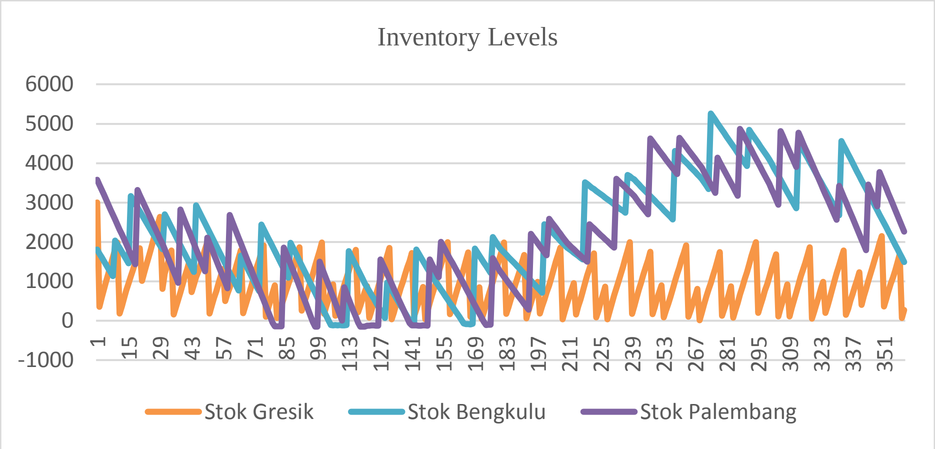

Figure 5. Inventory levels at three warehouses for supply disruption model combined with recovery production rate

From Figure 5, there are plenty of stockout condition at discharge port 1 and dicharge port 2. This stockout condition is higher than model without any disruption, but lower than model with supply disruption without recovery rate. When entered the nineth and tenth months, the inventory level reach 5000 tons, below 1000 tons compared to the first model, and above 1000 tons compared to model with supply disruption without recovery rate.

4. Conclusion

The disruption may occur in the maritime transportation for distributing a product. The disruptions may be in the form either the supply disruption when the breakdown of the facilities occur or the transportation disruption as the congestion to wait a berth at a port. Based on the experiments in the previous section, it can be concluded that disruptions will affect both delivery or production service level. When the supply disruption occurs, the delivery service level decreases about 14% and the production also decreases 15%. If the system has an option to increase production rate after breaking down, the delivery and production service levels can be increased both to 7% compared to without recovery scenario. The inventory levels in destination warehouses are also lower when the disruption occur.

The calculation for round trip days also gives the same result as the ones for production and delivery service levels. An interesting question is that whether the transportation disruptions will give the same consequences or worst than the supply disruption. This will be our research agenda.

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