The Capacitated Multiple-Allocation Hub Location Problem Model for Railway Logistics Transportation

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Abstract

Hub facility location in this study is related with driving the traffic from origin to destination of the railway logistics transportation by finding optimal hub facilities and allocating demand node to hubs. The objective of this research is to determine the locations of hubs to allocate non-hub nodes to hubs with minimizing total cost. Total cost includes transportation costs from origin to destination and fixed costs for new hub investments. An approach to the capacitated multiple allocation hub location problem is presented and an integer linear programming model is developed to find the solution of this problem. Computational analysis is conducted in order to observe the resulting hub networks. The final results of this research are the optimal locations for railway logistics transportation transfer terminals attached in a hub-and-spoke network.

Keywords
Hub and spoke, hub location problem, integer linear programming, railway logistics transportation.

1. Introduction

Hub Location Problem (HLP) is one topic that is widely discussed in facility location problem. Hub facility is defined as a place where all activities related to distribution, logistics, and transportation of goods for national or international transit are operated by a number of operators (Alam, 2013). In general, hub has three different function, namely: (1) consolidation or concentration function of flow received, to have a larger flow and let the economy of scale be exploited, (2) switch or transfer function that allows the flow to be redirected to the node, and (3) distribution or decomposition of large flow becomes smaller (Alumur and Kara, 2008). There are several main criteria that influence the determination of hub location, namely availability of labor, government and industry support, land availability, proximity to the market, and infrastructure facilities (Lipscomb, 2010). In addition, according to Handy and Niemeier (1997) there are additional criteria that can be used in determining the location of hub facilities which are accessibility measures. Accessibility measures consist of two parts, elements of attraction or activity and elements of transportation. The element of attraction or activity considers the spatial distribution of certain activities. While the transportation element considers the ease of travel to locations that are measured in distance, time or cost.

Based on research Farahani et al. (2013) HLP can be used in several applications area including, airlines and airport industries (Yang, 2009; Qu and Weng, 2009; Costa et al., 2010; Lin, 2010), emergency service (Hakimi, 1964; Berman et al., 2007), post delivery service and rapid delivery packing systems (Ebery et al., 2000; Cetiner, 2010), supply chain management-logistics (Wang and Cheng, 2010; Ishfaq and Sox, 2010; Ishfaq and Sox, 2012), telecommunication service and message delivery network (Bollapragada, 2006; Kim and O'Kelly; 2009), transportation systems (Vidovic et al., 2011; Gelareh and Pisinger, 2011; Vasconcelos et al., 2011), and maritime industry (Zheng et al., 2015). The well-known application areas of HLP is transportation. In transportation applications, like postal delivery and rapid transit, large trucking system, express shipment overnight deliver-, air freight, airlines, public transportation systems, the demands that transferred from origin to destination are physical flows in form of goods or passengers. Transportation serves as a basis for economic development, community development and industrial growth. Transportation and logistics have a vital role in the distribution of goods. Transportation of goods is one of the many problems discussed in the logistics literature today, because of the high costs arising from this activity when compared to the total logistics costs faced by companies from various industries. Therefore, the shipping cost is very significant, so it requires efficient and effective transportation (Ghiani et al., 2013).

The process of movement for transportation of goods can be by land, air and water. Aircraft, taxis, trains, trucks, buses, etc. can be considered for the level of facilities with different transportation vehicles (Zabihi and Gharakhani, 2018). Transportation of goods is a core component of the supply chain as the right solution for the availability of raw materials and finished goods (Crainic, 2003). The transportation chain is basically divided into three sections: pre-transport (or the first mile for the retrieval process), long-distance transportation (door-to-door container), and final transport (or the last mile for the shipping process) (SteadieSeifi, 2013). In many cases, pre-transport and long-distance transportation is carried out by road, but for long-distance modes of transportation, the use of water, air, and rail can be considered.

