Analysis of coal allocation on steam power plants and the effect of multi-suppliers, demand and time variations on coal’s safety stock

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Abstract. Fulfilling coal-based electricity needs has its own challenges. It is because coal supply chain is a complex network in which various coal specifications could be supplied by more than one supplier. Uncertainty in demand and lead-time also complicates the situation. Moreover, each supplier can offer different price for the coal and different transportation. This paper empirically examined the coal allocation for steam power plants in Indonesia. There are 12 coal suppliers and 25 power plants as the subjects of evaluation. In order to find the set of suppliers and its allocations, optimization model that minimizing the purchasing and transportation cost was developed. The output from the optimization was then used as an input to find the level of safety stock, order quantity, and reorder point in each plant that can prevent the occurrence of stock out. A sensitivity analysis was also carried out to understand the impact of variation in demand and lead-time. The results show that lead time variations needs to be considered more in determining safety stock level rather than demand variations, including when having multi-suppliers.

1. Introduction
The role of electricity is crucial for a country. Most activities, from production to consumption, use electricity as their fuel. Therefore, the availability of electricity has an important role in improving national economy. Because of its importance, the Indonesian government has been consistently trying to increase the national electrification ratio, with a target at 99% in 2019. In order to achieve it, the government continues to build various types of power plants in many regions in Indonesia. From various types of power plants, coal-fired steam power plants dominate the installed capacity by 45.1% from total installed capacity, followed by gas powered electric generator (30.2%), diesel electric generator (10%), hydroelectric power plants (8.1%), steam power plants using oil fuel (3.1%), and renewable energy power plants (0.26%). Because of the dominancy, the government must be able to guarantee a reliable coal supply for each steam power plant. Reliably means to have sufficient amount of coal with the right calorific value to fulfil the electricity production needs with the smallest possible cost. However, to achieve this condition, there are some challenges such as the locations of suppliers and steam power plants, which are at different islands. Coal suppliers are in Sumatera and Kalimantan islands while the location of steam power plants are scattered in many areas in Indonesia. Consequently, transportation plays a significant role in the cost of coal procurement [1]. Unpredicted weather condition on variation in lead-time, demand fluctuations, and the different calorific values of coal in each plant are other challenging factors to be concerned. In order to overcome those challenges, this study tried to evaluate the optimal coal allocation in the context of...
Indonesian steam power plant. Supply chain planning, i.e. determination of suppliers and its allocations, safety stock level, order quantity, reorder point for each plants turns out to be essential aspects in providing an efficient, reliable with minimum cost, coal supply [1-3].

Determination of suppliers and its allocations are important in evaluating a coal supply chain, as done by some research, e.g. [1,4-8]. Mentioned in [1], supplier’s selection may lead to significant yearly savings. The process of selecting optimal suppliers requires several variables that should be taken into account, such as purchasing and transportation cost, lead-time from suppliers to power plants, and demand in each plant.

Besides determining suppliers and its allocations, inventory management is also crucial to dealing with uncertainties in demand and lead-time. These uncertainties could lead to coal shortages and seriously influence the production of electricity. To ensure that there is no occurrence of stock-out, usually a large amount of coal will be stored in each plant. This decision may result in a higher service level but at the same time will increase plant’s inventory cost [2]. By selecting a reasonable safety stock value, then the amount of coal purchased may lead to higher profit [9]. According to [3,10], order quantity also has a crucial role in dealing with uncertainty and in decreasing the overall procurement cost. By having an optimal order quantity, each plant will have more stable stock supply of coal, especially in multi-suppliers environment. Some studies shows that the implementation of multi-supplier system may reduce variations in lead-time [11] and hence safety stock level [12]. This paper uses the above concepts to evaluate the determination of the right suppliers with the right number of allocations for steam power plants in Indonesia. The impact of variations in demand and lead-time as well as the influence of multi-suppliers on safety stock level were also investigated. It is expected that the results could provide information for steam power plants to run a more efficient inventory management system.

The rest of the paper has the following structures. The next section describes the methodology and mathematical model used in this study. Section 3 presents the results and discussion. The last section summarized the findings of this study.

2. Methodology
Data used in this study consists of 12 coal suppliers, which are located in Sumatera (17%) and Kalimantan (83%) islands. There are 25 steam-power plants as the demand generators, which are scattered in many areas in Indonesia. The 80% of demand are located in Java Island, followed by Sumatera (16%), and the rest of 4% are located in Sulawesi, Maluku, Kalimantan, East Nusa Tenggara and West Nusa Tenggara. In this study, coal allocation was conducted by using an optimization model that minimizing the total cost. The total cost consists of purchasing cost and transportation cost.

