Modeling and Optimization of Location Selection of Fuel Terminal Considering Vessels and Pipeline Operations

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Abstract. This study discusses mathematical modeling using the mixed-integer linear programming (MILP) technique for selecting the optimal fuel terminal location which considers not only aspects of ship and pipeline transportation, but also marine technical aspects. In addition, coverage days are also included in the model because of their important position in maintaining not only stock resilience, but also consumer serviceability. The model is searched for the optimal solution using branch and bound and tested on real cases of building new terminals in Indonesia. The solution produces the best location in the fuel supply chain network at the lowest cost and is able to maintain minimum coverage days from the current terminal. The total cost of the entire supply chain for the relocation of fuel terminal is IDR 127,508,400,000. The results of the sensitivity analysis show that the model is capable of dealing with parameter changes. It was concluded that the selected terminal should prepare for the field conditions of the three parameters, considering the potential average additional cost increase of up to 200%. However, it is necessary to pay close attention to the parameters for the cost of building pipes that are sensitive to changes. In the future, it is necessary to consider a model that is capable of finding solutions from alternative continuous locations.

Keywords: Fuel Terminal, Location Selection, Coverage Days.

1 Introduction

1.1 Motivation

The petroleum industry is a sector that is crucial in human life. In the future, the demand for fuel oil will continue to increase. However, high income from the oil industry is also offset by large operating costs such as exploration costs, production costs, crude oil supply costs, refinery processing costs, and distribution and marketing costs [1]. The petroleum industry has its own challenges in developing its business. There are three major divisions of problems in the development of the petroleum industry, namely investment planning, location determination and facility allocation, and operational planning [2]. These three classifications correspond to the types of decision making in a supply chain, namely strategic, tactical, and operational [3], where strategic decisions

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are usually for the long term and operational decisions for the short term. In every type of decision, mixed integer linear programming (MILP) modeling is widely used [2].

The fuel oil supply chain system can be divided into three levels, namely upstream, midstream, and downstream. Broadly speaking, upstream includes exploration, extraction, separation, and transportation activities of crude oil to refineries. The midstream category includes the transformation of crude oil carried out in refineries and petrochemicals. Meanwhile, the downstream category is classified for storage, distribution, and marketing activities. Unlike what is mentioned in [4] refinery activities are defined in the downstream classification. One of the most important nodes in the fuel oil supply chain system is the fuel oil terminal/depot. The terminal functions to receive products from sources and then store them before being distributed to consumers.

The transportation aspect is one of the key factors in fuel oil terminal operations. In a terminal, there are various possible modes of transportation, where the most common is sea transportation using ships, due to consideration of economies of scale. The mode of delivery, from raw materials in the form of crude oil to finished products, is also sent between points using oil tankers. The types of ships used include general purpose (GR), medium range (MR), long range (LR), and very large crude carrier (VLGC). A ship used on one route cannot be used on another route. Therefore, one of the performance criteria for sea transportation is round trip days (RTD), which is the number of days taken by a ship in one trip from the loading port to the discharge port and then back to the loading port [5]. With this definition, the length of time using the ship consists of 2 times the travel time and 2 times the operating time of the pier. In general, wharf operations are a series of ship inspection and documentation activities as well as ship pumping activities. Ship pumping is an activity of taking and removing fuel.

In addition to ship transportation modes, pipelines are also being developed. There are several economic advantages to be gained from using pipes as a mode of fuel transportation, including continuous delivery in batch form, no packaging required, high accuracy, and low cost per unit of delivery [5]. There are three types of pipeline operations, namely gathering pipeline systems, crude oil pipeline trunk systems, and refined products pipeline systems. Gathering pipeline systems are pipelines used in the process of extracting petroleum from the ground. Crude oil that is transferred from the source of the well to the temporary storage tank. The pipes used at this stage are generally of small diameter. Crude oil pipeline trunk systems are pipelines that move petroleum from storage tanks to other storage systems, tanks, and other trunk lines. Unlike the other two pipelines, refined products pipeline systems deliver products that have been refined and are in the form of finished products. In general, this pipeline is used in product transmission from refineries to fuel storage depots.

