Incorporation Of Allowance Time In Simulation Of A Railway Network

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Contents

1 Abstract **4**

2 What is Allowance allocation for a train **4**

2.1 Reason for allocating allowance time to a train while planning a schedule for the train 4

3 Engineering allowance and Traffic allowance **5**

3.1 Allowance rate assignment based on speed 6

3.2 Special Allowance 8

3.3 Calculating allowance during post processing 9

4 Scope for improvement **9**

5 Conclusion **10**

1 Abstract

The report aims to convey to the reader a method for calculating, allocating, and thereby utilizing allowance times for various trains in a railway network. In section 2, an explanation for the need for allowance was discussed. In section 3, the method of calculating and utilizing the allowances is explained. Section 4, discusses the various steps that can be incorporated to make this method more accurate in terms of incorporating allowances in the simulation of the railway network.

2 What is Allowance allocation for a train

Allowance is the amount of additional traversal time given to a train in each region to account for random delays.

For a train

$$t_{traversal} = t_{allowance} + n_{halt} * t_{halt} + \int_{path} \frac{d_{traversed}}{v_{train} + \int acc\ dt + \int dec\ dt}\ dt \tag{1}$$

where,

$t_{traversal}$ is the total traversal time of the train along a path

$t_{allowance}$ is the allowance time alloted for the train

n_{halt} is the number of halts for a train along the path

t_{halt} is the time for which the train has halted at its scheduled halt along the path

v_{train} is the velocity of the train along the path

acc or $acc(t)$ is the acceleration of the train along a portion of the path

dec or $dec(t)$ is the deceleration of the train along the portion of the path

$d_{traversed}$ is the distance traversed by a train along the portion of the path

2.1 Reason for allocating allowance time to a train while planning a schedule for the train

A train in a railway network due to various reasons can have a stochastic amount of delay in its traversal time. Some of the reasons due to which a train can be delayed are:

1. Unscheduled maintenance work: Unscheduled maintenance work introduces a change

(usually a reduction) in the velocity of trains that journey in a path that is undergoing maintenance. This changes the occupancy-time-window of block sections by the trains in a path. The results in a delay in the arrival times at the consecutive stations/regions. This delay contributes to congestion in the network.

2. Unplanned halt of a train: This usually happens in an emergency event in which an unscheduled halt occurs to the train. This introduced delay into the schedule of the train.

For the convenience of the passengers, the scheduled halt timings of a train have to be maintained constant during the journey of the train. Hence a delay in a train's path is carried over to the consecutive stations in the path of the train. This means the arrival times at all the consecutive stations in the train's path are delayed by the same amount of time. Additional delays follow superposition. These delayed arrival times result in congestion especially at block sections adjacent to stations with high throughput. The congestion results in more number of delayed trains in the network.

To minimize the carry-over delays we introduce excess time in the total traversal time of the train. This excess time is added into the traversal time as allowance time. Since the allowance time is an additional time allocated to the train, if a train is delayed it can still catch up to its schedule by the next station. The allowance can be thought of as buffer time that is utilized to absorb the delays introduced into a train's schedule. In a practical scenario, any unused allowance time can then be utilized by voluntarily delaying the train. This can either be done by delaying the departure time, or by reducing the velocity of the train.

3 Engineering allowance and Traffic allowance

The allowance allocated is to be consumed in the traversal time of the train, either by stochastic delays or by deliberate delays. In the current method, the allowance allocated between interchange stations, or major stations is consumed in the inter traversal. Consider two major stations A and B, generally not consecutive, then for a train, the time difference between departure at station A and departure of station B must include the allowance time to be consumed.

Hence a total allowance between two interchange points or major stations is to be calculated.

