Integer programming of cement distribution by train

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Abstract. Cement industry in Central Java distributes cement by train to meet daily demand in Yogyakarta and Central Java area. There are five destination stations. For each destination station, there is a warehouse to load cements. Decision maker of cement industry have a plan to redesign the infrastructure and transportation system. The aim is to determine how many locomotives, train wagons, and containers and how to arrange train schedules with subject to the delivery time. For this purposes, we consider an integer programming to minimize the total of operational cost. Further, we will discuss a case study and the solution the problem can be calculated by LINGO software.

1. Introduction

Railroad transportation has a good role in transportation. Many researchers work in this area. Newman and Yano [2] consider rail transportation of intermodal container. Intermodal transportation consists of combining modes, usually ship, truck, or rail to transport freight. They formulate the problem as an integer programming and develop a novel decomposition procedure to find near optimal solution. Ahuja et.al. [1] study the locomotive scheduling problem with multiple types of locomotives. The locomotives have different pulling and cost characteristic. Locomotives pull a set of trains from their origin to their destinations. The mixed integer is formulated to minimize fixed cost and operational cost.

In Central Java, cement distribution from factory to big city is handled by train. For long distance, train transportation is more efficient than truck transportation. Cement Industry will redesign transportation system with container system. Transport surveys have been conducted on alternative locations loading and unloading to provide an overview of location development unloading and redesigning the loading process. For business feasibility of transportation development then calculation of transport operation pattern is considered that oriented to utilities the means. Design of operation pattern and investment is ideal transport. These design structure are the estimation of volume transportation, design of operation pattern, the number of transportation facility, design of facilities and supporting facilities and finance. The manufactured cement should distribute within a day. Many things need to be reviewed to support the distribution system. Surveys conducted against feasibility of facilities and infrastructure, including station, unloading location, unloading time, warehouse, carriage capacity and long hopper.

2. Model

Based on assessment by Pustral [3], we construct the integer programming model with refer to [4] to help Cement Industry. To meet daily demand in Central Java areas, Cement Industry
plans the container system to distribute cement. Here, we want to determine the number of locomotive, train wagon, container to support distribution system that minimize fixed cost. And then we want to determine distribution’s pattern to minimize the operational cost that is equivalent to minimize the total of delivery times. Integer programming is based on the transshipment principle. Output of this model can be used to determine the number of locomotive, train wagon, container and train routes. A distribution networks in Central Java is given in the Figure 1. Node 0 represents a source station and nodes 1,2,3,4,5 represent five destination cities.

In our model, we have some assumptions in the system as follows:

(a) There are two tracks in the rail way i.e. departure and arrival, respectively.
(b) The loading time is not depend on the time distribution. It means that the number of container is enough to support distribution system. Whereas, the time distribution depends on time of departure preparation in source station. They are the same for each train.
(c) The maximum of train’s velocity is suitable with the rail way condition. This is influenced by the travel time between two stations.
(d) Locomotive pulls train wagons that contain containers to distribute cement to the destination station. The container is unloaded in the destination station. Then the train continue to delivery to the other destinations. In the way back to the source station, train takes empty container that was unloaded in the destination stations. Except, since train delivers to the station 3, then train should take container after containers are unloaded. After that train continues to deliver to other destination or going back to source station. This policy is applied to efficiency delivery times. So, there is no train that go to station 3 only to take empty containers. Assume that unloading time for containers from train wagon are the same, such that loading time for empty container to train wagon are assumed the same.
(e) Pattern of distribution system is per day. So, in one cycle (one day), each train operate less than 24 hours. Although, to keep a trouble in the trip, we give slack time.
(f) Consider the delivery times from source station to station 1 (the longest distance). We assume that there is no train takes a trip twice in one day.
(g) Containers capacity are equal.
(h) Train capacity is equal.
(i) Power of pull locomotive is equal.

**Figure 1. Stations Network**
According to our assumptions, we let the parameters in the following:

(a) Power of pull locomotive : $G$ train wagons.
(b) Train wagon capacity : $K$ containers.
(c) Container capacity : $C$ tons.
(d) Demand for station $j$ : $D_j$ container. Measure of demand is container, if demand $D$ in ton, we let $D_j = \lceil \frac{D}{C} \rceil$ container.
(e) Locomotive availability: $L$. Let $L = \sum_{j=1}^{5} D_j$.
(f) Travel time from station $i$ to station $j$ : $t_{ij}(t_{ij} = t_{ji})$. We have $t_{ij} = \frac{S_{ij}}{V_{ij}^{max}}$, where $S_{ij}$ is distance from station $i$ to station $j$ and $V_{ij}^{max}$ is maximum velocity for each train.
(g) Unloading time of container from train wagon per container : $TB$.
(h) Loading time of blank container to train wagon per container : $TM$.
(i) Slack time of each train : $TS$.
(j) Preparation time in source station : $TP$.