The results of coal allocation were used to calculate safety stock level, reorder point and order quantity. As emphasised by Stock et al. [6], the idea of safety stock itself is that the average amount of inventory must be able to cover the variability of demand and lead-time. Demand and lead-time data was taken from [8] and [2], respectively. Both are normally distributed. Coal demand for each plant was obtain based on electricity needs every day, which is converted into calorific values. The value of safety stock level, reorder point and order quantity obtained were simulated for a year in order to check the possibility of stock-out. Sensitivity analysis on demand and lead-time variations, and the effect of multi-supplier on the inventory level are discussed later.

2.1 Determination of coal allocation
The optimization method used in this study formulated the main objective as the minimization of purchasing and transportation cost. The detailed model for each objective is as follows:

\[ f_1 = \sum_i \sum_{i \in I} \sum_{q \in Q} c_{ij} x_{ij} \rho_{iq} \]  

(1)

\[ f_2 = \sum_i \sum_{i \in I} \sum_{q \in Q} c_{ij} \max \{ C_i x_{ij} \} \rho_{iq} \]  

(2)
Equation (1) and (2) calculate purchasing cost and transportation cost, respectively. $P_{i,q}$ is the given price of coal $q$ at suppliers $i$. $X_{i,j,q}$ represents the total amount of coal $q$ to be sent from supplier $i$ to plants $j$ (in tons). $TrC_i$ represents the transportation cost from supplier $i$ and $R_{i,j}$ represents the distance between supplier $i$ and plant $j$. The model aims to minimize the total cost as in equation (3):

$$\text{Min } f = f_1 + f_2$$

Equation (4) – equation (9) are the constraints. Equation (4) means that each plants has to meet the $D_{i,j}$ (amount of coal needed at plant $j$). However, $X_{i,j,q}$ should be below $C_{i,q}$ (the contract value of each supplier $i$) as shown in equation (5).

$$\sum_{i} X_{i,j,q} \geq D_{i,j} \forall j \in J, q \in Q \quad (4)$$

$$\sum_{i} X_{i,j,q} \leq C_{i,q} \forall j \in J, q \in Q \quad (5)$$

The model also needs to make sure that the suppliers has the right caloric value of coal ($CV_q$). The right calorific value is between the minimum caloric value ($CV_{min}$) and the maximum caloric value ($CV_{max}$), as represented in Equation (6) below:

$$Y_{i,j} \begin{cases} 1, & \text{if } CV_q \in [CV_{min}, CV_{max}] \\ 0, & \text{otherwise} \end{cases} \quad \forall j \in J, q \in Q \quad (6)$$

### 2.2 Determination of safety stock level

Safety stock level ($SS_j$) was determined by adopting the formula stated by Stock et al. [6] where the average lead time from supplier $i$ to plant $j$ ($LT_{i,j}$) will be multiplied with the variation of demand ($\sigma_{D_j}$) at plant $j$. The result is added by the multiplication of the squared amount of demand ($D_j^2$) at plant $j$ with the variation of lead-time ($\sigma_{LT}$). The result of this addition then be square rooted as in equation (7):

$$SS_j = \sqrt{LT_{i,j} \sigma_{D_j}^2 + D_j^2 \sigma_{LT}^2} \quad (7)$$

The model was then modified to accommodate a multi-supplier aspect. The modifications are made by changing $LT_{i,j}$ to the maximum inter arrival time ($IA_{i,j}$). It can be obtained by subtracting the maximum $LT_{i,j}$ with the second highest lead-time; the second highest lead time is subtracted by the third highest lead time, and so on. By using $IA_{i,j}$ instead of $LT_{i,j}$, the level safety stock in a plant can be adjusted by still incorporating the lead time and demand variation. The calculation of $IA_{i,j}$ is shown in equation (8):

$$IA_j = \max (LT_{i,j}[1] - LT_{i,j}[2], LT_{i,j}[2] - LT_{i,j}[3], LT_{i,j}[n - 1] - LT_{i,j}[n]) \quad (8)$$

The modification was also made by changing $\sigma_{LT}^2$ into the maximum variation of lead-time among $n$ suppliers ($\sigma_{LTmax}$) for plant $j$. Therefore, it will cover even the highest possible variation. The modified formula is represented in equation (9) below:

$$SS_j = SF \sqrt{IA_{i,j} \sigma_{D_j}^2 + D_j^2 \sigma_{LTmax}} \quad (9)$$

### 2.3 Determination of Reorder Point

Reorder point at plant $j$ ($ROP_j$) was determined by adopting formula from [13] as follows:

$$ROP_j = D_j \times LT_{i,j} + SS_j \quad (10)$$
The formula was modified by changing $LT_{i,j}$ to the minimum $LT_{i,j}$ as follows:

$$\text{ROP}_j = D_j \times \min (LT_{i,j}) + SS_j$$ (11)

This modification was made in order to make the reorder point as low as possible. By having the lowest reorder point, the arrival of coal is expected not to lead an excessive amount of coal in the plant. Consequently, inventory cost could be lower.