The total allowance is calculated as a sum of engineering allowance (EA) and traffic allowance (TA). Broadly engineering allowance takes maintenance time delays into account and traffic allowance takes the congestion time delays into account.

$$t_{allowance} = t_{EA} + t_{TA} \tag{2}$$

Each of the engineering and traffic allowances is computed from the distance traversed by the train. Until utilized, the allowances are aggregated as the train traverses.

$$t_{EA/TA} = f_{EA/TA}(\int_{t_0}^{t} v\ dt) \tag{3}$$

Where v is the velocity of the train at a particular block section, and t_0 is the starting time of the train. Corresponding to a pro-rata allocation of allowance, the function f is considered to be a linear function of the distance traversed by a train.

$$f_{EA} = rate_{EA} \int_{t_0}^{t} v\ dt \tag{4}$$

$$f_{TA} = rate_{TA} \int_{t_0}^{t} v\ dt \tag{5}$$

$$\begin{bmatrix} t_{EA} \\ t_{TA} \end{bmatrix}_{train} = \begin{bmatrix} rate_{EA} & rate_{TA} \end{bmatrix}_{train} \begin{bmatrix} \int_{t_0}^{t} v\ dt \\ \int_{t_0}^{t} v\ dt \end{bmatrix}_{train} \tag{6}$$

The engineering and traffic allowance rates are dependent on the priority of the train. A high-priority train needs less traffic allowance since it can only be interrupted or overtaken by another high-priority train. Whereas a train with the lowest priority will be overtaken by any train with higher priority.

4 priority levels of trains were considered for the project. $pr \in \{1, 2, 3, 4\}$. In general, the following relation is maintained for allocation of traffic allowance.

$$t_{TA}(train \mid pr = i) < t_{TA}(train \mid pr = j) \text{ when } i > j \text{ and } i, j \in pr \tag{7}$$

3.1 Allowance rate assignment based on speed

The speed of a train is in direct correspondence with the priority of a train. Hence, the faster the designated speed of the train, the higher is its priority.

$$v_{train} \propto pr \tag{8}$$

This makes sense because faster trains need higher acceleration time (t_{acc}) and deceleration time (t_{dec}) to halt. The acceleration and deceleration times are functions of the velocity of a train. Usually, the acceleration and deceleration curves are nonlinear functions of time.

$$t_{acc} = h_{acc}(v_{train}) \tag{9}$$

$$t_{dec} = h_{dec}(v_{train}) \tag{10}$$

The functions h_{acc}, h_{dec} are assumed to be linear functions and hence the acceleration and deceleration of a train are assumed to be constant.

In the implementation, a speed-based EA ($rate_{EA}$) and TA rate ($rate_{TA}$) are first mapped to all the trains which were later overruled if the trains were chosen as exceptions.

The distance traveled by train between two stations A and B is known before the simulation, from the path of the train.

$$distance_{A,B} = start\_km_A - start\_km_B \tag{11}$$

In routes Howrah-Chennai,Howrah-Mumbai,Chennai-Mumbai:

$$\begin{aligned}
&\text{if } (v_{train} \leq 110kmph): \\
&\qquad rate_{EA} = 6(mins/100km) \\
&\qquad rate_{TA} = 5(mins/100km) \\
&\text{if } (v_{train} > 110kmph): \\
&\qquad rate_{EA} = 8(mins/100km) \\
&\qquad rate_{TA} = 7(mins/100km)
\end{aligned}$$

$$t_{EA:A,B} = distance_{A,B} * rate_{EA} \tag{12}$$
$$t_{TA:A,B} = distance_{A,B} * rate_{TA} \tag{13}$$

Two methods exist to consume the accumulated allowance time:

The first method is to vary the train speed between stations A and B (as much as PSR's in that particular block sections would permit) such that the traversal time accounts for the allowance to be consumed.

The second method is to introduce additional halts between stations A and B such that the net time lost for deceleration, halting, and acceleration matches the allowance time to be consumed.

The second method was chosen for implementation in the project.

Hence,

$$t_{allowance:A,B} = (0.7 * \sum_{stations \in [A,B]} (t_{acc} + t_{dec})) \quad + \quad t_{halt} \tag{14}$$

In actual implementation,

$$t_{allowance:A,B} = (0.7 * |[A,B]| * (k_{acc} + k_{dec})) \quad + \quad t_{halt} \tag{15}$$

Where:

[A,B] represents the path of a train (set of stations) between stations A and B and $||[A, B]||$ represents the cardinality of the set [A,B].

k_{acc}, k_{dec} are pre-calculated acceleration, deceleration values (from a look-up table) based on the maximum permissible speed of the train.

Based on the feasible traversal times, 0.7 was a scaling factor chosen at the time of the project to account for the nonlinear nature of acceleration-deceleration times.