One of the important aspects in the downstream part of the fuel supply chain is the determination of the location of the terminal. The referenced studies [6-8] primarily focus on classical transshipment problems, which represent a common network-flow challenge in industrial logistics often addressed using linear programming (LP). In study [6] the MILP model was used to determine the optimal location of a fuel terminal that uses piping, taking into account the capacity and pipeline route which aims to maximize the total profit of the fuel company. The determination of multi-product fuel terminals discussed in research [8] uses MILP with decision variables in the form of choosing a terminal location that uses ship transportation modes, product flow speed from supply to depot, and production capacity. The primary aim of this study is to minimize the costs of the entire supply chain, thereby maximizing the company's profits through the relocation of terminals. Transportation modes that use ships and pipelines are discussed in research [7], where in the MILP model the selected depot locations are determined, the depot capacity, the quantity of shipments from the refinery to the depot, and the quantity of shipments from the depot to demand points.

1.2 Contribution

The literature discussed above shows that determining the optimal location of the fuel terminal is mostly determined using the classical transshipment model, where the main considerations are transportation costs from source points to destination points and storage costs up front. However, the technical aspects were not considered. This is the first contribution of this study, in which technical aspects such as ship draft, wharf draft and road conditions are involved in the mathematical modeling. The second contribution is the integration between terminal operations that use ship and pipeline transportation modes, where technical considerations need to be determined such as pipe routes, pipe flow rates, and the types of vessels used. The third contribution is the inclusion of coverage days in modeling. Coverage days are a measure of the terminal tank's ability to serve consumer demand in the next few days. The existence of coverage days in the study system will add to the complexity of the model because it will affect the size of facilities and facilities at the terminal, not only those that are directly affected such as tanks and filling sheds, but also the jetty on the wharf side.

This paper is presented in several parts. The first section discusses the background of the problem, motivation, and research contribution. The second section discusses the modeling framework, which is then detailed in the form of mathematical modeling in the third section. The fourth section discusses simulation and analysis. Finally, conclusions and suggestions for further research are discussed in the fifth section.

2 Modeling Framework

The reference model approach used is the model developed by [7]. In this model the objective function is to minimize the cost of the entire supply chain starting from the supplier to the depot and forwarded to the point of demand. The following is mapped in Table 1 of the characteristics of the system with the characteristics of the reference model.

The first consideration in choosing a reference model is the similarity of the type of industry used in the model with the type of industry in the system that is the object of research. The reference model uses the same entities and parameters that exist in this system. This will certainly make it easier to understand the model. The second consideration is that one of the decision variables in the reference model answers the main problem of determining the optimal fuel terminal location. The reference model determines the optimal number of depots and locations to meet demand. This decision variable certainly accommodates the problems that exist in this research object.

Table 1. Analysis of reference model's characteristics with system's characteristics.

System's characteristics	Reference model's characteristics	Analysis
1. Petroleum industry supply chain system. 2. Choose the best depot facility location. 3. Supply activities require a combination of supply methods using ships and pipes. 4. Determine the vessel capacity and pipe flow velocity in supply operations.	1. The model aims to design a supply chain system for the oil and gas industry with minimal costs. 2. Choose the location of the depot facility from several potential locations. 3. Accommodate distribution with multimodal transportation. 4. Provides product flow information from the point of supply to the depot and to the point of demand.	1. The similarity of the supply chain system in the petroleum industry. 2. There is a decision variable for choosing a depot location. 3. There are decision variables determining the flow of supply and demand.

The third consideration is that the reference model is suitable for use because this model accommodates multimodal transportation in the supply chain. This is in line with considerations to involve ship and pipeline operations in the location determination. Multimodal transportation in this model is the different modes of transportation used in the refinery flow to the depot and the depot flow to the point of demand. The drawback of this model is that each selected depot location only uses one mode of transportation in its supply pattern. If one is selected, all of the refineries that will supply will use a certain mode of transportation. The final consideration is the decision variable regarding the amount of flow in unit volume accommodated in the reference model. This can help determine the supply and distribution flow network in the selected fuel terminal supply chain.

