

# The Fleet and Berth Selection Model to Improve Energy and Environment Sustainability

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## ABSTRACT

This research aims to improve energy sustainability in transportation management. The case was derived from port-to-port coal transportation problem commonly faced by third-party logistic (3PL) company. During planning, they must determine which shipsets to be used and assign them to the loading/unloading berths. Each berth varies in terms of its loading/unloading speed and each shipset varies in terms of its capacity, sail speed, and fuel consumption rate. The selection of shipset impacts the auxiliary and main engine fuel consumption while the selection of berth impacts only the auxiliary engine fuel consumption. The target is to minimize the total fuel consumed by both engines for the whole shipset. We modelled the case through Multiple Vehicle Allocation Problem (MVAP) framework and proposed a heuristic algorithm to find the solutions. The heuristic algorithm is proven to be able to reach an optimal solution for small cases and near-optimal for medium to large cases.

Keywords:  
Logistics; Transportation  
Sustainability; Multiple  
Vehicle Allocation Problem;  
Fleet and Berth Selection;  
Fuel consumption

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## 1. INTRODUCTION

### 1.1. Background

The issue of sustainability has impacted the way we manage transportation system. Jeon et al. explained that there is no standard definition for transportation system sustainability, but one general way to measure it is through fuel consumption level [1]. This is because transportation fuel, as we know, is dominated by fossil based non-renewable energy and its price is highly expensive. The use of fossil fuel is also problematic due to its environmental impact since it has been identified as the main cause for the rising of world temperatures. Many land transportation systems, such as cars, trucks and trains have switched into using electrical system as a new energy option, but this is not the case for air and marine transportation systems. At the time of writing this paper, no concrete efforts have been found for these transportation systems to switch to renewable energy. Jet engines are still used in air transportation systems and diesel engines are used in marine transportation system.

The case examined in this study was derived from a third-party logistics company (3PL), which is engaged in coal distribution sector. It ships coal from Kalimantan, Indonesia to many ports in Asian countries. The 3PL company has several barges that have different transport capacities (i.e., 500, 3800, 5000, 7500, 8000, 8400, 9000, 9600, and 10,000 tons). Each barge will be pulled by a tugboat, which has two engines, the main and auxiliary engine. The main engine is used to drive the propeller of the ship, while the auxiliary engine is used to produce electricity. A combination of a tugboat and a barge is called a shipset. In this study, we assume that this combination is fixed, so there is no discussion about how to form this combination. A shipset will be identified by its barge capacity, sail speed, and the fuel consumption rate of its main and auxiliary engine.

The coal transportation process starts with a stockpile at the departure port which needs to be shipped to the destination port. The amount of coal at the departure port is in accordance with the demand ordered by the destination port. Both ports have several berths. Each berth is equipped with different crane facility thus resulting different speed for loading and unloading the coal to the shipset. High speed loading/unloading equals to low fuel consumption by auxiliary engine, this means choosing the fastest berth is always preferable. The problem is not necessarily trivial for determining which shipset to be used. As we explained earlier, each shipset is identified by its barge capacity, sail speed, and fuel consumption rate of its main and auxiliary engine. Prioritizing for a large barge capacity would minimize the number of shipset used but would result in lengthy loading/unloading duration and high fuel consumption rate by its auxiliary engine. In the other side, selecting a shipset with high sail speed will minimize the trip duration but will increase the amount of fuel consumption per hour of the main engine. The target of the management is to minimize the total fuel consumption used by the whole fleet of shipsets.

Our research contributes to transportation management field especially to those which considers energy sustainability. Other research with the same direction as our paper are Pasha et al., which proposed an integrated method for transportation planning in liner shipping with heterogenous ship fleet by considering environmental impact [2]. Meanwhile, Shankar et al., developed approach for assessing sustainability risk in freight transportation system [3]. Messaoud et al. implemented ant colony approach to solve the case of dynamic routing problem and minimize energy and carbon emission [4]. Our contribution lies in designing mathematical model which characterizes the common practical problem faced by a 3PL company when selecting shipset and berth both at the departure and destination port. Along with the mathematical model, we also developed a heuristic algorithm which able to find solution with a reasonable computational duration.