### 2.4 Determination of Reorder Point

In determining the order quantity ($OQ_j$), it is necessary to consider the probability of inventory level below the safety stock level. Hence, when the order arrived, it will always make the inventory level above the safety stock value. The order quantity was determined by multiplying the inverse value of demand ($\text{NORM.INV}(SL, D_j, \sigma D_j)$) with the inverse value of lead time distribution ($\text{NORM.INV}(SL, IA_j, \sigma L_{max})$). For the lead-time distribution, $IA_j$ was used as the average lead-time and $\sigma L_{max}$ will be used as its standard deviation. The service level ($SL$) is set to be 99.99% in order to ensure coal availability in each plant. The multiplication result is divided by the total number of suppliers ($n$) that have to supply plant $j$. This is called as order splitting. The formula of order quantity is shown in equation (12) below:

$$OQ_j = \frac{\text{NORM.INV}(SL, D_j, \sigma D_j) \times \text{NORM.INV}(SL, IA_j, \sigma L_{max})}{n}$$ (12)

### 2.5 Parameter Evaluation

The calculated value of safety stock, reorder point, and order quantity were simulated for one year in order to see the capability of each plants for not experiencing the stock-out.

### 2.6 Sensitivity Analysis

In this study, there are two sensitivity analysis conducted. The first one is to analyze the effect of demand and lead-time variations on safety stock. It only considered demand and lead-time variations because the idea of safety stock itself comes from the variations of demand or lead time or the combination of both so that the average inventory needs to cover those variations. The second one is to analyze the effect of increasing number of suppliers on safety stock.

### 3 Results and Discussion

#### 3.1 Optimal allocation, safety stock, reorder point and order quantity determination

The optimal amount of coal allocated from supplier $i$ to plant $j$ was obtained by running the objective function and all of the constraints using What’s Best’s which is similar as Microsoft Excel solver. By using primal simplex method, the results are already globally optimal. The result is shown in figure 1. The impact of the centralized coal supply on the island of Kalimantan made them to supply most of the coal to Java as the largest demand area. Consequently, Kalimantan – Java routes become the most densely populated sea transportation in the coal supply chain for steam power plants. In addition, the optimization result shows that the distance between suppliers and steam power plants is not a determining factor in choosing the optimal suppliers. This can occur because purchasing cost contributes 71% of the overall costs compared to transportation costs, which is only 29%.

The optimization result above was used to calculate safety stock level, reorder point and order quantity of each plant. Those parameters were then simulated for 365 days to see whether each plants will experience stock out. Figure 2 shows an example of the simulation result of a plant, where x-axis indicates days and y-axis represents the inventory level. The green line represents the reorder point values and the orange line represents the safety stock values. Figure 2 shows that during the simulation there is no occurrence of stock out, which means that the value of safety stock, reorder point and order quantity are fine to be used. All
steam power plants were evaluated using the same way and all produced no stock out during the simulation period.

![Map of Supplier’s and Plant’s Location]

**Figure 1.** Optimization results of coal allocation

**Figure 2.** Example of Simulation result for parameters’ evaluation

### 3.2 Effect of Lead Time and Demand Variations on Safety Stock

To analyze the effect of lead-time and demand variations on safety stock, a sensitivity analysis was conducted on those two variables. Figure 3 shows that the variations in demand or lead time will increase the amount of safety stock in the plant. This figure also explains that variations in lead-time have more influence on the safety stock values compared to that of the variations of demand. Thus, reducing the inventory costs by lowering the amount of safety stock can be done by cutting back the lead-time variation.
Figure 3. Comparison between lead-time and demand variations effect on safety stock

3.3 Effect of Multi-Suppliers on Coal’s Safety Stock
From equation (9), the value of safety stock is affected by the value of maximum inter-arrival time between suppliers. Therefore, if the addition of suppliers increases the maximum inter-arrival time, the safety stock needed will also be increased and vice versa. Figure 4 shows that when additional suppliers increases maximum inter-arrival time, safety stock level also increases, while figure 5 shows that when the additional of supplier decreases the maximum inter arrival time, the level of safety stock also decreases.

Figure 4. Level of safety stock when supplier addition increases maximum inter-arrival time
Figure 5. Level of safety stock when supplier addition decreases maximum inter-arrival time

4 Conclusions
This research has implemented the optimization model for coal allocation of steam power plants in Indonesia. Results obtained can provide information regarding the selection of suppliers and its allocation with the lowest possible cost. This research also found that variations in demand and lead-time might increase the value of safety stock required in a plant. Lead-time variations was found to influence more to the safety stock level compared to demand variations. This research also concluded that the addition of suppliers could increase or decrease the value of safety stock values depends on how it affects the maximum inter-arrival time between suppliers.

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