Freight Train Scheduling using Integer Linear Programming: A case study of cement distribution

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ABSTRACT

Transportation process is responsible for providing efficiency of moving products considering time, cost, and vehicle utilities through inbound and outbound logistics. Transportation disruptions such as congestion, delays, or cancellations can have a detrimental impact on the company. PT X uses trains to transport unpackaged cement in bulk from factory to port. PT X has not met the daily train delivery target due to train delays, inconsistency delivery frequency and ineffective schedule. Therefore, the quantity of shipment does not meet the expected target. In this study, optimization of train rescheduling was carried out to minimize total train delays. This optimization is expected to be able to create a new train schedule that meets the daily delivery target. The proposed model is formulated as and solved as Integer Linear Programming (ILP) problem by considering single-track railway constraints. Results show the optimal train schedules give a total delay of 26 minutes. Compared to the existing condition, train delays are reduced by 69.7% and provide a more effective schedule with consistent delivery frequency.

1. INTRODUCTION

PT X is a national company operating a chain of cement production, sales, and distribution that supplying domestic and export demands. In the distribution process, PT X uses two different channels there are land transportation and sea transportation. Some of the finished products will be shipped directly to customers or distributors and another will be transferred to storages silos at the port before being shipped by vessel. In factory-to-port transport process, truck and train are used. In actual condition, train delivery faces some disruption which has an impact on the quantity of shipment does not meet the expected daily delivery target that has been set.

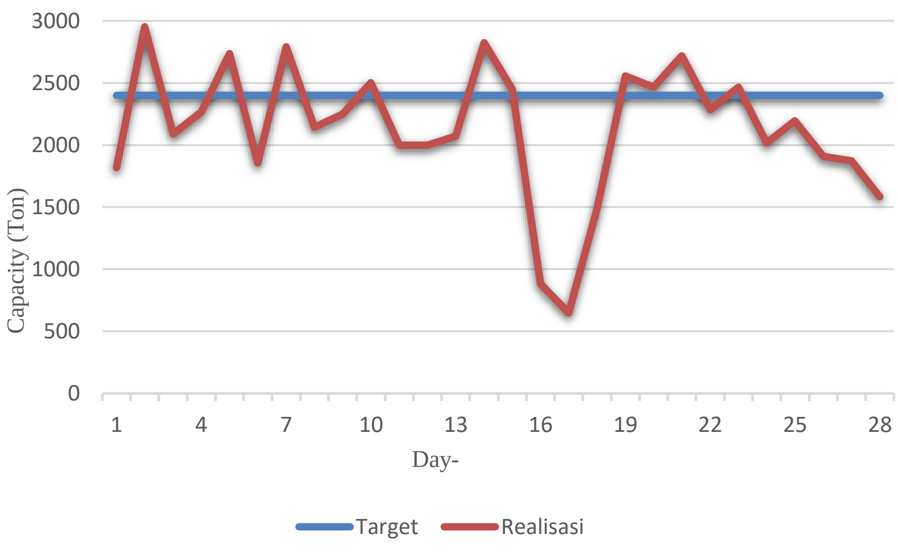

Figure 1. Realization and targets of daily cement delivery

In figure 1, cement delivery by train have not fully reach the daily targets although there are shipments that exceed the targets. Based on monthly target, the actual delivery only met 81,3% of 100% targets. In this condition, the average daily stock at port's silos is 18,23% equivalent to 17.200 tons. This condition can cause stock out if there are export ships that generally demand an average of 20,000 tons. Therefore, the company must ensure the daily delivery meets the target to avoid stock out that will be costing. PT X has not met the daily train delivery target due to train delays, inconsistent delivery frequency, and ineffective schedule.

Freight train scheduling focused on cargo delivery performance considering the time schedule, delays, and demand fulfillment rates [1]. In PT X, freight train delivery also focuses on fulfillment of daily delivery targets by considering delivery schedule, train delays, and train cancellations. In some cases, trains have been delayed due to several reasons such as unavailability of empty lanes and single track conditions so that trains have to stop and wait on certain lines to avoid collisions between trains [2]. This condition is experienced by PT X which is to avoid collision in single-track a train must stop to let another train in opposite direction run first and ensure the line is safe to pass. This causes the train cannot arrive at the destination station in the expected time so that the train cannot meet the expected frequency of trips. To overcome the problem, optimization of train rescheduling was carried out to minimize total train delays using ILP and implemented in LINGO Software.

The ILP approach was chosen because this method can be customized so that the decision variables, objective function, and constraints used will be formulated according to actual condition. This method is in accordance with the characteristics of the problems faced by PT X where in scheduling single-track trains there are many constraints that apply. The linear programming model that will be used in this problem is an ILP where the decision variables used are integers [3]. The Branch and Bound method is also used for the solution because this method is suitable to be applied to linear programming. In addition, to simplify calculations, LINGO software will be used which is able to solve various optimization problems including linear programming. N. A. Dwiyatcita, F. Hanum and T. Bakhtiar [4] conduct research using ILP to solve trains scheduling. B. Pascariu, et al.[5] solve train routing problem by comparing Ant Colony Optimization (ACO) algorithm and ILP to minimize total potential delay due to the route choice in two cases Rouen and Lille. The results show both ACO and ILP are able to find the optimal solution.