## 1.2. Literature Review

There is numerous research that deals with marine coal transportation problem. The research by Mifang et al. studied coal transportation in China and proposed the use of genetic algorithm to find transportation mode and path to serve several demand destinations which minimize the total transportation cost [5]. Li, Jinying et al. developed mathematical model to determine optimal path from the colliery and coalpit to distributors and several power plants. While these research focuses on transportation mode and route optimization, separate group of research focus on the transportation equipment management [6]. Zhen et al. studied tug-scheduling model for barge and tugboat to minimize the total price. They proposed a mixed integer programming model and introduced a branch-and-price-based as an exact solution finding approach. In their paper, a tug and barge can be considered as a fleet of ships [7]. In the context of fleet management, ManWo Ng. et al. developed fleet deployment model to determine the combination of chartered and privately owned ship that will be deployed in a certain route and set of ship types. This combination is selected to minimize the total operation cost [8]. Wang et al. studied a fleet scheduling problem on a probabilistic situation due to port congestion and uncertainty in container handling time. The scheduled is aimed to minimize the waiting time [9]. Still in the context of transportation equipment management, Dulebenets modelled a vessel scheduling problem and explained that the assignment must consider several factors, which are the type of ship, the cruising speed, the port handling rate, as well as the fuel consumption [10]. Another research is conducted by Guan et al. which consider the problem of allocating space at berth for vessels to minimize waiting time [11]. Meanwhile Nishimura showed that a sound decision would only be achieved through knowledge gained from data analysis. They collected and estimated handling time to increase yard and berth planning efficiency [12]. Loading and unloading process occupied a significant amount of time on coal transportation, research which specifically highlighted this process are conducted by Lin et al. and Huang et al. Lin solved freight assignment problem and determined shipping route for the Northern Sea. The decision is made to minimize the total cost which includes the shipping cost, the loading and unloading costs [13]. While Huang designed a liner service network and consider empty container repositioning to anticipate future needs. Through all the papers mentioned on this paragraph, we can see that assignment of ship to demand or allocation of ship to berth as well as route (port to port path) planning are major decision variables in coal transportation management. Whereas minimizing total waiting time and total cost are the general performance measures [14].

When incorporating the issue of sustainability in transportation management, researcher mostly try to find operational performance measure of sustainability within their system. One general way is to measure the fuel consumption volume. This is reasonable because by the time this paper is written, most of transportation vehicle especially marine transportation is still using diesel engine, which is a fossil based non-renewable energy. Fuel cost is expensive and still dominates the total shipping cost. Moghdani et al. summarized papers concerning green vehicle routing problem and highlighted the focus on reducing fuel consumption to avoid negative environmental impacts [15]. Karagul et al. solved the green vehicle routing problem which considered fuel consumption. In line with that, carbon emission level has also been considered as another performance measure of sustainability [16]. Comprehensive literature review regarding green supply chain and optimizing carbon emission is done by Memari et al. They explained that mitigation attempt to minimize carbon emission should begin with an effort to estimate the carbon footprint [17]. Example of such estimation is done by Jaegler et al. on a road freight firm [18]. Qi et al. developed a model which shows the impact of berth scheduling and route re-engineering on fuel consumptions and carbon-dioxides emissions in container shipping [19]. Abdullahi et al., proposed multi-objective optimization models and extend the existing sustainable vehicle routing problem (VRP) models by including vehicle operation costs, carbon emission cost, and safety cost. These costs are important for ensuring sustainability in transportation activities, especially when considering a coordination between the economic, environmental, and social dimension [20]. Rabbani et al. designed logistics network which minimize CO<sub>2</sub> emission quantity as well as the logistic costs [21]. Golias et al. proposed berth scheduling model which considered carbon emissions control by minimizing fuel consumption [22]. To summarize, fuel consumption and carbon emission level have been generally used as performance measures of transportation sustainability.