Delivery of goods by train can be one of the alternative solutions that are increasingly in demand from time to time because the prices are cheap, safe, and fast. Train is an efficient and effective rail-based mode of transportation. Railways as a modes of transportation have unique characteristics and advantages, especially in their ability to transport, both people and goods in bulk, save energy, save space use, have a high safety factor, have a low level of pollution, and more efficient than road transportation modes for long-distance transportation and for traffic-intensive areas, such as urban transport (UURI 23/2007). With these advantages, trains in Indonesia can be used as an alternative solution in solving congestion problems in the delivery of goods.

This research will resolve logistical issues related to the selection of optimal hub facility locations for delivery of goods by train that minimize transportation costs. Because the hub position will affect transportation costs from the origin to the destination point. The used method in this study is discussed in chapter 2. Then, in the chapter 3 is presented mathematical modeling formulation, chapter 4 is presented the analysis and result of the study. At last, the conclusion and advanced study will be presented in the chapter 5.

2. Method

2.1 Initial Identification

In Indonesia, a freight forwarding company that serves shipping via rail-road transportation mode is PT Kereta Api Logistics (Kalog). Kalog is one of the companies under PT Kereta Api Indonesia (Persero) with rail-road based logistics distribution services, with door-to-door (DTD) services to provide full service for customers. One of the services available at Kalog is courier and cargo services. There are 46 Kalog locations spread across Java and Sumatra. Where the location of the Kalog office is not all inside the station. There are several Kalog branch offices located outside the station area. This is certainly not effective for companies in carrying out loading and unloading activities at the station. Therefore, this study will accommodate the selection of stations as hubs.

2.2 Model Development

This stage consists of determining the model components, modeling, verification and validation of the model. This research model is categorized as capacitated and multiple allocation problems. It is because hub nodes have limited capacity and demand of non-hub nodes can be satisfied from more than one hub (Zabihi and Gharakhani, 2018). This model is often called a model capacitated multiple allocation hub location problem (CMAHLP) model. Marin (2005) uses CMAHLP to determine optimal hub, assumed that the flow between a given origin–destination pair can be split into several routes. Boukani et al. (2014) uses CMAHLP model to deal with the problem of parameter uncertainty in the design of the supply chain network. Ghaffari-Nasab et al. (2015) uses CMAHLP model to determine capacities, location, and the number of hub facilities and the allocation of demand to facilities so that the transfer of all commodities in the network is ensured, while the total cost of the entire system is minimized.

With this CMAHLP model, later in this study will be used an optimization model of the location of goods delivery facilities by train. The model used in this study aims to determine the optimal hub location for sending goods from the point of origin i to the destination point j. Where the criteria used are minimizing transportation costs. Delivery of goods from i to j cannot be done directly, but must go through hubs k and l. The description of the flow of goods from the point of origin *i* to the destination *j* in HLP is shown in Figure 1. This problem was arranged in the Integer Linear Programming (ILP) model. The ILP method can be used in a variety of cases to solve optimization problem.

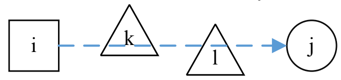

Figure 1. Examples of flow in HLP

2.3 Coding and Analysis

At this stage the model encoding uses IBM ILOG CPLEX Optimization Studio V12.6.1 software. This software is commonly used to solve linear and integer programming optimization problems. The model that was created was changed to the codes in ILOG CPLEX. In addition, at this stage an analysis of the results of the model was also carried out. The output of the model is the location of the selected hub. The decision making process in this study is shown in Figure 2.