In train operations there are rules that must be followed for single-track and double-track railway [6]. At the same time, the use of one line by two trains is not allowed. This applies to single-track trains. Therefore, one of the trains must stop or wait on a certain line so that the line to be traversed is empty and safe to pass [7]. The rules of crossing and overtaking are if there is a train from the opposite direction or from the same direction to the same line, there can be delays. On each line there is a certain speed limit for each train which is determined based on the length of the line and the allowed travel time on that line [8]. According to the recent research by Yohanna Purnawangsih about single-track train scheduling, model formulated as ILP and calculated using LINGO software. The results were obtained in the form of a mathematical model to minimize train delays and also obtained the processed train schedule results with a total delay of 7 minutes [9]. Fadhila, Y. H. (2016) minimize the travel time to avoid the delays in single line train scheduling using greedy job-shop scheduling model [10]. [11] improve train service in terms of delay time and train capacity by determining an optimal train schedule in New South Wales, Australia. Based on the research, it is proven that the alternative service is better than the existing train service. This study is proposed to do optimization that is expected to be able to create a new train schedule that meets the daily delivery target.

2. METHOD

In this study, linear integer programming model was formulated to minimize train total delay and create new train schedule based on the optimization model. The train is considered identical and has the same speed. Meanwhile, weather conditions, rail breakdowns, and train engine damage are not considered. The input data model was collected from historical data, system documentation, and observation. Total delay for the existing condition will be calculated first, then the existing delay will be compared with train delay based on optimization results using linear programming to evaluate whether the new train schedule from formulated model gives better results than existing conditions.

The mathematical models used in this study are modified from several recent research. The mathematical model is modified from research conducted by Purwanangsih [9] which has the same objective function. Constraint (4) concerning the rules for avoiding collisions between two trains in the same line for both same direction and the opposite direction is modified from the research conducted by Dwi Setianto that to avoid collisions there is a safe time difference that is allowed [12].

Inputs and parameters

K	: Set of train
B	: Set of lines
S	: Set of stations
B_L	: Set of outside stations's lines
B_s	: Set of inside stations's lines
$Tmin_{ik}$	: Minimum times required by train k on line i
$Tmax_{ik}$	: Maximum times required by train k on line i
B_{0k}	: The firs line pass by train k
B_{Fk}	: The last line pass by train k
$B-_{ik}$	: The previous line used by tain k before line i
B_k	: Set of lines use by train k

Decision variables

$Trip_k$	: Times required to complete the whole trip
C_{ikl}	: minimum difference times required for train i and k when using line i sequentially
$delay_k$	: Total delays time of train k
a_{ik}	: Time when train k start using line i
d_{ik}	: Time when train k leave line i
y_{ik}	: The delays time of train k on line i

Objective function

$$\text{Min Z} = \sum_{k=0}^{n} delay_k \quad (1)$$

Constraints

$$d_{ik} \geq a_{ik} + T_{ik} \qquad \forall i \in B_k, \forall k \in K \quad (2)$$
$$d_{ik} \leq a_{ik} + y_{ik} + Tmax_{ik} \qquad \forall i \in B_k, \forall k \in K \quad (3)$$
$$a_{ik} - d_{il} \geq C_{ikl} \qquad \forall i \in B_l, \forall k, l \in K, k \neq l \quad (4)$$
$$d_{B}-_{ik}k = a_{ik} \qquad \forall i \in B_k, \forall k \in K \quad (5)$$
$$d_{B_{Fk}}k - a_{B_{0k}}k = delay_k + Trip_k \qquad \forall k \in K \quad (6)$$
$$a_{ik}, d_{ik}, y_{ik}, delay_k \geq 0 \text{ dan } integer \qquad \forall i \in B, \forall k \in K \quad (7)$$

The objective function (1) from this mathematical model is to minimize train total delay time in one day for the whole trip. Total delays are calculated from the new train times schedule based on optimization. Constraints are formulated to states that train k occupies line i for $Tmin_{ik}$ (2). Constraint (3) states that if train k occupies line i more than $Tmin_{ik}$, then the exceed times are considered as a delay. Constraint (4) ensure that there will be no collisions on the same line by two trains that may be coming from the same direction or from opposite directions. To avoid a collision between train k and train l on the same track, a time difference of C_{ikl} is required. Constraint (5) states that the time train leaves one line and the time the train start using the next is the same. Total delay is calculated using constraint (6) that states that the delay is the difference between the total time taken by train to complete the trip from origin station to destination station and the actual time allowed to complete all trips. Finally, constraint (7) ensures that all variables are non-negative and integers.