Compared to the previously mentioned research, our paper focuses on minimizing fuel consumption. We do this by determining the assignment of shipset to berth, both in the departure and destination port. We approached this problem through Multiple Vehicle Allocation Problem (MVAP) model. Usually, MVAP is developed to determine which vehicle to be used and what destination each vehicle must pass to minimize certain criteria. In this research, MVAP is used to determine which shipset to be used, at which berth at the departure port should it be loaded, and finally at which berth at the destination port should it be unloaded. Thus, several adjustments to the original MVAP model are needed. One of the adjustments is to consider the assignment of loading and unloading berth for each shipset as a point-to-point route determination. Rodrigue explained that point to point route strategy is commonly used by companies among other typical route such as corridors, fixed routes, flexible routes, & hubs and spoke [23]. We developed mathematical model for the problem and solved it through total enumeration process, but as the size of the problem increase, the computational time would exponentially increase. This is due to the NP-Hard characteristic of the model which is confirmed as the nature of a VRP problem [24].

When thinking about transportation management, resiliency is an important factor to be considered. A system is defined to be resilient when it has the capability to adapt to changing conditions or interruptions as mentioned in Dui et al. [25]. One way to achieve resiliency is to ensure that the computational time for arriving to decision variables is as short as possible. Therefore, when changes or interruptions occur, new solution can be easily recomputed. Generally, computational time is highly related to the size of the problem, its complexity, and the nature of the model (i.e whether it is an NP hard or not). A lot of transportation management can be referred to the problem of managing fleet. The size of the problem certainly arises when dealing with large number of fleets compared to single vehicle. Baykasoğlu et al. highlighted the complexity of fleet planning, especially when it consists of various interrelated subproblems which span at strategic, tactical, and operational decision levels and under responsibility of multiple decision makers [26]. Asadabadi et al. shows the complexity of managing a global port network and proposed co-opetition methodology to achieve system reliability [27]. Cricanic et al. highlighted the significant use of simulation model to capture the complexity of managing an intermodal transportation network [28]. In such complex system, shortening the computational time can be achieved by implementing metaheuristic or heuristic methods. Li used genetic algorithm to determine transportation mode and path [5], Karagul proposed the use of simulated annealing to solve vehicle routing problem [16], while Rabbani [21] compared the use of genetic algorithm and particle swarm optimization to solve freight assignment and ship routing problem. The genetic algorithm is also used in Abdurrahman's research [29] to find the best route and vehicle number. This research has objective to minimize the transportation costs. Meanwhile, two phase tabu search method is introduced by Brilliane et al. [30] to minimize travel distance in the vehicle routing problem with time windows. Although metaheuristic method can come up with a solution in a timely fashion, most of them needs exhaustive parameter fine tuning. When the parameter is not easy to find, heuristic method would be preferable. To be able to implement a heuristic method, one must understand the detail of the problem at hand and configure the most suitable steps to arrive to a solution. Our paper also contributes on this issue. Having designed the mathematical model for the fleet and berth selection problem, solved it through total enumeration process, we continue to craft heuristic method for finding the solution in real time.

## 2. METHOD

This paper is presented in several parts. The first part mentioned the background of the research, the second part discussed relevant literature related to marine coal transportation system and highlighted the position of this paper, the third and fourth part described the model building and experimentation using several sets of data, at the last part, we presented analysis and conclusion.

The research methodology is to build the mathematical model as an approach to minimizing fuel consumption, that has impact on improving energy and environmental sustainability. The mathematical model is defined as follow:

### 2.1 Notation List

The following notations will be used when we explain the mathematical model for the problem. The components of the berth and the shipset determination model are as follows:

- $I$  : The set of the departure port.  
 $J$  : The set of the berth at the departure port.  
 $P$  : The set of the destination port.  
 $U$  : The set of the berth at the destination port.  
 $K$  : The set of the shipset (consists of a tugboat and a barge).