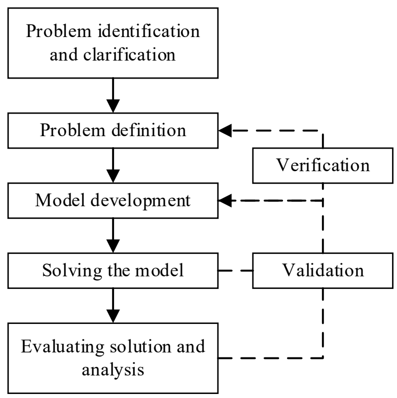

Figure 2. Decision making process of this research

3. Model Formulation

In this research we used basic model capacitated multiple allocation hub location problem (CMAHLP) published by Ebery et al. (2000) and some modifications are made according to the real conditions in accordance with this study. Table 1 shows the parameters used in this study. Table 2 shows the decision variables. This decision variable is used to determine the optimal solution of this model. The model formulation divided into two parts: the objective function and the constraint function. Model formulation conducted focusing on the optimal hub selection of freight forwarder via train transportation.

Table 1. Parameters of CMAHLP Model

Notation	Explanation
χ	Collection coefficients
α	Transfer coefficients
δ	Distribution coefficients
W_{ij}	Amount of flow from origin *i* to destination *j*
C_{ij}	Unit cost from *i* to *j*
D_{ij}	Distance from origin *i* to destination *j*
F_k	Setup cost of establishing a hub at *k*
Γ_k	Capacity of a hub located at *k*

Table 2. Decision Variables of CMAHLP Model

Notation	Explanation
H_k	1 if a hub is located at *k* 0 otherwise
X_{lj}^i	Flow from origin *i* to destination *j* via hub *l*
Y_{kl}^i	Flow from origin *i* via hubs *k* and *l*
Z_{ik}	Flow from origin *i* to hub *k*

Objective Function:

$$min\ Z = \sum_{k\in N} F_k H_k + \sum_{i\in N}\left(\chi \sum_{k\in N} C_{ik}\, D_{ik} Z_{ik} + \alpha \sum_{k\in N}\sum_{l\in N} C_{kl} D_{kl} Y_{kl}^{i} + \delta \sum_{l\in N}\sum_{j\in N} C_{lj} D_{lj} X_{lj}^{i}\right) \quad (1)$$

Subject to:

$$\sum_{k\in N} Z_{ik} = \sum_{j\in N} W_{ij} \qquad \forall i \in N \qquad (2)$$
$$\sum_{l\in N} X_{lj}^{i} = W_{ij} \qquad \forall i,j \in N \qquad (3)$$
$$\sum_{l\in N} Y_{kl}^{i} = Z_{ik} \qquad \forall i,k \in N \qquad (4)$$
$$\sum_{i\in N} Z_{ik} \le \Gamma_k H_k \qquad \forall k \in N \qquad (5)$$
$$\sum_{l\in N} Y_{kl}^{i} + \sum_{j\in N} X_{kj}^{i} = \sum_{l\in N} Y_{lk}^{i} + Z_{ik} \qquad \forall i,k \in N \qquad (6)$$
$$Z_{ik} \le \sum_{j\in N} W_{ij} H_k \qquad \forall i,k \in N \qquad (7)$$
$$\sum_{i\in N} X_{lj}^{i} \le \sum_{i\in N} W_{ij} H_l \qquad \forall l,j \in N \qquad (8)$$
$$X_{lj}^{i}, Y_{kl}^{i}, Z_{ik} \ge 0 \qquad \forall i,j,k,l \in N \qquad (9)$$
$$H_k \in \{0,1\} \qquad \forall k \in N \qquad (10)$$

The objective function in this study is (1) to minimize hub opening and transportation costs. The first part shows the equation for the total setup costs of establishing a hub. The second part shows the total transportation costs of all origin to all selected hubs. The third part is the total cost of each origin through two hubs. Then the last part of this model shows the total cost for each destination that comes from the second hub.

Constraints (2) indicates that the flow from origin to the first hub is equal to the amount requested by the destination. Constraints (3) requires flow from origin to destination through all open hubs that meet the demand of the pair. Limitations of open hub capacity are showed by constraints (5). Constraints (6) allow the hub to be the first or second by saving the flow from origin to the hub. Constraints (7) and (8) ensure that the hub is opened at the node if receiving or forwarding goods from another node or hub. Constraints (9) and (10) determine the character of decision variables.