In using the MILP model, the selected location is a discrete location. The use of MILP requires a potential location first. The model [7] determines potential locations based on the demand value of an area. Demand per year will be broken down into requests per regional location using the proportion of population density. A different method is used by [9] where in determining the location using the center of gravity theory. The theory is used to determine optimal points in an area that will become potential locations. Furthermore, to select a location, the MILP will select the location with the smallest cost. In this research, the approach used in determining the potential location is based on the area recommended by the company as the case study.

The model employed in this paper incorporates four adjustments and assumptions compared to the reference model, as outlined below: (i) the model determines a solitary optimal location as the final result, (ii) it doesn't impose a prerequisite for a minimum percentage of supply flow designated to specific transportation modes, (iii) the transportation variations considered embrace not only various transport types but also cater to distinct ship categories, and (iv) the fixed costs associated with location development are specifically outlined, covering expenses for pier construction and office facilities.

3 Mathematical Modeling

The objective function of the model is to minimize supply chain costs which are accumulated in total costs per year. The total cost of the supply chain is broadly divided into two, namely, development/investment costs calculated in a yearly period and operational costs (supply costs and distribution costs) per year. In determining these costs, there are several decisions made by the model, namely, the selected location, the volume of product to be stored, the allocation of supply and distribution shipments, and the status of selecting the pipeline transportation mode. In this model the notations shown in Table 2 is used.

Table 2. Model's notations.

Notation	Description	Unit
i	Supply point	
j	Potential terminal location point	
k	Demand point	
p	Product type	
r	Transportation modes (1 = pipe, 2 = vessel GP I, 3 = vessel Small Tanker II, 4 = vessel Small Tanker I, 5 = vessel Lighter)	
D_{kp}	Annual demand of product *p* at the demand point *k*	kl
f_j	Cost of terminal area development	Rp
C_{ijr}	Transportation costs from supplier *i* to alternative location *j* with mode of transportation *r*	Rp/kL
T_{jk}	Transportation cost from alternative location *j* to point of demand *k*	Rp/kL
S_{ip}	Supplier capacity per product (in kL per year)	kL
M	Large number	-
F_{ij}	Office and facility development costs	Rp
P_{ij}	Pipe installation costs, pipe ROW, and pipe pump costs	Rp
M_j	Jetty construction costs per location	Rp
L_j	Tank construction costs	Rp/kL
U_j	Tank area cost per kL	Rp/kL
CD	Ratio of coverage days to the total time of one year	-
X_j	The variable will be 1 if depot is selected; value 0 otherwise	binary
Y_{ijpr}	Product quantity *p* is sent from factory *i* to depot *j* by mode of transportation *r*	kL
Z_{jkp}	A quantity of product *p* is shipped from depot *j* to point *k*	kL
V_j	Depot capacity *j* (in units of kL per year)	kL
N_{ij1}	The variable will have a value of 1 if the pipe transportation used from supply point *i* to depot *j* is selected and is zero otherwise	binary
H_j	The intermediate variable is the total demand that the terminal must meet one year with the terminal storage capacity decision	kL

The mathematical models are as follows.

$$Min \sum_{j\in J}\sum_{k\in K}\sum_{p\in P} T_{jk}\, Z_{jkp} + \sum_{i\in I}\sum_{j\in J}\sum_{p\in P}\sum_{r\in R} C_{ijr} y_{ijpr} + \sum_{i\in I}\sum_{j\in J} N_{ij1}\, P_{ij} + \sum_{j\in J} L_j\, V_j + \sum_{j\in J} V_j\, U_j + \sum_{j\in J} X_j\, M_j + \sum_{j\in J} X_j\, f_j \quad (1)$$

A more detailed explanation regarding the objective function will be explained below.

$$\sum_{i\in I}\sum_{j\in J}\sum_{p\in P}\sum_{r\in R} C_{ijr} y_{ijpr} \quad (2)$$

Equation (2) shows the function of calculating the costs incurred to send fuel products from a supplier to a depot location using a certain mode of transportation. As stated in the index, there are five types of transportation options used to supply fuel.