#### Indexes:

- $i$  : The departure port, which is  $i \in I$   
 $j$  : The berth at the departure port, which is  $j \in J$   
 $p$  : The destination port, which is  $p \in P$   
 $u$  : The berth at the destination port, which is  $u \in U$   
 $k$  : The shipset, which is  $k \in K$

#### Parameter:

- $D_p$  : The demand of the port- $p$  (in metric ton)  
 $G_{j,p}$  : The distance from the berth at the port- $j$  to the port- $p$  (in kilometre)  
 $FE_k$  : The fuel consumption rate of the main engine for the shipset- $k$  (in litre/hour)  
 $FA_k$  : The fuel consumption rate of the main auxiliaries for the shipset- $k$  (in litre/hour)  
 $A_i$  : The loading speed at berth- $i$  at departure port in (in metric-ton/hour)  
 $B_u$  : The unloading speed at berth- $u$  at destination port (in metric-ton/hour)  
 $Q_k$  : The barge capacity at shipset- $k$  (in metric ton)  
 $V_k$  : The shipset speed in units of kilometres per hour

#### Variable:

- $CS_{j,p,k}$  : The total sailing fuel consumption (in litre)  
 $CU_{p,u,k}$  : The fuel consumption for unloading (in litre)  
 $CL_{i,j,k}$  : The fuel consumption for loading (in litre)  
 $TT_{j,p,k}$  : The traveling time, of the shipset- $k$ , from port- $j$  to port- $p$  (in hour)  
 $TL_{i,j,k}$  : The loading duration on ship- $k$ , at berth- $j$  in departure port- $i$  (in hour)  
 $TU_{p,u,k}$  : The unloading duration on ship- $k$ , at berth- $u$  in destination port- $p$  (in hour)

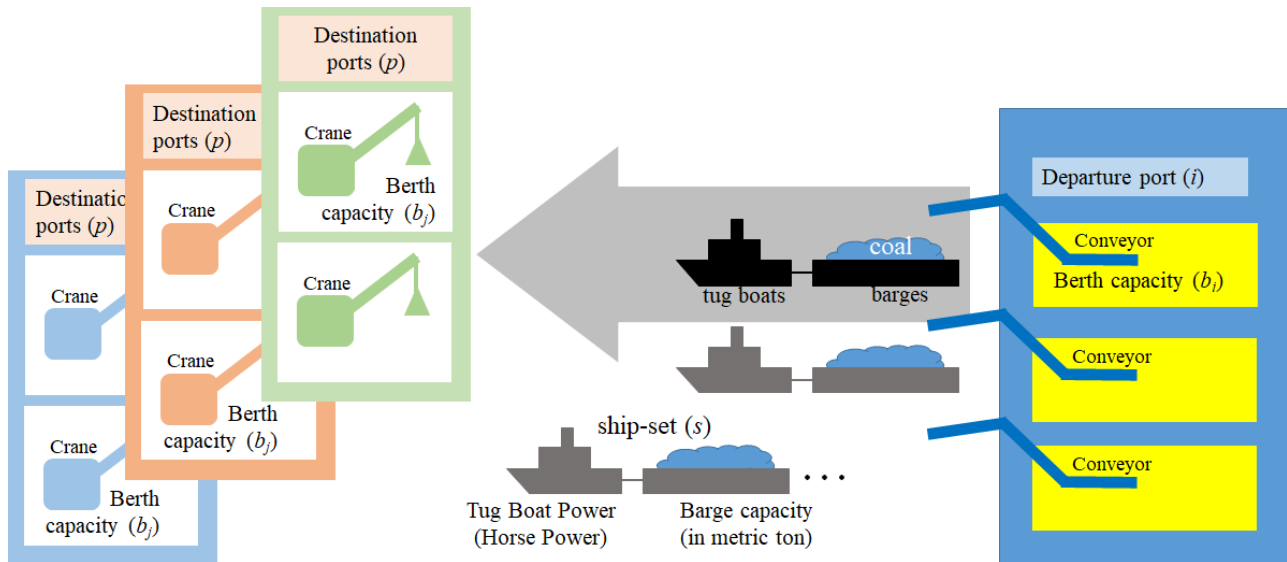
#### Decision Variable:

