SIMULATION MODEL OF TRAIN CONNECTIONS FOR DELAYED TRAINS IN PASSENGER STATIONS

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Summary:
One of major profits of train operation simulation models at passenger train station can be analysis of system when time deviations from train timetable occur. Time deviations in reality of passenger train operation are represented in most cases by arrival delays of trains coming to station.
When the simulation model is supposed to solve the situations with delayed incoming trains, there are two main types of decisions to be made: what train connections of the delayed train shall wait for it and what track shall the delayed train in the station use. Solving of the first decision-making problem is the subject of this paper. The presented algorithmic solution in terms of event-driven simulation model follows rules applied in the reality of railway system in Czech Republic and Slovakia.

1 Introduction

There are situations in passenger railway transport that most of us know: a passenger train gets a delay and comes to a station later than is its scheduled arrival. In larger stations usually, there are train connections waiting for passengers from the delayed train. How long should the connections wait? What should be the delay for connections to leave?

Moreover, passenger stations have a plan for serving trains. It contains platform tracks that the trains regularly use. It may also contain railway employees and/or some additional technical equipment needed to serve the train and its passengers. How can this plan be used for the delayed train? Can the train still use the regularly assigned track? Are the employees or equipment available at the time of the delayed train arrival?

Railway companies have a set of rules for solving these situations. These rules are applied by dispatchers in reality. However, if you want to apply them in computer simulation model of passenger railway station, the dispatcher reactions must be modeled by computer algorithm.

This is the primary motivation for our attempt to model solving of these situations. Rather complex decision-making problem could be divided into sub-problems:

a) Decide what train connections will wait for delayed train and when they can leave
b) Decide what platform track will be used when regularly assigned track is occupied
c) Define other changes in the plan, specific for the delayed train (locomotive changes, train set changes, work of railway employees, etc.)

This paper deals with the first sub-problem: train connections related to the delayed train. In the next sections, we'll first describe the problem more in detail, give an example of solving rules applied in reality and outline our solution for simulation model of passenger train station.

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2 Problem description

For description of the problem, we'll use an example from the Prague main station (picture 1).

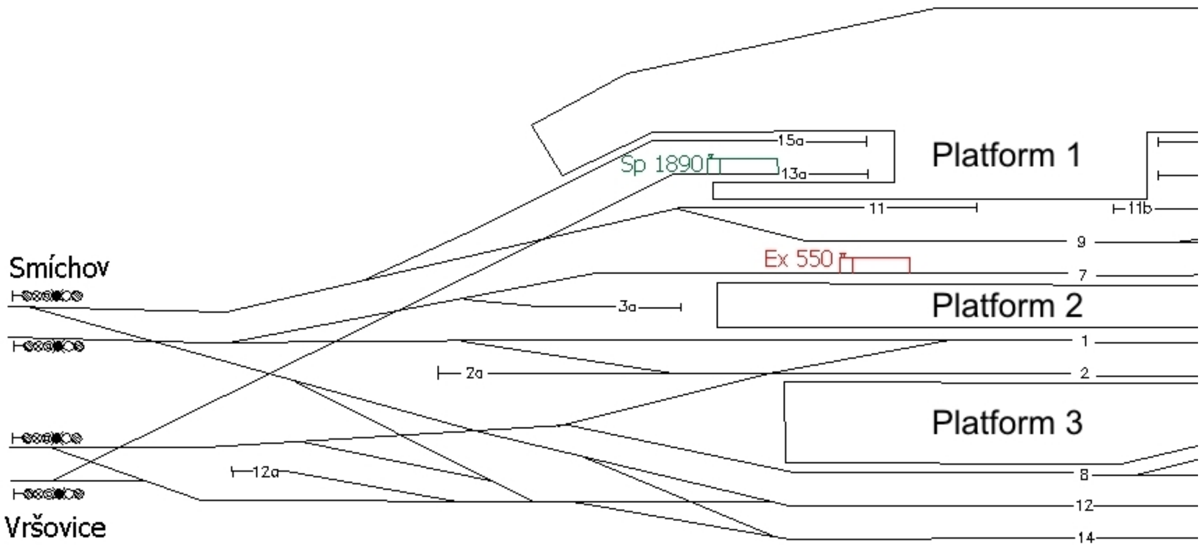

Figure 1

It contains two trains:

- An express train Ex 550 coming from Trutnov and Hradec Králové and continuing to Prague-Smíchov with scheduled arrival at 9:23 A.M.
- Its connection, a slower train Sp 1890 starting at the station and going in direction of Kladno and Rakovník with scheduled departure at 9:35 A.M.

