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Model of delivery consolidation of critical spare part : case study of an oil and gas company

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Abstract. The availability of spare parts in oil and gas industry is very important to prevent the occurrence of very high opportunity cost, that is the loss caused by exploitation equipment which must stop because of unavailability of the spare part. This is done by providing safety stock with a very high service level that leads to high inventory costs. If the company wants to lower inventory costs, the choices are not to lower the service level but to lower the ordering cost. One of the components of ordering cost is the delivery cost. Exploitation facilities are usually located in remote areas so that the cost of delivery is high. In addition, many spare parts are supplied by the same supplier. Therefore, there is an opportunity to lower the cost of delivery of spare parts by consolidation. In this paper,mixed integer linear programming (MILP) model is developed to plan the procurement of spare parts so that inventory costs which include holding and ordering cost for spare parts can be minimized. The model has been verified and validated. Using this model the company can lower inventory costs of the spare part by 32%.

1. Introduction

Oil and gas exploitation facilities are usually located in remote areas[1]. This causes the high cost of delivery the various needs for production, including the needs of spare parts. Spare part requirement is determined by maintenance schedule and historical data of spare part requirement[2][3]. So far, the company is planning the procurement of spare parts with lot for lot method that is procured the spare part with the amount and time as needed. This method will minimize holding cost but ordering cost will be high[4]. Improvement can be done by using other lot sizing methods such as economics order quantity (EOQ), periodic order quantity(POQ), least unit cost, wagner whitin and others. These methods try to find a procurement schedule that can minimize inventory costs that include both holding cost and ordering cost[5][6][7][8].

These lot sizing methods are used to minimize the cost of certain types of inventory spare parts. The method has not considered any potential savings by consolidating delivery from several spare parts supplied by the same supplier. The company manages thousands of spare parts. Many of these types of spare parts are supplied by the same supplier. Therefore, a model is needed to assist the company in determining the spare part procurement plan that considers the potential savings by combining the delivery of multiple spare parts supplied by the same supplier.

Delivery consolidation can lower the cost of delivery[9]. If the delivery of some type of spare part is combined in one delivery then the means transportation used is most likely to deliver spare parts in nearly full or full capacity. Cost reductions can be significant because oil and gas exploitation facilities are often located in remote areas.

Consolidated delivery can also lead to higher holding costs. Delivery consolidation often causes the spare part to be delivered early so that the spare part must be stored for a longer time. So the decrease in delivery costs due to consolidation can lead to an increase in holding cost. Therefore, the consolidation of delivery of spare parts must be done carefully so that minimum total cost can be obtained. In this paper, a mixed integer linear programming model is developed to determine procurement plans that can minimize total inventory costs. The objective function is to minimize the holding cost and ordering cost which also includes the delivery cost.

2. Model Development

Objective function in integer linear programming model is minimize the total cost of delivery, ordering cost and holding cost. The formulation can be described as follows.

Parameters:

- D_{it} : requirement of spare part i in period t
- H_i : holding cost per month of spare part i
- S : Delivery cost per supplier
- C : Ordering cost
- SS_{it} : safety stock for each spare part i in period t
- I_{it} : inventory spare part i for period t
- Q_t : total group of spare parts ordered in period t

Decision variables :

- Xi_t : the number of spare parts i that is ordered in period t
- Z_{it} : 1 if there is delivery of spare part i in period t, 0 otherwise
- Y_{1t}: 1 if there is more than one spare part which is scheduled to be delivered in period t,0 if it does not place an order
- Y_{2t}: 1 if there is only one spare part that is scheduled to be delivered in period t,0 if it does not place an order
- Y_{3t} : 1 if there is no delivery, 0 if there is a delivery
- I_{it} : inventory spare part i in period t

Ordering cost is calculated by multiplying ordering cost and ordering frequency. Holding cost can be calculated by multiplying the average inventory in a year and holding cost. While the delivery cost is calculated by considering three conditions that are delivery without consolidation, consolidated delivery and no delivery. Consolidated delivery requires a smaller cost because the conveyance can deliver at full or near full capacity. Delivery costs can be calculated by multiplying the delivery cost and the frequency of delivery.