- $X_{i,j,k}$  = 1 if the berth- $j$  in the destination port- $i$ , use the ship- $k$ .  
 = 0 otherwise  
 $Y_{j,p,k}$  = 1 if the ship- $k$  departs from berth- $j$  to destination port- $p$ .  
 = 0 otherwise  
 $Z_{p,u,k}$  = 1 if the berth- $u$  is selected at destination port- $p$ , uses ship- $k$ .  
 = 0 otherwise

### 2.2 Model Building

We model a situation faced by a 3PL company which deals with coal transportation. The company have orders to transport a specified amount of coal ( $D_p$ ) from departure ports ( $i$ ) to destination ports ( $p$ ). The distance between the departure and the destination port is denoted by a from- $i$  to- $p$  matrix ( $G_{i,p}$ ). At the departure port, there are shipsets ( $k$ ) used to transport the coal. Each shipset is a fixed combination of barge and tugboat, which can be identified by their barge capacity ( $Q_k$ ), main engine fuel consumption rate ( $FE_k$ ), auxiliary engine fuel consumption rate ( $FA_k$ ) and speed ( $V_k$ ). Each shipset must

be assigned to a berth at the departure port for loading activities and this is the first decision variable ( $X_{i,j,k}$ ). The assignment must consider the coal transport orders, the characteristic of shipset mentioned earlier and the fact that each berth varies in terms of their loading speed ( $A_j$ ). Considering the coal transport order means we have to simultaneously determine the destination port for the shipset, this is the second decision variable ( $Y_{j,p,k}$ ). Finally, each shipset must also be assigned to a specific berth at the destination port, which is the last decision variable ( $Z_{p,u,k}$ ). The situation at the destination port is similar to the departure port, there are several berths which vary on their unloading speed ( $B_u$ ). Each of the decision variables impact the main and auxiliary fuel consumption and therefore impact the total transportation cost. Figure 1 illustrates this problem.



**Figure 1 – Illustration of the shipping assignment problem**

The following is a brief description of the coal delivery problem:

1. A ship set consists of a tug ship and a barge.
2. The company will bear fuel consumption used to run the main and auxiliary engine. Main engine is used when the shipset is on their way to the destination port, while auxiliary engine is used when the shipset is on queuing position during loading and unloading.
3. The travel time from departure port to destination port is determine by the distance and the speed of the shipset. The speed is dependent on the engine type and characteristic.
4. The objective is to minimize the total fuel consumption incurred for transporting coal from departure port to destination port to fulfil demand for a certain period.
5. The decision variables are the assignment of shipset to berth at the departure port, the selection of shipset to serve a particular port and the assignment of shipset to berth at the destination port.
6. The parameters are the shipset capacity, the berths loading and unloading speed, the duration for loading and unloading, and the speed of tub boat.

The complete mathematical model for this problem is presented as follows.

$$Min Z = \sum_{i=1}^I \sum_{j=1}^J \sum_{k=1}^K \sum_{p=1}^P \sum_{u=1}^U (X_{i,j,k} \cdot CS_{i,j,k}) + (Y_{j,p,k} \cdot CL_{j,p,k}) + (Z_{p,u,k} \cdot CU_{p,u,k}), \quad (1)$$

$$\forall i, \forall j, \forall k, \forall p, \forall u$$

Subject to:

$$\sum_{p=1}^P \sum_{j=1}^J Y_{j,p,k} \leq 1, \quad \forall j, \forall p, \forall k \quad (2)$$

$$\sum_{j=1}^J \sum_{k=1}^K Y_{j,p,k} = 1, \forall j, \forall p, \forall k \quad (3)$$

$$\sum_{i=1}^I \sum_{k=1}^K X_{i,j,k} = 1, \forall i, \forall j, \forall k \quad (4)$$

$$\sum_{i=1}^I X_{i,j,k} - \sum_{p=1}^P Y_{j,p,k} = 0, \forall i, \forall j, \forall p, \forall k \quad (5)$$

$$\sum_{u=1}^U \sum_{k=1}^K Z_{p,u,k} \leq 1, \forall p, \forall u, \forall k \quad (6)$$