The question is how long the Sp 1890 train will wait in the case, when the Ex 550 is delayed.

Let's denote the following:

- The arriving train (delay of which we solve) – $\mathbf{r_i}$ (Ex 550),
- Its scheduled arrival time to platform – $\mathbf{{}^i t_{Pa}}$ (9:23 A.M.),
- Its real arrival time to platform – $\mathbf{{}^i t_{Ra}}$,
- The departing train (train connection of the delayed train) – $\mathbf{r_j}$ (Sp 1890),
- Its scheduled departure time from platform – $\mathbf{{}^j t_{Pd}}$ (9:35 A.M.),
- Its real departure time from platform – $\mathbf{{}^j t_{Rd}}$.

Difference between real and scheduled times create delay time:

- Delay of arriving train – $\mathbf{{}^i T_{Da}} = {}^i t_{Ra} - {}^i t_{Pa}$
- Delay of departing train – $\mathbf{{}^j T_{Dd}} = {}^j t_{Rd} - {}^j t_{Pd}$

Furthermore let's denote:

- Time period needed for passengers changing from r_i train to r_j train – $\mathbf{T_C}$,
- Maximum time period that the r_j train can wait for the r_i train – waiting time period – $\mathbf{{}^j T_{Wi}}$,

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It is clear that

$^{j}t_{Rd} \geq {}^{i}t_{Ra} + T_C$,

in case the r_j train waits for the r_i train.

Picture 2 illustrates relations among symbols in the case without time deviations from timetable. Time period between arrival of the first train (r_i) and departure of the second train (r_j) must be long enough to include the time period needed for passengers changing the trains.

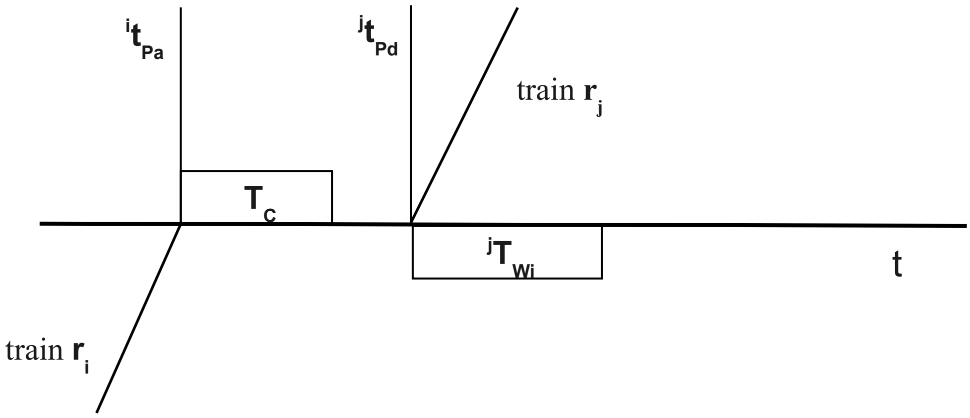

Figure 2

Picture 3 illustrates relations among symbols in the case when time deviations from timetable occur. Scheduled times are differentiated from real times by dash lines.

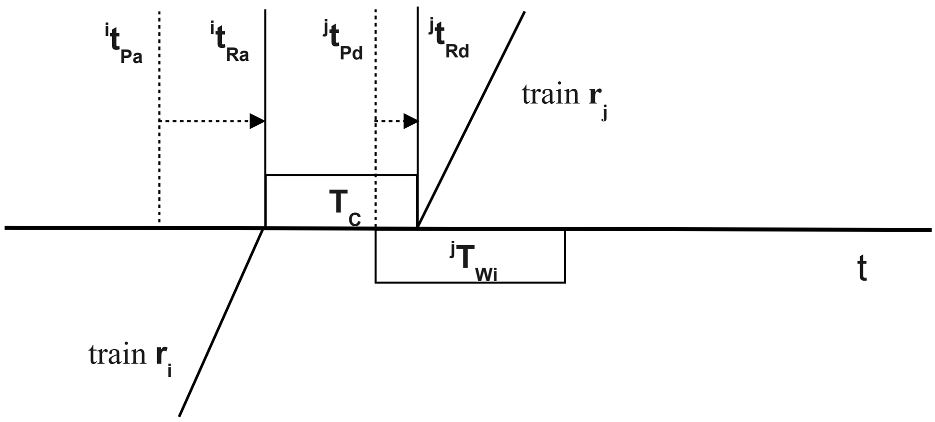

Figure 3

If delayed train r_i arrives before end of waiting time period $^{j}T_{Wi}$, real departure of train r_j will be scheduled on time $^{j}t_{Rd} = {}^{i}t_{Ra} + T_C$. But in case the arriving delayed train arrives later than that, connection train r_j will leave at the time of its scheduled departure.