In this case, 3 stations were considered, and each station has different number of lines, illustrated in Figure 2. X station is the starting point where the plant located near X station. Trains originating from X Station do not stop at Y Station but will go directly to the station which is located close to the unloading area at Z Station. The train will only stop at Y Station if there are two trains moving in opposite directions so one train must stop and let the other train pass to avoid a collision.

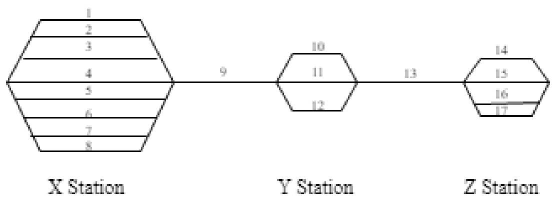

Figure 2. Train's lines and stations

3. RESULTS AND DISCUSSION

In the existing conditions, the train experienced a total delay of 86 minutes for all trips in a day. The delay calculated by considering the actual arrival time with the scheduled time. For optimization, the formulated model is converted into LINGO syntax and run using LINGO optimization solver. The result creates a global optimal solution with an objective function of 26. The results show the optimal train schedule results in a total delay of 26 minutes. The optimal train schedules can be seen in Table 1 and Table 2. Based on the optimization results, it is found that almost all trains will stop at Y station for 3 minutes. This configuration is done to prevent the two trains from colliding while using the same line at the same time.

Table 1. Optimal Train Schedule for Route X-Z Station

No	**Trains**	**X Station**		**Y Station**		**Z Station**
		Arrival	Departure	Arrival	Departure	Arrival
1	KA Semen 1	00.38	00.41	00.58	01.14	01.37
2	KA Semen 2	00.54	01.00	01.17	01.30	01.53
3	KA Semen 3	04.05	04.08	04.25	04.28	04.51
4	KA Semen 4	09.47	09.50	10.07	10.10	10.33
5	KA Semen 1	11.58	12.01	12.18	12.21	12.44
6	KA Semen 2	13.34	13.37	13.54	13.57	14.20
7	KA Semen 3	15.49	15.52	16.09	16.12	16.35
8	KA Semen 4	17.37	17.40	17.57	18.00	18.23
9	KA Semen 1	19.30	19.33	19.50	19.53	20.16
10	KA Semen 2	21.22	21.25	21.42	21.45	22.08
11	KA Semen 3	22.32	22.35	22.52	22.55	23.18
12	KA Semen 4	23.12	23.15	23.32	23.35	23.58

Table 2 Optimal Train Schedule for Route Z-X Station

No	**Trains**	**Z Station**		**Y Station**		**X Station**
		A	D	A	D	A
1	KA Semen 1	05.17	05.20	05.43	05.46	06.03
2	KA Semen 2	07.21	07.24	07.47		08.04
3	KA Semen 3	09.48	09.51	10.14		10.31
4	KA Semen 4	12.08	12.11	12.34		12.51
5	KA Semen 1	14.05	14.08	14.31	14.34	14.51
6	KA Semen 2	15.29	15.32	15.55	15.58	16.15
7	KA Semen 3	16.20	16.23	16.46	16.49	17.06
8	KA Semen 4	17.40	17.43	18.06		18.23
9	KA Semen 1	19.10	19.13	19.36	19.39	19.56
10	KA Semen 2	21.12	21.15	21.38	21.41	21.58

11	KA Semen 3	22.48	22.51	23.14	23.17	23.34
12	KA Semen 4	23.30	23.33	23.56	23.59	00.16

Optimization result still creates a total delay of 26 minutes that occur on KA Semen 1 and KA Semen 2 on the X-Y route. In existing conditions, KA Semen 1 and KA Semen 2 train completed the entire trip in 46 minutes. In the optimization schedule, KA Semen 1 and KA Semen 2 complete the entire trip in 59 minutes. There was 13 minutes delay for each train. Delay happened because the train stop at Y station was 13 minutes longer than the allowed stop time. Furthermore, KA Semen 2 stop 3 minutes longer at X station and 10 minutes longer at Z station than allowed time. Therefore, the optimization results show the new train schedule results in a total delay of 26 minutes.

4. CONCLUSION

The optimization of train scheduling was carried out to minimize total train delay. In existing condition, the train experienced a total delay of 86 minutes for all trips. ILP model is formulated to solve the problem using LINGO and results a global optimal solution. The optimization model gives the train schedules with the total delay of 26 minutes for all trips. This delay occurred on KA Semen 1 and KA Semen 2 on the X-Y route. Furthermore, the total daily trips and expected daily delivery quantities are met although there are still delay on certain trains. Compared to the existing condition, train delay is reduced by 69.7% and provide a more effective schedule with consistent delivery frequency.

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