$$\sum_{j\in J}\sum_{k\in K}\sum_{p\in P} T_{jk}\, Z_{jkp} \quad (3)$$

Equation (3) shows the fuel distribution cost calculation function from an alternative location to the consumer's place. The type of transportation used for this distribution activity is only the truck mode of transportation.

$$\sum_{i\in I}\sum_{j\in J} N_{ij1}\, P_{ij} \quad (4)$$

Equation (4) shows the cost calculation function required for the installation of pipeline transportation modes, the cost of the right of way (RoW) and the cost of purchasing a pump. The cost of pipe installation is the total cost required in the construction of the pipe. While the ROW fee is a fee paid for renting an area beside the road that will be used as a pipeline route. In each pipeline construction route, there is one pump installation.

$$\sum_{j\in J} L_j\, V_j \quad (5)$$

$$\sum_{j\in J} V_j\, U_j \quad (6)$$

$$\sum_{j\in J} X_j\, M_j \tag{7}$$

$$\sum_{j\in J} X_j\, f_j \tag{8}$$

Equation (5) shows the costs required in the construction of the tank. This fee depends on the fuel capacity required by the terminal. Equation (6) shows the area cost calculation function required for the tank location area. This fee depends on the area price of the prospective depot location. Equation (7) shows the function of calculating the cost of constructing a wharf at each alternative location. The wharf that is built depends on the type of ship that can dock at a prospective depot location. Equation (8) shows the cost calculation function for building office and terminal facilities. In this model there are several constraints used which will be explained below.

$$\sum_{j\in J} Z_{jkp} = D_{kp} \quad \forall p \in P, \forall k \in K \tag{9}$$

$$H_j \le MX_j \quad \forall j \in J \tag{10}$$

$$H_j\, CD = V_j \quad \forall j \in J \tag{11}$$

$$\sum_{p\in P}\sum_{k\in K} Z_{jkp} \le V_j \quad \forall j \in J \tag{12}$$

$$\sum_{j\in J}\sum_{r\in R} Y_{ijpr} \le S_{ip} \;\; \forall i \in I, \qquad \forall p \in P \tag{13}$$

$$\sum_{i\in I}\sum_{r\in R} Y_{ijpr} - \sum_{k\in K}\sum_{r\in R} Z_{jkpr} = 0 \quad \forall j \in J, \forall p \in P \tag{14}$$

$$\sum_{r\in R} Y_{ijpr} \le MN_{ij1} \tag{15}$$

$$\sum_{j \in J} X_j = 1 \tag{16}$$

$$X_j \in \{0,1\} \quad \forall j \in J \tag{17}$$

$$N_{ij1} \in \{0,1\} \tag{18}$$

Constraint (9) serves to ensure the demand for various products will be met for each point. This constraint ensures each product will be satisfied for each location. Constraint (9) serves to provide a limit if the capacity of a depot is obtained only when the alternative location is selected. Constraint (10) determines the storage volume each time of the terminal. *CD* is the ratio of coverage days to the total time in one year. Constraint (11) ensures that the volume of fuel distributed by a depot must be less than the capacity of the depot. The constraint (12) functions to limit the flow of supply from a supplier to the depot not to exceed the capacity of the supplier. The constraint (13) ensures that the flow of product into the depot will be the same as the flow of product out of the depot. Constraint (14) serves to determine the status of pipe transportation usage on a supply route. If there is a supply flow to the depot using the pipeline transportation mode, then the status of N_{ij1} will be selected. Constraint (15) shows that in this model only one depot is selected from several potential depot locations to become terminal locations. The constraint (16) indicates that the depot selection status is binary. When a depot is selected, the value is 1. Conversely, if it is not selected, the value is 0. Constraint (17) indicates that the status of the pipe transportation mode is binary. When there is a supply using the pipe mode, the value is 1. Otherwise, if there is none, it will be 0.

4 Optimization

Before doing simulation, we need to verify that the models are correct. By checking the left-side and right-side dimensions for all equations, we prove that the models are verified. Later, we generated small scale datasets and find the solution with both of LINGO and manual procedure using Excel. We found that the comparison deviates 0.02% and it proves that the models are correct.

