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Development model of train rescheduling model consider predictive delay

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Abstract. Delay on the train is caused by some disturbance that occurs on the train or at the station, such as a broken train engine, broken train line signals, and others. The train operator at the station will reschedule the train schedule in the event of a delay. Currently, the train only reschedules when the delay occurs on the spot, consequently the rescheduling determination takes a long time. This can be anticipated by taking preventive action, ie rescheduling by using predictive delay. Possible conflicts that will occur when rescheduling single track are overtaking and crossing. This research will focus on the development of rescheduling considering predictive delay. The purpose of this study is to minimize the total delay time. The output of this research is a decision support tool that can generate free-conflict timetable when delay occurs.

1 Introduction

Disturbance can lead to delay. According to [6], in the event of a delay, the train has to wait at the previous station (especially the delay) and may cause other schedules to be delivered (delay knock-on). In the delay handling, the railway must quickly and precisely overcome the interference and make the train reschedule.According to [7], reschedule on trains is complex and there are two challenges to be taken into account. First is how to formulate real traffic can produce acceptable results (feasible) and practical. That is how to generate a good solution within a short time limit. Some possible outcomes on the train re-schedule are adjusting time and time using primary delay and secondary delay (retiming), reordering and adjusting the selected tracks (rerouting).

Many studies of railway schedules that occur occur delays using exact algorithmic methods and heuristic algorithms. Research [3] study using branches and bound to obtain optimal scheduling on a single track track, it can find the optimal amount that can increase the number of rail passenger demand. Later research [6] developed a branch and bound mathematical model to solve the problem of compilation timer trains occurring delay on a single-track railway. Reasearch [4] used a job-shop scheduling with FCFS (First Come First Serve) dispatching rule and paid attention to the function to delay time on multiple

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paths. Research [2], a decision support system (DSS) for real-time management can affect and resolve problems in the event of a delay. Research [1] conducted a re-train study using Mixed Integer Linear Programming (MILP) to minimize total delay time.

Based on previous studies, in this study made a tool for rescheduling train schedules by using predictive delay. The method used is Mix Integer Linear Programming (MILP) with FCFS delivery rules and carriage class priorities. The object of this research is Surabaya - Banyuwangi train line with single track. In this model some predictive delay scenarios will be derived, ie compilation occurs single delay in each train class and double delay between different train classes.

2 Problem Description

A description of the concept of detail in the design of decision making tools (tools decision making) in this research is contained in Figure 1 and the detail description is:

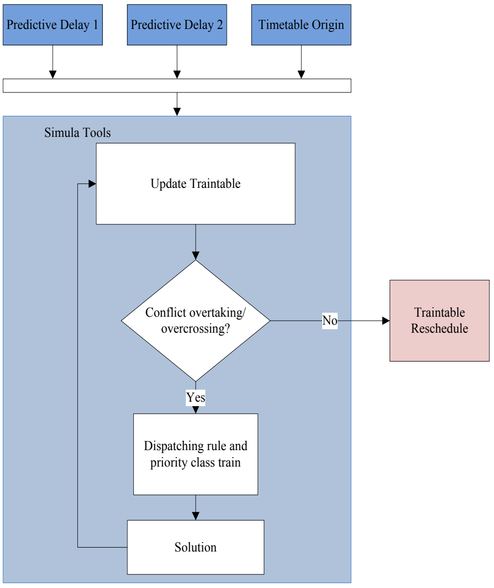

Fig. 1. Concept of DSS

One of the most important things in rescheduling on a single track track is the settlement when there is a conflict between two trains in same direction or opposite directions. Here is an explanation of how to resolve the conflict.

2.1 Overtaking

Overtaking occur when two trains are in one line with different train priorities. Example: train 1 and train 2 (higher priority). Train 1 departs first at 4 am from station A to station B. Then when train 1 stays at station B, train 2 speeds through the A-B line. Since train 2 has a higher priority, then train 1 has to wait at station B until train 2 overtakes train 1. When train 1 and train 2 are larger than headway, then train 1 new can depart. Figure 2 is a Train graph schedule diagram of overtaking.