3.2 Special Allowance

The speed based allowance mapping is overridden by one of the following cases.

- Manual special allowance: Trains such as Rajdhani are chosen to have a lower traffic allowance rates (usually, $rate_{TA} = 0$)
- Certain low priority trains due the high number of overtakes end up having very long halts at some stations ($t_{halt} > 30$ mins). For these trains a special allowance rate is assigned on a block section-to-block section basis.
$$rate_i = g(\text{block section}) \text{ where } i \in \{EA, TA\}$$
- Automated special allowance: Except for certain selected sections in routes Delhi-Mumbai, Delhi-Chennai, and Delhi-Howrah, every other sections in this route were given $rate_{EA} = 6(mins/100km)$ and $rate_{TA} = 5(mins/100km)$. The $rates_{EA},\ rates_{TA}$ for the trains passing through all other sections in this route were assigned individually

After modifying the $rates_{EA},\ rates_{TA}$ rates for each train, based on the above rules a final mapping between $rates_{EA},\ rates_{TA}$ and the trains in a particular route is obtained.

The path of the train is split at the interchange points (IC points) (which are a set of selected major junctions and zone interchange stations in each path). The allowance aggregated between two IC points (as the train travels from IC1 to IC2) is consumed as halts before reaching the later IC point (IC2 in the considered example).

If the station already has a halt, the halt is extended and if there was not scheduled halt at the station a new halt is introduced such that

$$t_{allowance} = t_{acc} + t_{dec} + t_{halt} \tag{16}$$

The number of stations considered for allowance consumption (N) is dependent on the following logic:

$$N = 1 \text{ if } t_{allowance} \leq 8 \text{ minutes}$$
$$N = 2 \text{ if } t_{allowance} \leq 12 \text{ minutes}$$
$$N = 3 \text{ if } t_{allowance} \leq 16 \text{ minutes}$$
$$N = 4 \text{ if } t_{allowance} > 16 \text{ minutes}$$

Based upon the above equations, we can calculate the halt time at each station using:

$$t_{halt} = \frac{t_{allowance}}{N} - (t_{acc} + t_{dec}) * u(i) \tag{17}$$

where, $u(i) = 1$ if halt does not exist at station i, and
$u(i) = 0$ if halt exists at station i

3.3 Calculating allowance during post processing

In the post-processing stage, the required allowance has already been included in the scheduled halt time at the stations after accounting for the acceleration and deceleration losses. For further processing and verification purposes, the allowances were back-calculated from the simulator input by assuming the constant acceleration model.

The following are the steps followed:

1. From the simulator train input (from unscheduled.txt), the halt pattern (containing the allowance) of a train was extracted (sim_input).
2. From the train data (obtained from CRIS) the original halt pattern (without the allowance) was obtained (gqd_halt)
3. The basic idea is that the difference between these two halt patterns is the incorporated allowance. The following cases can occur for each station:
   - Halt present in sim_input but not in gqd : The allowance in this case is the halt time in sim_input + the acceleration and deceleration losses for this train type.
   - Halt present in both sim_input and in gqd : the allowance is equal to the extra halt (i.e. gqd_halt - sim_input_halt)
4. Since the allowance is aggregated between two IC points and consumed near the IC point, we perform the calculations on a IC section. The following steps are repeated for each IC section:
   - For each station in this section, find out extra time as per the rules stated in step 3.

4 Scope for improvement

1. The current rates of allowances are modified to account for the losses in the acceleration and deceleration times. But in future versions, the functions h_{acc}, h_{dec} can be modeled using non-linear functions for more realistic realization of the railway network.

2. The way of allocating allowances can be made more robust by identifying trains that need special allowance in an automated way

3. The current method of consuming allowance is uniform across all trains. A realistic method of consuming allowance can be planned where some special trains can consume the allowance in a different manner compared to other trains. This reduces the amount of congestion occurring in the network

5 Conclusion

A method of calculating allowances based on the distance traversed by a train was discussed in the report. Further, a method of consuming the allowances was also discussed. Using these methods, a pair of allowance times were allocated to various trains in the network and thereby accounting for the stochastic delays on the railway network. This, in turn, helps in maintaining the punctuality of the trains.

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