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There are some situations when connection train must wait for delayed train, outside of the outlined rule. These situations are described in the next chapter.

3 Railway rules

Railway companies set rules for dispatchers to obey in solving such a situation. They differ from company to company. As the basic example for our research, we took the rules from railways in the Czech and Slovak Republics.

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The rules describe these details:

- Time period for passenger changing,
- Waiting time period of train connections for delayed trains,
- Acceptance of delay time by train connection to wait.

1 Passenger changing time period

This time period depends strongly on station layout and size.

In smaller stations, like e.g. a station with 3-4 tracks for passenger trains without platforms and underground passage, there is one value.

In larger stations with platforms connected with each other by underground passage or bridge, there is usually more than one value. The T_C value is than equal to the relevant value for the corresponding trains or tracks.

In our example from the Prague main station, there is:

- 4 minutes for passing between trains standing on tracks at the same platform,
- 8 minutes for any other combination of tracks, i.e. passengers need to move between platforms.

2 Waiting time period

Waiting time period ${}^{j}T_{Wi}$ determines how long should departure train r_j wait for delayed arriving train r_i. It does not include the previously mentioned passenger changing time period T_C, i.e. the departing train may be in fact delayed on its departure more than its waiting time period is:

$${}^{j}t_{Rd} \geq {}^{j}t_{Pd} + {}^{j}T_{Wi}.$$

For every departing train, there is either a “basic” or “different” waiting time period set.

Basic waiting period is assigned to relation between categories of arriving and departing trains. Values for this kind of waiting period are defined in railway rules. For example trains in the category of express (SuperCity, EuroCity, Intercity and Expres trains in Czech Republic) wait for another delayed train of the same category 5 minutes and for train of all other categories (like fast train, slow train) 0 minutes. For other combinations of train categories, the waiting time periods are set accordingly.

Certain combination of concrete trains may have a different waiting time period set. This overrides the basic waiting period, derived from categories of the trains.

3 Acceptance of delay

As an example of railway rules for dealing with situations when the delay occurs, we include also a set of rules from Czech railways. They describe specific situations, when the connection train r_j must wait for the delayed train r_i:

a) Train r_i arrived before time of scheduled departure of train r_j, i.e. ${}^{i}t_{Ra} \leq {}^{j}t_{Pd}$,

b) Train r_i arrived before the end of waiting time period of train r_j, i.e. ${}^{i}t_{Ra} \leq {}^{j}t_{Pd} + {}^{j}T_{Wi}$.

c) Current position of train r_i is between home or last route signal and platform at the moment, when the waiting time period of train r_j is over, i.e. at the time ${}^{j}t_{Pd} + {}^{j}T_{Wi}$. If at that moment the arriving train r_i stands by home or last route signal, the waiting time period of train r_j ${}^{j}T_{Wi}$ is further prolonged by additional 5 minutes.

d) Station rules for dispatching claim that train r_i must wait for delayed train r_i in any case, i.e. we can say that ${}^{j}T_{Wi}$ is infinite.

If any of these 4 situations occur, the departure train will get no signal from dispatcher to leave until the delayed arriving train arrives and passenger change trains.

4 Model

In this section, we describe how the outlined rules can be transformed into an event-oriented model that will be a part of the simulation model of the whole railway station system.

The model is build out of 4 events and their processing. It is further explained with help of the picture 4.