2.2 Overcrossing

Crosses will occur when train 1 and train 2 opposite direction will use the same track. For example: when train 1 will cross the C-B-A line and train 2 will cross the A-B-C line at one time then one of the trains will have to wait at a certain station until the other train has crossed the line so the track becomes available to pass. Figure 3 is a Train graph schedule diagram of overcrossing

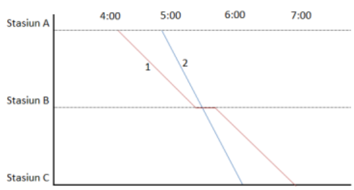

Fig. 2 Train graph schedule diagram

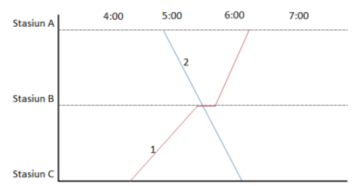

Fig. 3. Train graph schedule diagram

3 Model and Algorithm

This study refers to the single track line reschedule model of [1] Here's a mathematical model :

Sets/Parameter Input

T Set of Trains
B Set of Segment
E Set of Event
K_i Ordered set of event trains i
L_j Ordered set of events of segment *j*
i Train
j Segment
l_j 0 if not in station segment, 1 if in station segment
P_j Parallel track
H_j Headway Time
k Route in 1 train
ḱ Train route after event k
a_k^s Arrival time schedule
d_k^s Departure time schedule

Decision Variabel

a. Decision Variabel Integer

a_k^R Arrival time reschedule
d_k^R Departure time reschedule
z Delay

b. Decision Variabel Biner

$$tr_k^t \begin{cases} 1, if\ event\ k\ use\ track\ t \\ \quad 0, others \end{cases}$$

$$s_{k\acute{k}} \begin{cases} 1, if\ (d_{\acute{k}}^R \quad d_k^R \geq 0) \wedge (a_k^R \quad a_{\acute{k}}^R \geq 0) \\ \quad 0, others \end{cases}$$

In case of disturbance, then event k may need to reschedule and occur after event ḱ. To determine which event takes precedence then there must be a decision variable $\lambda_{k\acute{k}} and\ \gamma_{k\acute{k}}$.

$\lambda_{k\acute{k}} = \begin{cases} 1, if\ event\ k\ occur\ before\ event\ \acute{k} \\ 0, others \end{cases}$

$\gamma_{k\acute{k}} = \begin{cases} 1, if\ event\ k\ occur\ before\ event\ \acute{k} \\ 0, others \end{cases}$

Based on the above explanation, the form of a mathematical model formula is:
Minimize

$$\sum \ z_{n_i} \tag{1}$$

Minimum delay time for all trains on the operation
Subject To:

***Trains Constrain* (2-7)**

The next train had to wait for the train in front of him to finish, before starting the journey

$$a_k^R \ \leq \ d_{k+1}^R, \mathrm{k} \in \mathrm{K}_i, \mathrm{i} \in \mathrm{T} : \mathrm{k} \ \neq \ n_i \tag{2}$$

Train events that are greater than or equal to the previous train plus *running time*

$$a_k^R \ \geq \ d_k^R + \Delta_k, \ k \in \ \mathrm{E} \tag{3}$$

Constraints (4) and (5) for higher priority, the arrival of the train must be the same as the train departure when the train does not stop at the station.

$$a_k^R \ = \ d_{k+1}^R, \mathrm{k} \in \mathrm{K}_i, \mathrm{i} \in \mathrm{T} : \mathrm{k} \ \neq \ n_i \tag{4}$$

The arrival of the train should be the same as the train departure at the next station plus *running time*.

$$a_k^R \ = \ d_k^R + \Delta_k, \ k \in \ \mathrm{E} \tag{5}$$

The re-schedule of train schedules must be greater than or equal to the original train schedule

$$d_k^R \ \geq \ d_k^S, k \in \ \mathrm{E} \tag{6}$$

Constraint (7) is to calculate the delay time, ie the interval between the scheduled carriage reschedule schedule and the initial schedule.

$$a_k^R \ - \ a_k^S \ \leq \ z_k \ \ k \in \ \mathrm{E} \tag{7}$$

***Technical Constrains* (**8 - 13)

Constraint (8) to ensure 1 train for 1 track.

$$\sum_{t=1}^{p_j} tr_k^t = 1, k \in L_j, j \in \mathrm{B} \tag{8}$$

Constraint (9) to ensure the number of trains on track does not exceed the track capacity.

$$\sum_{k=f_s}^{f_i} \sum_{t=1}^{p_j} tr_k^t \ \leq \ P_j, t \in P_j, k \in \ \mathrm{E}, j \in \mathrm{B} \tag{9}$$