4. Result and Discussion

The research was carried out on the delivery of goods from the point of origin *i* to the destination point *j*. Where to reach the destination point, the goods must go through hub *k* and *l*. The train route used as the object of research is the train that departs from Solo to Pasar Senen. So that the list of stations that are used as candidate hubs *k* (marked with *) and *l* are presented in Table 3. In this study assumed that χ = 1, δ = 1, α = 0.75, C_{ik}= IDR 1,000, C_{kl}= IDR 5,000 dan C_{lj}= IDR 1,000. Based on the results of interviews with related companies, it is known that F_k= IDR 500,000,000 dan Γ_k= 20 ton. Then for the list of origin and destination used in the study shown in Table 4.

Table 3. Candidates for Hub Station

Station Name	Station Code	Station Name	Station Code
Solo Jebres	SK*	Kroya	KYA
Solo Balapan	SLO*	Purwokerto	PWT
Purwosari	PWS*	Cirebon	CN
Klaten	KT	Bekasi	BKS
Yogyakarta	YK	Jatinegara	JNG
Kutoarjo	KTA	Pasar Senen	PSE

Table 4. Origin-Destination Pair

Origin (*i*)	Destination (*j*)	W_{ij}(kg)
CS1	KS1	100
CS2	KS2	111
CS3	KS3	165
CS4	KS4	93

In this study, D_{ij} distance is divided into three types of distance. The distances are the distance from the point of origin *i* to the location of the hub *k* (D_{ik}), then the distance between the hub *k* and hub *l* (D_{kl}), and finally the distance from the hub *l* to the destination point *j* (D_{lj}). The three distances are each presented in Table 5- Table 7.

Table 5. Distance from Origin *i* to Hub *k*

D_{ik}	SK	SLO	PWS
CS1	2	0.7	5.2
CS2	2.5	4	8.3
CS3	0.026	2.7	6.9
CS4	28.2	29.9	34

Table 6. Distance from Hub *k* to Hub *l*

D_{kl}	KT	YK	KTA	KYA	PWT	CN	BKS	JNG	PSE
SK	36.5	65	121	201	214	319	527	542	548
SLO	34.3	62.8	119	198	211	317	524	540	546
PWS	31.2	59.7	116	195	209	315	522	537	543

Table 7. Distance from Hub *l* to Destination *j*

D_{lj}	KS1	KS2	KS3	KS4
KT	544	545	545	538
YK	519	519	519	512
KTA	462	462	462	455
KYA	389	390	390	383
PWT	364	364	364	357
CN	229	230	230	223
BKS	22.3	22.5	22.5	15.7
JNG	6.3	6.9	6.9	1.2
PSE	0.95	1.1	1.1	6.6

Determination of the optimal hub location based on the model, taking into account transportation costs and hub opening costs. The transportation cost is calculated from the process of taking goods from origin *i* to hub *k*, transfer of goods from hub *k* to hub *l*, and distribution from hub *l* to destination *j* taking into account distance and number of loads. Based on these calculations the results of decision variables are obtained as shown in Table 8 – Table 12.

In the calculation, it was found that out of the three available hub candidates, PWS stations were chosen as hubs *k*. So that the goods from the origin *i* are collected first in the hub *k*, then sent to the destination *j* by train. Furthermore, in the hub *l*, it is known that all the selected stations are hubs *l*, starting from KT to PSE stations.

Table 8. Results of Hub Located at *k*

Hub Station (*k*)	Value
SK	0
SLO	0
PWS	1

Table 9. Results of Hub Located at *l*

Hub Station (*k*)	Value
KT	1
YK	1
KTA	1
KYA	1
PWT	1
CN	1
BKS	1
JNG	1
PSE	1

In this study flow is defined as the unit of weight of the item to be sent. Based on the results of the model calculation, it is known that the entire item can be shipped. This is because the total load does not exceed the available capacity on the selected hub. Thus, each load from origin *i* can be sent to destination *j* via PWS station as hub *k*, station KT-YK-KTA-KYA-PWT-CN-BKS-JNG-PSE as hub *l*. The load that can be sent through each hub is shown in Table X-XII.