$$\sum_{j=1}^J Y_{j,p,k} - \sum_{u=1}^U Z_{p,u,k} = 0, \forall j, \forall p, \forall u, \forall k \quad (7)$$

$$TT_{j,p,k} = G_{j,p} \cdot \frac{1}{V_k}, \forall p, \forall j, \forall k \quad (8)$$

$$TL_{i,j,k} = D_p \cdot \frac{1}{A_j}, \forall p, \forall i, \forall k \quad (9)$$

$$TU_{p,u,k} = D_p \cdot \frac{1}{B_u}, \forall p, \forall u, \forall k \quad (10)$$

$$CS_{j,p,k} = TT_{j,p,k} \cdot (FE_k + FA_k), \forall j, \forall p, \forall k \quad (11)$$

$$CL_{i,j,k} = TL_{i,j,k} \cdot FA_k, \forall i, \forall j, \forall k \quad (12)$$

$$CU_{p,u,k} = TU_{p,u,k} \cdot FA_k, \forall p, \forall u, \forall k \quad (13)$$

$$\sum_{j=1}^J \sum_{p=1}^P Y_{j,p,k} \cdot D_p \leq Q_k, \forall j, \forall p, \forall k \quad (14)$$

$$X_{i,j,k} = \{0,1\}, \forall i, \forall j, \forall k \quad (15)$$

$$Y_{j,p,k} = \{0,1\}, \forall j, \forall p, \forall k \quad (16)$$

$$Z_{p,u,k} = \{0,1\}, \forall p, \forall u, \forall k \quad (17)$$

The objective function (1) is to minimize the total fuel consumption incurred at three transportation activities: sailing from departure to destination port, loading at the departure port and unloading at the destination port. The formula (2)-(17) represents the constraint for the problem. The formula (2) is to ensure that each ship- $k$  can only be used in one route from berth- $j$  to destination port- $p$ . The formula (3) is to ensure that each destination port- $p$  must be visited by a ship- $k$  from departure berth- $j$ . The formula (4) is to ensure that only one berth- $j$  in the departure port- $i$  is used by a ship- $k$ . The formula (5) shows the relationships between decision variables  $X_{i,j,k}$  and  $Y_{j,p,k}$  to ensure route continuity that the ship- $k$ , will sail from berth- $j$  at port- $i$  to the destination port- $p$ . The formula (6) shows the selection of the berth- $u$  at each destination port- $p$  by a ship- $k$ . The constraint (7) explains the relationship between variables  $Y_{j,p,k}$  and  $Z_{p,u,k}$  to ensure route continuity, which is the ship- $k$ , will sail from the berth- $j$  to the berth- $u$  at the destination port- $p$ . The formula (8) shows the duration of the trip to the destination port is equal to the distance from departure port- $j$  to destination port- $p$  by the shipset velocity  $V_k$ . The formula (9) explains that the loading duration at the berth- $j$  at the departure port- $i$ , which is equal to the demand of the port- $p$  divided by the loading capacity  $A_j$  at the berth- $j$ . The formula (10) shows the duration of unloading at the berth- $u$  in the destination port- $p$ , that is equal to the demand of the port- $p$  divided by the loading

capacity  $B_u$  at the berth- $u$ . The result of shipset and berth selection decisions is determined by the total fuel consumption, namely fuel consumption during sailing, during loading and unloading. The main engine fuel consumption and auxiliary engine during the sailing, is defined in the formula (11). The auxiliary engine fuel consumption rate  $FA_k$  on ship- $k$  during loading at the origin port- $i$  of the berth- $j$  and the loading time  $TL_{i,j,k}$  is stated in the formula (12). The unloading fuel consumption, at the destination port- $p$  of the berth- $u$  and the loading time  $TU_{p,u,k}$  for the auxiliary engine fuel consumption rate  $FA_k$  on ship- $k$ , is stated in the formula (13). The formula (14) is a constraint that ensures that the capacity transported to the port of destination does not exceed the transport capacity of the shipset. The formula (15) states binary numbers for the selection of berth- $j$  at the departure port- $i$  by the ship- $k$ . The formula (16) explains the binary numbers for the selection of destination port- $p$  by the ship- $k$  from the berth- $j$ . The formula (17) states the binary numbers for the selection of berth- $u$  at the destination port- $p$  by the ship- $k$ .