Objective function:

Minimize:

$$Z = \sum_{t=1}^{T} \left((C + \frac{S}{Q_t}) Y1_t + (C + S) Y2_t \right) + \sum_{i=1}^{I} \sum_{t=1}^{T} H_i \, I_{it} \quad (1)$$

Constrains :

$$I_{it} = \sum_{i=1}^{I} \sum_{t=1}^{T} X_{it} + \sum_{k=1}^{t} I_{i(t-1)} - \sum_{t=1}^{T} D_{it} \qquad \forall i; \forall t \quad (2)$$

$$X_{it} \leq M \, Z_{it} \qquad \forall i; \forall t \quad (3)$$

$$2 - \sum_{t=1}^{T} Z_{it} \leq M * (1 - Y1_t) \qquad \forall i; \forall t \quad (4)$$

$$1 - \sum_{t=1}^{T} Z_{it} \leq M * (1 - Y2_t) \qquad \forall i; \forall t \quad (5)$$

$$\sum_{t=1}^{T} Z_{it} - 1 \leq M * (1 - Y2_t) \qquad \forall i; \forall t \quad (6)$$

$$\sum_{t=1}^{T} Z_{it} \leq M * (1 - Y3_t) \qquad \forall i; \forall t \quad (7)$$

$$Y1_t + Y2_t + Y3_t = 1 \qquad \forall t \qquad (8)$$
$$\sum_{t=1}^{T} I_{it} \geq \sum_{t=1}^{T} D_{it} + \sum_{i=1}^{I} \sum_{t=1}^{T} SS_{it} \qquad \forall i; \forall t \qquad (9)$$
$$Z_t \ , Y1_{it}, Y2_{it}, Y3_{it} \in \{0,1\} \qquad \forall i; \forall t \qquad (10)$$

Constraint (2) ensures that the amount of inventory during a period is the sum of inventory in the previous period and the number of units received during that period reduced by demand in that period. Constraint(3) is required to determine the value of the binary variable Z_{it} based on the value of the X_{it} decision variable. If there is a spare part delivery schedule in period t, then Z_{it} should have a value of 1. This is ensured by using big M on the constraint. Constraint (4), (5), (6) and (7) are constraints needed to determine the value of variables Y_1, Y_2 and Y_3. The decision variables Y_1, Y_2, and Y_3 are binary variables. Y_1 will have a value of 1 if consolidating delivery for some spare part type in one delivery. Y_2 will have a value of 1 if sending only for one type of spare part. Whereas Y_3 will have a value of 1 if there is no delivery in period t. Constraint (8) is required to make sure that Y_1, Y_2 and Y_3 cannot have a value of 1 simultaneously. The value of the variables Y_1, Y_2 and Y_3 will be multiplied by the ordering cost. Ordering cost is a fixed cost whose amount is determined by the frequency of delivery and does not depend directly on the quantity of the spare part delivered. Constraint(9) is necessary to ensure that spare part requirements in t periods must always be met. This is done by ensuring that the amount of inventory in the period t is always equal or greater than the requirement in that period plus safety stock. Constraint (10) are an integer decision variable.

3. Results and Discussion

The spare part procurement process in the company involves 4 divisions: operations, warehouse, procurement and inventory. At the beginning of the year, the operation division makes maintenance plans and spare parts needed for maintenance activities both preventive maintenance and corrective maintenance. Recapitulation of spare part requirement is informed to the inventory division, then the inventory division checks whether the spare part inventory is sufficient to meet the requirement of maintenance program of the operation division. If the supply is still sufficient to meet the requirement within one year then there is not procurement but if the supply is not sufficient then the order is made. Procurement planning which includes the number of spare part and when the delivery should be done for each spare part. If by chance there are spare parts supplied by the same supplier, scheduled to be delivered at the same time and can be consolidated in the same mode of transportation then the spare parts will be delivered simultaneously. Delivery consolidation can reduce delivery costs. The decrease in delivery costs is due to mode of transportation used (truck, train, ship, plane) can deliver spare part in full or almost full capacity so that the delivery cost per unit will be lower.