Table 10. Flow from Origin *i* to Hub *k*

Origin (*i*)	**Hub Station (*k*)**	**Value**
CS1	PWS	100
CS2	PWS	111
CS3	PWS	165
CS4	PWS	93

Table 11. Flow from Origin *i* via Hub k and *l*

Origin (*i*)	**Hub Station (*k*)**	**Hub Station (*l*)**	**Value**
CS1	PWS	KT	100
CS2	PWS	KT	111
CS3	PWS	KT	165
CS4	PWS	KT	93

Table 12. Flow from Origin *i* to Destination *j* via Hub *l*

Origin (*i*)	**Hub Station (*l*)**	**Destination (*j*)**	**Value**
CS1	PSE	KS1	100
CS2	PSE	KS2	111
CS3	PSE	KS3	165
CS4	PSE	KS4	93

Based on the results of calculations with this model, it was found that the total cost that must be paid to open hub facilities and transportation of goods is IDR 561,125,000. This is cheaper compared to the current situation which requires a total cost of IDR 586,072,500. In the current situation, the shipping office is outside the station. So that the goods to be sent are collected first in the office, then sent to the station to be forwarded to the destination. In this process there are 2 items collection activities, from the customer to the office, then from the office to the station. This is what makes total costs expensive. The current situation for related freight forwarding companies is shown in Figure 3. The graph of the comparison of the total costs is shown in Figure 4.

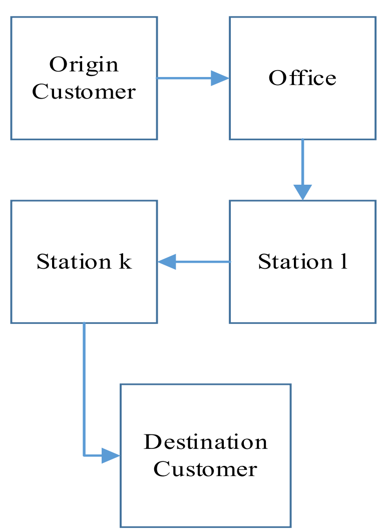

Figure 3. The current situation for related freight forwarding companies

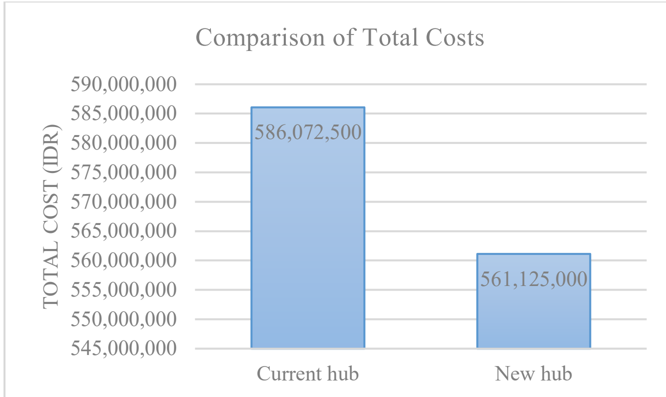

Figure 4. Comparison of total cost in current and new situation

5. Conclusion

In this study, to solve HLP related problems in the delivery of goods by train is done with a capacitated multiple allocation hub location problem (CMAHLP) model using the Integer Linear Programming (ILP) method. The function of the objectives that have been achieved is the minimization of the total costs consisting of the cost of establishing a new hub and the cost of transporting the goods. The results obtained are PWS stations selected as hub facilities. The selection of the PWS station to become a hub, the total required cost of IDR 561,125,000, which previously amounted to IDR 586,072,500.

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