Constraint (10) to check the sequence between an event and an ongoing event

$$tr_{\mathrm{k}}^t + \ tr_{\acute{\mathrm{k}}}^t - 1 \ \leq \lambda_{k\acute{k}} + \ \gamma_{k\acute{k}}, \ \ k, \acute{\mathrm{k}} \in \ L_j, t \in P_j, j \in \mathrm{B}: \mathrm{k} < \acute{\mathrm{k}} \tag{10}$$

Constraint (11) to ensure the value of $\lambda_{k\acute{k}}$ or $\gamma_{k\acute{k}}$ is 1 or 0.

$$\lambda_{k\acute{k}} + \ \gamma_{k\acute{k}} \ \ \leq \ \ 1, k, \acute{\mathrm{k}} \in L_j, j \in \mathrm{B}: \mathrm{k} < \acute{\mathrm{k}} \tag{11}$$

Constraints (12) and (13) to ensure that the distance between two moving trains must be more than the headway, either at the station or not at the station. (12) or (13) will be active depending on the value $\lambda_{k\acute{k}}$ and $\gamma_{k\acute{k}}$. The M value on this constraint is the positive and integer large numbers.

$$d_{\acute{\mathrm{k}}}^R - \ \ a_k^R \ \ \geq \ H_j \gamma_{k\acute{k}} \ - M\ (1 - \gamma_{k\acute{k}}) \quad k, \acute{\mathrm{k}} \in \ L_j, j \in \mathrm{B} : \mathrm{k} < \acute{\mathrm{k}}, o_{\acute{\mathrm{k}}} = \ o_k, l_j = 0 \tag{12a}$$

$$d_{\acute{\mathrm{k}}}^R - \ \ a_k^R \ \ \geq \ H_j \gamma_{k\acute{k}} \ - M\ (1 - \gamma_{k\acute{k}}) k, \acute{\mathrm{k}} \in \ L_j, j \in B : k < \acute{\mathrm{k}}, o_{\acute{\mathrm{k}}} = \ o_k, l_j = 1 \tag{12b}$$

$$d_{\acute{\mathrm{k}}}^R - \ \ a_k^R \ \ \geq \ H_j \lambda_{k\acute{k}} \ - M\ (1 - \lambda_{k\acute{k}})\ k, \acute{\mathrm{k}} \in \ L_j, j \in B : k < \acute{\mathrm{k}}, o_{\acute{\mathrm{k}}} = \ o_k, l_j = 0 \tag{13a}$$

$$d_{\acute{\mathrm{k}}}^R - \ \ a_k^R \ \ \geq \ H_j \lambda_{k\acute{k}} \ - M\ (1 - \lambda_{k\acute{k}})\ k, \acute{\mathrm{k}} \in \ L_j, j \in B : k < \acute{\mathrm{k}}, o_{\acute{\mathrm{k}}} = \ o_k, l_j = 1 \tag{13b}$$

***Variable Constrains* (**14-17)

Constraint (14) ensures that the value of the variable is greater than or equal to 0

$$d_{\acute{k}}^{R}, a_{\acute{k}}^{R}, z_{k} \geq 0, k \in \mathrm{E} \quad (14)$$

Constraints (15), (16) and (17) make sure the variable is a binary number.

$$tr_{k}^{t} \in \{0,1\}, k \in L_{j}, t \in P_{j},, j \in \mathrm{B} \quad (15)$$

$$\gamma_{k\acute{k}}, \lambda_{k\acute{k}} \in \{0,1\}, k, \acute{k} \in L_{j}, j \in \mathrm{B} : \mathrm{k} < \acute{\mathrm{k}} \quad (16)$$

$$tr_{k}^{t} \in \{0,1\}, k \in L_{j}, t \in P_{j},, j \in \mathrm{B}$$

Table 1. Class Train based on priority

Class	Train Type
6	Executive
5	Mixed
4	Business
3	Economy
2	Local
1	Cargo

4 Development of Scheduling Scenarios

The development of some scenarios will be done by changing the input of the change of the train id, the train class that is delayed, the location of the station occurs delay, and the delay duration. If the test is complete then it produces several different model outputs in each scenario. Table 2 is a scenario rescheduling plan for railway scheduling by considering predictive delay on the Surabaya-Banyuwangi railway line.