The developed model is intended to minimize the total cost. Lowering delivery costs and also ordering costs by consolidating delivery can lead to higher holding costs. Conversely, the decrease in holding cost leads to higher delivery costs as well as ordering costs. Holding cost is a cost that includes warehouse cost, material handling, worker, obsolence, and cost of capital. The cost of leasing the warehouse, material handling and workers is estimated by dividing the warehouse costs by the number of spare parts stored in a year. Spare parts usually become dead stock if after five years the spare part is not used. Therefore, obsolence cost each year is obtained by dividing the spare part value by five. The main component of holding cost, cost of capital, is estimated using the prevailing loan interest in the market. The loan interest rate in the market is 10.25%.

Ordering cost is the cost required to procure spare parts. Ordering cost is not directly dependent on the quantity of spare parts delivered in a single delivery, but depends on the frequency of delivery. Ordering cost includes administrative costs, loading, unloading, quality check and delivery costs. Most of spare part suppliers are located in Surabaya and Jakarta. Distance from Surabaya to the company's warehouse is about 500 km and Jakarta to the company warehouse is about 2000 km. In Table 1 can be seen distance of supplier to company warehouse.

Table 1. Distance and cost of delivery from each Supplier to company's warehouse.

Supplier	City	Distance (Km)	Delivery Cost (IDR/delivery)
1	Surabaya	566	4.015.960
2	Surabaya	546	3.974.760
3	Jakarta Utara	2084	9.216.040
4	Jakarta Utara	2090	9.228.400
5	Surabaya	550	3.983.000
6	Jakarta Selatan	2068	9.183.080
7	Surabaya	548	3.978.880
8	Jakarta	2072	9.191.320
9	Surabaya	564	4.011.840

Therefore, the cost of delivery is large cost. There is a need to reduce the cost of delivery. Delivery costs can be lowered by consolidating delivery of some spare part. Delivery costs are estimated by taking into account the costs of drivers, fuel, tolls, levies, and truck rentals. Delivery costs of nine suppliers can be seen in table 1. In table 1 also can be seen that the cost of delivery is a considerable cost. Decrease in delivery costs by consolidation can be calculated by dividing shipping cost in one shipment by truck capacity ratio with average shipping quantity.

Grouping spare parts is needed to determine the spare parts that can be shipped in one delivery. There are three factors to be considered in the grouping. These three factors are the size, shape and the suppliers that supply the spare parts. Spare part grouping can be seen in table 2. KT is group of spare part of big dimension so that its delivery cannot be combined with other spare part. SH and JT are spare part groups in the form of sheets and pipes so that the delivery also cannot be combined with other spare parts. While group EA, CT and SET is a group of spare parts in the delivery can be combined with other spare parts because the spare part has a similar dimension.

Table 2. Classification of spare parts.

Function of the spare part	Group of Spare Part	UOM	Group
pare Part for Pipe Fits	08	EA	1
		JT	3
Spare Part for Blower	11	EA	2
Spare Part for Valve	12	EA	1
Spare Part for Cartepillar Engine	13	EA	5
		KT	6
Spare Part for Genset	14	EA	1
Spare Part for Compressor	15	EA	2
Spare Part for Water Pump	16	EA	1
Electrical Component	18	EA	1
Spare Part for Control Valve	19	EA	1
Spare Part for Fire Safety	22	EA	1
		SET	1
Spare Part for Material Handling	40	EA	1

The developed model is run for each supplier and for each group of spare parts that can be delivered simultaneously. Output of the model shows that the model has been able to produce a spare part procurement plan that minimizes costs including delivery costs, holding cost and ordering cost. For example, output of the model for supplier 1 can be seen in table 5.

Table 3. Output model for supplier 1.