### 3. RESULT AND DISCUSSION

#### 3.1 The model testing

To test the model, we experimented with several sets of hypothetical data. In this paper, we presented only one small data set. The small data sets are tested for model validation purposes and the other is to see the behavior of solution quality and computational time given an increase in the problem size. For this data set, we consider a situation where the transportation will be conducted from one departure port to four destination ports. The coal transport order to each destination port is given on Table 1. The distance between the departure port- $i$  to destination port- $p$  in kilometers, is shown in Table 2. The unloading speed of berths both at the departure and destination port is given in Table 3 and Table 4. Table 5 summarizes the characteristics of available shipsets.

**Table 1 - Coal transport order to destination ports- $p$**

$D_p$ (in metric ton)			
$p = 1$	$p = 2$	$p = 3$	$p = 4$
100	100	100	100

**Table 2 - Distance from departure port- $i$  to destination port- $p$**

$G_{i,p}$ (in kilometer)			
$p = 1$	$p = 2$	$p = 3$	$p = 4$
700	950	1200	1500

**Table 3 - The characteristic of berths at the departure port ( $A_i$ )**

$i$	The loading speed of berth- $i$ $A_i$ (in metric-ton/hour)
1	500
2	500
3	450
4	350
5	350
6	300

**Table 4 - The characteristics of berths at the destination port- $p$  ( $B_u$ )**

The unloading speed at berth- $u$ ( $B_u$ ) at destination port- $p$ (in metric-ton/hour)							
$u$	$p = 1$	$u$	$p = 2$	$u$	$p = 3$	$u$	$p = 4$
1	500	7	500	13	500	19	500
2	500	8	500	14	500	20	500
3	450	9	450	15	450	21	450
4	350	10	350	16	350	22	350
5	350	11	350	17	350	23	350
6	300	12	300	18	300	24	300

**Table 5 - The average fuel consumption rate, average speed, and capacity of shipsets**

Shipset ( $k$ )	Fuel consumption rate of the tugboats		$V_k$ (km/hour)	$Q_k$ (in metric ton)
	$FE_k$ (liter/hour)	$FA_k$ (liter/hour)		
1	100	8,2	20	100
2	105	8,5	25	200
3	108	8,7	30	300
4	112	8,7	35	400
5	115	8,7	40	500

We run the mathematical model through commercial optimization software. The software then returns a global optimal result. We present the optimal fleet and berth selection result on Table 6.

**Table 6 - The optimization results**

Departure port	Departure berth	Destination port	Destination berth	Shipset
1	1	2	7	3
1	2	4	19	5
1	3	3	13	4
1	4	1	1	2

In line with the first data set which are previously mentioned, there are one departure port (see column 1), the solution shows that berth number 1 to 4 would be selected at the departure port (column 2), each shipset at departure berth would travel to different destination port (column 3) and unloaded at a particular destination berth (column 4). The shipset that sails from the departure to destination port is mentioned in the last column. The total fuel consumption of this solution is 13,727.89 liters.

### 3.2 The analysis

The case that we discussed in the previous section can be considered as a small problem size. When given such cases, the optimization software can give a global optimal result within a short computational time. We conducted sensitivity analysis to the model by varying the value of the parameter, such as port-to-port distance, loading and unloading speed at each berth, shipset capacity, and shipset fuel consumption rate per hour. The analysis shows that the total fuel consumption volume is sensitive towards the change in port-to-port distance, shipset sail speed and fuel consumption rate per hour.

The solution also displays a general behavior, such that when the demand requested by each destination port is the similar and the value is beneath the smallest shipset capacity, the model tend to prioritize the fastest shipset unto the farthest destination port. The pattern continues to be seen on selecting which berth to load and unload the shipset, the fastest berth is always prioritized. We then enlarge the problem size by adding the number of destination ports, the number of berths both at the departure and destination ports and the number of shipsets available. As the problem size increases the computational time increase exponentially.