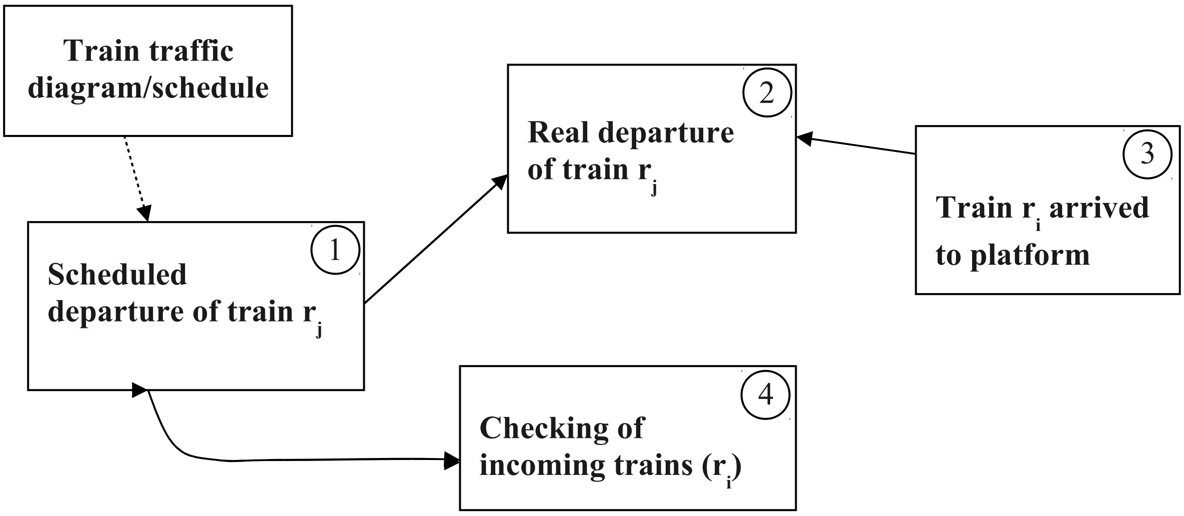

Figure 4

The basic impulse to start this algorithm comes from train traffic diagram (train schedule). The schedule contains, among other details, information about scheduled arrivals and scheduled departures of trains. The impulse is realized by planning a departure of the train r_j to the time axis - ${}^{j}t_{Pd}$.

4 Event 1

When the event 1 is evoked at the time ${}^{j}t_{Pd}$, i.e. the train r_j is about to depart according to schedule, the algorithm (as part of the decision-support subsystem) checks all connections of the train r_j. In case that all of them arrived before its scheduled departure ${}^{j}t_{Pd}$, i.e. all the connections arrived in time or with a delay not exceeding the ${}^{j}t_{Pd}$, we can schedule the event of real departure of train r_j to time axis. The real departure time ${}^{j}t_{Rd}$ may be equal to or later than ${}^{j}t_{Pd}$. The latter would happen, if some of the arriving trains were delayed so much that the passengers changing time period for them T_C, is not yet finished. For every train connection from the arrived trains, the ${}^{j}t_{Rd} \geq {}^{i}t_{Ra} + T_C$ reference must be fulfilled. Scheduling of the departure event is illustrated by arrow between events No. 1 and No. 2.

In case that not all connection trains of train r_j arrived yet, the procedure processing the event No. 1 must decide (based on the indicated railway rules), whether the train r_j should wait for delayed train(s) or not. When the decision is to wait, i.e. at least one train can come within the waiting time period ${}^{j}T_{Wi}$, the event No. 4 is scheduled – checking of incoming trains – at the time ${}^{j}t_{Pd} + {}^{j}t_{Wi}$. This is illustrated by arrow between events 1 and 4. In case all delayed trains are so much delayed that the rules don't allow the train r_j to wait, the train r_j can leave from platform – the same will happen as described above – scheduling the event No. 2.

5 Event 2

This event is a simple signal to the control subsystem that the scheduled train can leave at the current time point.

6 Event 3

The event 3 represents a situation when a delayed train r_i arrives to platform. Algorithm must check, if the train r_i is not awaited by any of its connection trains r_j. In case that it is awaited, the possible departure time of all the train connections r_j must reflect the formula

$${}^{j}t_{Rd} \geq {}^{i}t_{Ra} + T_C$$

If necessary, the possible departure times of train connections r_j are modified.

If for any train r_j, the train r_i has been the last delayed train, for which the train connection r_j waited, departures of such trains r_j are scheduled to the time point ${}^{j}t_{Rd}$ – by scheduling the event 2.

7 Event 4

The event 4 has been scheduled in case a train r_j was forced to wait for delayed arriving train connections r_i. It should be evoked at the time ${}^{j}t_{Pd} + {}^{j}t_{Wi}$, i.e. in the end of allowed waiting period for delayed trains.

When processing this event, algorithm checks current positions of all awaited delayed arriving trains r_i. Based on rules, it decides, if there are any delayed trains r_i that should be still awaited for additional waiting time period. If yes, the waiting continues and no event is scheduled. If not, the departure time of the r_j train ${}^{j}t_{Rd} = {}^{j}t_{Pd} + {}^{j}t_{Wi}$ and the train departs immediately.

5 Next steps

Outlined suggested algorithm undergoes, at the time of writing of this paper, implementation and verification stages in simulation model of the Prague main station. Its full verification however depends on solving other decision-making problems like for example:

a) what platform track will be used by delayed train,
b) changes in plan of locomotives circulations,
c) changes in plan of train sets circulations,
d) changes in work of railway staff.

These questions are the next steps to be taken in building the decision-making support subsystem for solving situations caused by delayed trains.

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