Table 2. Scenario Rescheduling

Scenario	Delay	Class Train
I	Single *Delay*	6
		5
		3
		1
II	Multiple *Delay*	1 & 6

There are two expected model outputs in each scenario: the newest rail timetable resulting from the conflict-free reschedule and measuring the performance of each train after a delay. Both output models will be analyzed at a later stage.The output of the scenario that has been done using the DSS is as follows.

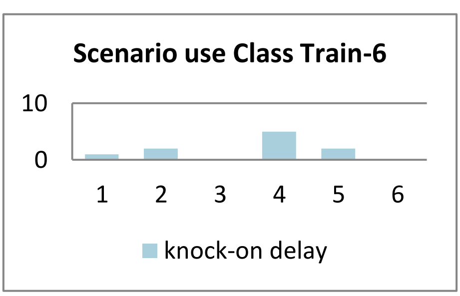

Fig. 4. Scenario use Class Train_6

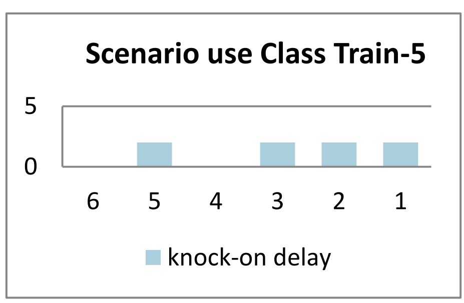

Fig. 5. Scenario use Class Train_5

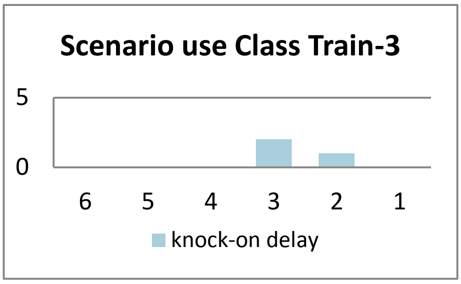

Fig. 6. Scenario use Class Train_3

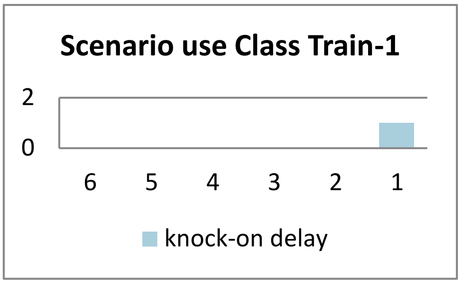

Fig. 7. Scenario use Class Train_1

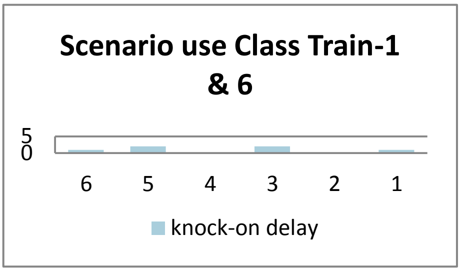

Fig. 8. Scenario use Class Train_1 and 6

In the scenario, use predictive single delay in some train classes. When the highest class is delayed, the lower train class experiences more delay, this is due to the priority of the train. When crossing, the lower-class train has to wait at the next station until the higher priority train passes. So also in the case of the overtaking. .

Different when the delay occurs on the lowest train class, ie cargo trains. According to [4], total primary delay are great when lowest class train is delay. On the way, these cargo trains have to wait for crossings and overtaking, which is why when the lowest class train is delayed, it does not significantly affect other train schedules.

Timetable rescheduling depends on the actual schedule [5]. If the actual schedule is different, then the rescheduling result will also be different. Other things that can cause differences in timetable rescheduling results are minimum headway, train stop location, dweel time and travel time.

5 Conclusion

The created DSS can generate a new timetable reschedule that is free conflict from crossing and overtaking . DSS can be used as an appropriate rescheduling decision tool when a delay occurs. This will benefit both KAI and passengers. KAI can explain what time the train schedule changes when there is a delay to the passenger.

In single delay, higher-class trains than it will not be interrupted his travel schedule, otherwise the schedules lower-class train than it will disturbed. When lowest train-class is delayed, will not have any impact on other train-class. Amount of the train schedules are interrupted depending on the timing of the primary delay, traffic noise of the train, and the number of trains per train class.

In multiple delay, the number of affected trains will increase, so it can be concluded that more amount primary delay occurs, more different classes of train affected, but will not affect the train class higher than the train class that has delay.

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