When changes or interruption occurs, it is crucial for a certain decision making to be conducted as fast as possible. Knowing the fact that the model we built is NP Hard and would require lengthy computational time given the large problem size, we developed a more concise solution search algorithm. The algorithm is built after we get enough knowledge regarding the general behavior of the model as explained earlier. The pseudocode for the algorithm is presented on Table 7.

**Table 7 - The proposed heuristic algorithm**

<b>Heuristic Algorithm: Fleet and Berth Selection for Coal Transportation</b>	
Input	: Distance matrices ( $G_{j,p}$ ), demand of destination ports ( $D_p$ ), loading speed at departure berths ( $A_i$ ), unloading speed at the destination berths ( $B_u$ ), shipsets characteristics ( $FE_k$ , $FA_k$ , $Q_k$ , and $V_k$ )
Initialization	: Arrange the distance matrices ( $G_{j,p}$ ), shipsets (in terms of $V_k$ ), departure berths (in terms of $A_i$ ), and destination berth (in terms of $B_u$ ), in non-



- decreasing order. Define them consecutively as list<sub>1</sub>, list<sub>2</sub>, list<sub>3</sub> and list<sub>4<sub>u</sub></sub> ( $u$  = number of destination port)
- Step 1 : Begin with the first port on list<sub>1</sub>, choose the farthest destination port on the list. Check for its demand value.
- Step 2 : Take the first shipset on list<sub>2</sub>, which is the fastest ship on the list. Check whether the capacity of this shipset is larger than the demand of destination port identified in Step 1. If yes, select this shipset to serve the destination port and go to Step 3. Otherwise, move on to the next shipset on list<sub>2</sub> and repeat the comparison until we find shipset with sufficient capacity.
- Step 3 : Assign the selected shipset into the fastest departure berth in list<sub>3</sub> and fastest destination berth in list<sub>4<sub>u</sub></sub> with  $u$  is associated with the destination port selected on the previous Step. Erase the served destination port on list<sub>1</sub>, the selected shipset on list<sub>2</sub>, assigned departure berth from list<sub>3</sub> and destination berth from list<sub>4<sub>u</sub></sub>. Check whether all destination port has been served, if not go back to Step 1, otherwise STOP.
- Output : Selection of shipset to destination port, selection of departure berth for loading shipset, selection of destination berth for unloading shipset and total fuel consumption due to the decisions.

We use the same data sets to evaluate the performance of the proposed algorithm. The results are shown in Table 8, Table 9, and Table 10. The total fuel consumption is 13,727.91 liters. Therefore, the difference with the result in analytical model is 0.02 liters, which is not significant.

**Table 8 - The loading fuel consumption in departure port**

Departure port	Departure berth	Ship set	Loading fuel consumption (liters)
1	1	2	1.49
1	2	3	1.52
1	3	4	1.69
1	4	5	2.18
Total			6.89

**Table 9 - The sailing fuel consumption**

Departure port	Departure berth	Ship set	Sailing fuel consumption (liters)
1	1	2	2,784.96
1	2	3	3,238.46
1	3	4	3,626.48
1	4	5	4,065.05
Total			13,714.96

**Table 10 - The unloading fuel consumption in destination port**

Destination port	Destination berth	Ship set	Unloading fuel consumption (liters)
1	1	2	1.49
2	1	3	1.52
3	1	4	1.52
4	1	5	1.52
Total			6.06

## 4. CONCLUSION

The analytical models can represent the problem of determining ships and berths in the coal transportation system to minimize the total fuel consumption. This is meant as the solution to improve energy and environmental sustainability. The model has been tested using hypothetical data with small size and the model shows sufficient results. Therefore, based on research on the determination of ships and docks in the coal transportation system, there are several conclusions that can be drawn: The total fuel consumption of determining the ships and the berths in the coal transportation system, calculated by the optimization application is 13,727.89 liters and manual algorithm development is 13,727.91 liters. There are five ships which are selected, both produced by the optimization application and the manual algorithms. The ship sets are the ship set ( $k$ ) = 2, 3, 4 and 5.

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