Furthermore, we let the decision variables in the following :

(a) Decision variable $0-1$,
$$L_{lij} = \begin{cases} 1, & \text{if train } l \text{ travels from station } i \text{ to station } j \\ 0, & \text{if train } l \text{ does not travel from station } i \text{ to station } j \end{cases}$$
(b) Non negative integer variable $d_{lj}$. It means that the number container that unloaded in station $j$ by train $l$.

To summarize, our problem is to determine the pattern of daily delivery for each train subject to delivery times to minimize the total of operational cost. Because the number of containers is fixed corresponding to demand and each train unload container at delivery and load again empty container to back to source station then $TB$ and $TM$ are not influence in objective function. But this condition influence in the delivery times constrain. Here, we have total time of delivery and going back is the same. So, in the objective function we want to minimize total delivery time of trains. The objective function is formulated in equation 1,
$$\min T = t_{01} \sum_{l=1}^{L} L_{l01} + t_{12} \sum_{l=1}^{L} L_{l12} + t_{23} \sum_{l=1}^{L} L_{l23} + t_{24} \sum_{l=1}^{L} L_{l24} + t_{45} \sum_{l=1}^{L} L_{l45}$$

The constrains of the model are formulated in the following:

(i) Locomotive capacity constrain (L constrains),
$$\sum_{j=1}^{L} d_{lj} \leq G.K, \quad l = 1, \ldots, L.$$  

(ii) Demand constrain for station $j$ (5 constrains),
$$\sum_{l=1}^{K} d_{lj} \geq D_j, \quad j = 1, \ldots, 5.$$  

(iii) If train $l$ delivers cement to station $j$, it should travel the railway $ij$, where station $i$ exactly after station $j$. There are $L \times 5$ constrains,
$$d_{lj} \leq D_j L_{lij}, \quad \forall l, j.$$  

(iv) Trip constrain (4 x L constrains)

Given arrange of station $i, j, k$. If train travels from station $j$ to station $k$, It is clear that train travels from station $i$ to station $j$. Due to Figure 1, we formulate these constrains,
$$L_{l12} \leq L_{l01}, \quad \forall l$$
$$L_{l23} \leq L_{l12}, \quad \forall l$$
$$L_{l24} \leq L_{l12}, \quad \forall l$$
$$L_{l45} \leq L_{l24}, \quad \forall l.$$  

(v) Travel time constrain for each train ($L$ constrains)
Total of preparation time, slack time, travel time, unloading time, loading time of empty container is less than 24 hours. This constrain can be formulated,

$$TP + TS + 2t_{01}L_{l01} + 2t_{12}L_{l12} + 2t_{23}L_{l23} + 2t_{24}L_{l24} + 2t_{45}L_{l45} + (TB + TM)\sum_{j=1}^{5}d_{lj} \leq 24, \forall l.$$

3. Case Study
In this section we give a case study that employe daily demand of cement industry in Central Java. Given parameters in the model. Travel times between two stations is given in Figure 2. Total of demand in ton is given in Table 1.

![Figure 2. Station Network with Travel Time](image)

| Station | Demand (in ton) |
|---------|----------------|
| Station1 | 600 |
| Station2 | 800 |
| Station3 | 400 |
| Station4 | 300 |
| Station5 | 400 |

Another parameters are $TP = 30$ minutes (0.5 hours), $TS = 60$ minutes (1 hour) and $TB = TM = 3$ minutes (0.05 hours). Based on emplacement data in station, locomotive is permitted to pull 16 train wagons. Container capacity is 20 ton. Train wagon capacity is 2 containers or 40 tons. It means that locomotive capacity is 32 containers. So cement industry should equip $\lceil \frac{1200}{40} \rceil = 4$ locomotives. The integer programming model has 40 variables and 49 constrains. We solve the model by LINGO software. The optimal solution has interpretation in the following:

(i) Locomotive 1 pulls 16 train wagons with 32 containers. The number of containers that deliver to station 3 and station 4 are 20 and 12 containers, respectively. The route for this train is 0-1-2-3-2-4-2-1-0 with travel times 20.2 hours.
(ii) Locomotive 2 pulls 16 train wagons with 32 containers. The number of containers that
deliver to station 2, station 4 and station 5 are 9, 3 and 20 containers, respectively. The
route for this train is 0-1-2-4-5-4-2-1-0 with travel times 22.2 hours.

(iii) Locomotive 3 pulls 16 train wagons. This train deliver to station 1 and station 2 a number
of 1 and 31 containers, respectively. The route for this train is 0-1-2-1-0 with time travel
15.2 hours.

(iv) Locomotive 4 pulls 15 train wagons with 29 containers for station 1. Travel times of this
train is 21.2 hours.

4. Conclusion
In this research, we construct a model based on station network in Central Java. Furthermore,
the model can be developed for another area.

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