Spare Part	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
11-950-0220-A	0	0	0	0	0	0	30	0	0	0	1	0
11-950-0237-A	0	0	0	0	0	0	0	0	0	0	4	6
11-950-0253-A	0	0	0	0	0	0	30	0	0	0	12	0
11-950-0258-A	0	0	0	0	0	0	0	0	0	0	1	0
11-950-0581-A	0	0	0	0	0	0	22	0	0	0	51	27
11-950-0709-A	0	0	0	0	0	0	2	0	0	0	1	1

In table 4, it can be seen that there are four types of spare parts are sent simultaneously that is spare part 11-950-0220-A, 11-950-0253-A, 11-950-0581-A and 11-950-0709-A. In the 11th month, there is delivery for all types of spare parts and in the 12th month, there are delivery of three types of spare parts that are 11-950-0237-A, 11-950-0581-A, and 11-950-0709- A. Delivery schedule will be different if lot sizing is done for every spare part and if by chance there are spare part that is scheduled to be delivered simultaneously it will be consolidated delivery. Procurement planning using this model can provide savings of 32%. The amount of inventory cost savings for each spare part supplied by each supplier can be seen in Figure 1.

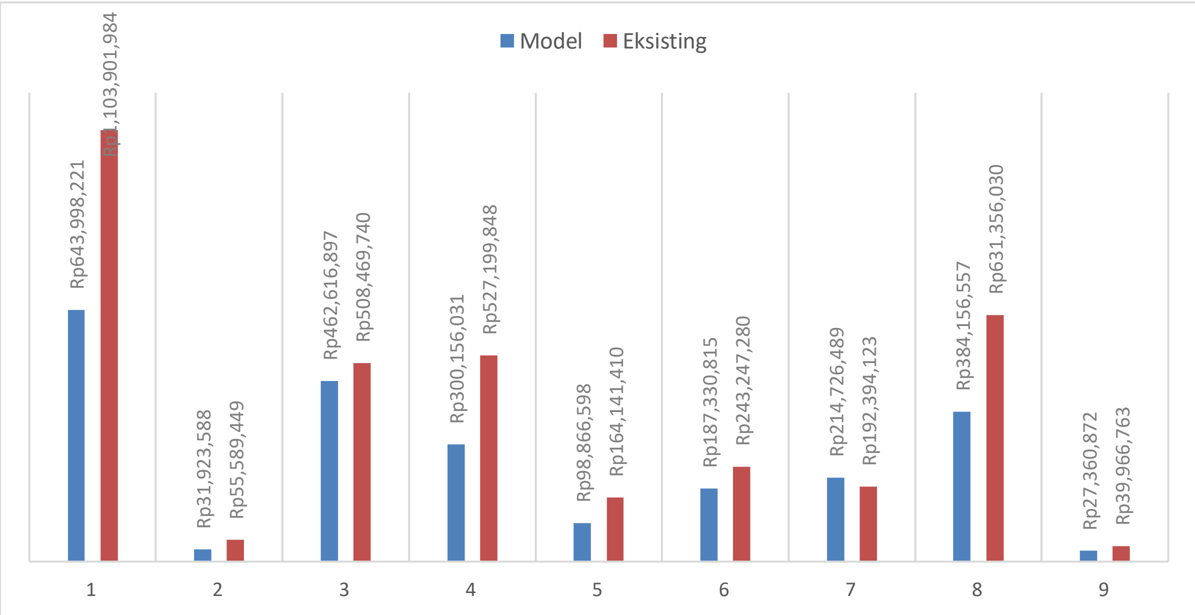

Figure 1. Total inventory cost of spare part supplied by each supplier.

4. Conclusion

Oil and gas companies are often located in remote areas so that the cost of delivery spare parts and other materials requires high costs. The cost of spare part delivery can be reduced by arranging the delivery schedule of the spare part that considers the possibility of consolidating the delivery. Consolidated delivery can be made on spare parts supplied by the same supplier and have characteristics that allow to be shipped in one delivery. In determining the delivery schedule must also consider the holding cost because the delivery schedule will have a direct impact on the holding cost. In this research has been developed integer linear programming model to determine the delivery schedule of spare parts.

The objective function of integer linear programming is minimization of delivery cost and inventory cost which includes holding cost and ordering cost. The model has been validated and the use of the

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model to plan the procurement of spare parts can reduce the total cost of spare part inventory by 32%. In the future research, the integer linear programming model can be further developed by considering some factors such as discount, warehouse capacity, multimode transportation, supplier capacity and budget for each period.

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