We tested our model for a real fuel terminal development project in Indonesia. The old terminal is at a riverside and face serious problems due to lack of available area to expand the terminal, and technical constraints such as the height of the existing bridges that limit the tanker vessels which can cross the river. There are 8 location alternatives of the new terminal, and the product types considered in the experiment is 5. The number of supply and demand points are 4 and 12, respectively. A subset of consumers demand data is given in Table 3.

Table 3. A subset of consumers demand data.

Consumers *(k)*	**Products *(p)***	***Dkp (kL)***
1	1	352.00
1	2	6,816.40
1	3	195.20
1	4	8.00
2	1	703.75
2	2	4,279.20

One important parameter is distribution costs. This fee is a fee issued by the terminal to distribute products to consumers. The mode of transportation used is a tank car. Tank cars used to distribute products to consumer locations will return to the terminal. Therefore the calculation of distribution costs takes into account the round trip of the tanker. Based on the terminal's historical data, the cost of using a tank car is IDR 3.99/km/kL. These costs need to be adjusted to the consumer's distance from the alternative terminal location. Table 4 shows a subset of each consumer's distance to alternative terminal locations and distribution costs.

Table 4. A subset of distribution data.

Alternative	**Consumer**	**Distance (km)**	**Distribution cost (Rp/kl)**
Alternative 1	Consumer 1	209	Rp 1,669.91
Alternative 1	Consumer 2	328	Rp 2,620.72
Alternative 1	Consumer 3	220	Rp 1,757.80
Alternative 1	Consumer 4	148	Rp 1,182.52
Alternative 1	Consumer 5	208	Rp 1,661.92

Table 5. Summary of parameter sensitivity analysis

Parameter Component	**Changed Decision?**	**New parameter to initial value**
Ship supply costs	Yes	30%
Pipeline supply costs	Yes	250%
Pipeline construction costs	Yes	1%
Jetty construction	No	-
Office and facility development costs	No	-
Tank Construction Costs	No	-
Area Costs (Office Building Area + Tank Area)	No	-

Fig. 1. The optimal supply chain based on the MILP.

Model solution search using LINGO software. The total cost of the entire supply chain for the relocation of fuel terminal Y is IDR 127,508,400,000. The search for a mathematical model solution results in a decision on the best location, terminal capacity, selected supplier, mode of supply transportation. The results of these decisions are shown in Figure 1. The best location according to the mathematical model is alternative 1.

A sensitivity analysis was conducted, and the outcomes are presented in Table 5. The parameters that change the decision of the model are the parameters of ship supply costs, pipeline supply costs, and pipeline construction costs. Based on the results of this analysis, it was concluded that with an average additional cost of up to 200%, the selected terminal needs to anticipate the parameter values in the field conditions of the three parameters. The initial solution is still valid to implement if the change in costs still does not reach a value of 30% for pipe supply costs, 250% for ship supply costs, and 1% for pipeline construction costs. It can be seen that the pipeline construction cost is very sensitive to the optimal decision.

5 Conclusion

In this research, the MILP model has been developed for selecting the optimal location for fuel terminal facilities considering transportation by ship and pipeline. In addition, technical aspects such as ship draft, wharf draft, pipe flow rate have been involved, as well as coverage days to ensure terminal consumer serviceability. The verified model is searched for the optimal solution using the branch and bound method for a real terminal development case in Indonesia. The solution shows that the model is capable of finding the best alternative fuel terminal locations in the company's supply chain network which is the case study. In addition, the coverage days of the old terminal can be maintained at the new terminal location. The best alternative location still considers ship transportation and piping.

In this study, the alternative locations considered are discrete. In the future, continuous location-based research on site selection can be developed so that optimization is carried out more optimally. With alternative locations that are continuous, natural obstacles (especially from the marine side) that cannot be overcome by a set of discrete locations can be relaxed. From the ship side, it can be considered to use an alternative with a larger number of ships. In this study, the performance criterion used is total cost. In many cases in fuel companies, the costs considered are in units of Rp/kL, therefore in the next model it is necessary to structure costs more realistically in accordance with industry practices. In addition, this model only addresses the operational decisions of the fuel terminal from a tactical aspect. In the future, it is necessary to develop a model that addresses operational aspects and conducts feasibility studies.

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