Railway junction simulation and analysis for mixed rail traffic

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***Abstract*—This paper focuses on the development of a tool for simulation and analysis of mixed rail traffic at a railway junction. The tool can be used to simulate scheduled passenger trains, then identify freight paths and estimate time required for freight paths to pass through typically congested junctions. The tool is useful for identifying key bottlenecks in a given infrastructure. Since the focus is on a junction in which various complex rail movements happen simultaneously or near-simultaneously, it is essential to have a detailed model about which resource causes a hindrance to another resource: this detailed model helps in a more accurate estimate of the capacity of the junction. With this focus as the objective, we propose a notion of a 'resource to resource hindrance matrix' which contains the time-values after which a resource is available for usage when another resource is in use. Since the hindrance matrix is key to the analysis, we elaborate how the hindrance matrix can be constructed automatically from formulae involving the existing station infrastructure layout and train running speeds at various points in the layout. We apply this to the case of Allahabad station as an example to demonstrate the capabilities of the tool.**

Keywords: hindrance matrix, resource to resource hindrances, junction analysis, mixed traffic, throughput

I. Introduction

A thorough analysis of rail traffic helps in meeting the increasing demand on a rail network/infrastructure. This paper considers the case of 'mixed traffic', i.e. when the infrastructure is to be used by both scheduled passenger and freight trains. While simulation studies for mixed-traffic have been investigated to various extents in the literature, this paper focuses on the case of a junction: this means complex simultaneous and near-simultaneous movements require elaborate modelling to obtain a more accurate simulation of the actual junction.

A simulation that uses a passenger timetable and yields freight paths is useful for scheduling freight trains from the starting point of the freight trains. Identification of bottle-neck resources too is possible using such a simulation tool.

In this paper we propose the notion of a resource to resource hindrance matrix which captures the extents of simultaneity of the various rail movements in a junction. The rows and columns in such a matrix are the resources that are available for a train to halt/pass through a junction, and the values are the minutes by which one resource hinders movement into another resource. A value of 0 in this hindrance matrix means that simultaneous movement is possible, while a high value at the i-j-th entry implies a large delay in the start of the j-th resource usage after starting of the usage of i-th resource. This is elaborated below in a simple example. Since the hindrance matrix turns out to help in obtaining an accurate estimate of the actual situation, we also elaborate on how the hindrance matrix can be generated directly from routine station layout details and maximum/safety train speeds at various points near a junction.

In general, a simulation of mixed rail traffic involves two parts.

1) Movement of trains *between* two stations,
2) Movement of trains *through* a station.

The two are quite different because the latter has to handle a lot of complexities based on the infrastructure. The complexities in the latter is further increased because of many more simultaneous movements permitted in a junction. By a careful combination of these two types of simulation, a real scenario can be modeled to better accuracy and a number of questions can be answered. Some objectives that can be achieved are:

1) identifying congestion and bottlenecks in the railway network,
2) effect of infrastructure improvement in the network,
3) finding good freight paths to minimize the traversal time.

II. Inputs required

With the above objective, we propose a procedure to simulate a junction. We describe our implementation in Python and use this to find the recommended halts for freight trains. We assume that the passenger timetable is followed as per the schedule. A set of inputs are required for the processing of the algorithm to simulate the junction. The inputs are as follows:

A. *Passenger train timetable at the junction*

1) arriving time
2) departing time
3) loop/line occupancy

B. *Infrastructure details: station layout and speed restrictions*

The hindrance matrices for movements in different directions are created using data about the station's infrastructure. In particular, information about which parts of the rail-lines

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are common and which are disjoint across different possibly-simultaneous movements is needed as an input. Further, over certain parts of the rail-network, there could be speed-restrictions: these need to be specified. This is elaborated below in the procedure to create the hindrance matrix.

III. Resource-to-resource hindrance matrices

When a train occupies a particular line at the station, it poses a hindrance to other trains with respect to the entering movement to that line for a certain duration of time. While this type of ‘self-hindrance’ is evident, the hindrance created by these movements of trains are not only restricted to the same resource. When a train enters a particular line/platform, there is additional hindrance created to other trains to enter into *other* lines or to exit from other lines as well. These hindrances are created due to fixed infrastructure and the need to share various common linkages during the process of entering/exiting a platform. Capturing these ‘cross-hindrances’ helps in a careful simulation of the junction. Simultaneity of various movements naturally have a hindrance value of 0 (minutes) as per our approach. The construction of these hindrance matrices is elaborated below.

A. Construction of resource-to-resource hindrance matrices

First the infrastructure is captured into two separate ‘spread-sheets’. This exercise needs manual entry of much of station data but does not need much understanding of construction of hindrance matrices: thus this effort can be from a station employee who is well-acquainted with the station layout and train movements. This data from the spreadsheets is used to compute the hindrances created by entry and exit movements of trains. The inputs required for creating these matrices are:

1) from station/loop,
2) to loop/station,
3) safety distance required between two trains,
4) length of IN link connecting the entry point of the station to the loop,
5) length of OUT link connecting the loop to exit point of the station,
6) loop length,
7) average speed on the IN/OUT links,
8) average speed on the loop line.

For a given station layout, the tracks are usually parallel to each other and we can define two directions, notionally called ‘up’ and ‘down’: this is shown in Figure 1.

With respect to a simple station layout example shown in Figure 1, consider the (example) hindrance matrix values given in Table I. A value of 0 minutes in the row indexed by StnDownP1 and column P3StnDown means that no hindrance is provided when a train moves from StnDown to P1 to trains moving from P3 to StnDown. On the other hand, the value 5 in the same matrix means that a hindrance of 5 minutes is provided for a train moving from StnDown to P3 to another train that moves from P4 to StnDown. More precisely, if a train T1 is to reach P3 at 8:25 am, for example, then T1 leaves a common entry point towards P3 at 8:16 am, and no train intending to enter P4 can leave from the common entry point between 8:16 am and 8:21 am. This constraint is imposed due to shared linkages for these two movements.

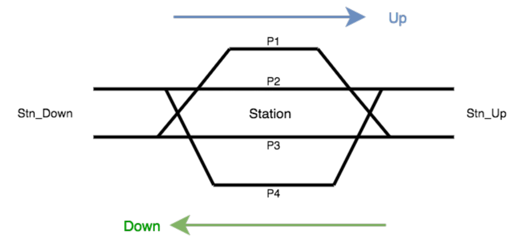

Fig. 1. Station layout

TABLE I
Hindrance matrix for UpEnter - DownExit (Station of Figure 1)

	P1StnDown	P2StnDown	P3StnDown	P4StnDown
StnDownP1	8	6	0	0
StnDownP2	6	8	0	0
StnDownP3	3	3	9	5
StnDownP4	3	3	7	9

Returning to the more general case of a complex layout, see Figure 2 of Allahabad station, for example, we outline the procedure to calculate the various hindrance matrices from the two spreadsheets. A infrastructure based analysis is performed on the above two spreadsheets to create hindrances created by utilizing different resources and these hindrances are then captured in the following 8 resource-to-resource hindrance matrices.

1) *Up Entry - Up Entry hindrance*
Train moving from *Stn_down* to *Station* creating hindrance to other trains moving from *Stn_down* to *Station*.
2) *Up Entry - Down Exit hindrance*
Train moving from *Stn_down* to *Station* creating hindrance to other trains moving from *Station* to *Stn_down*.
3) *Up Exit - Up Exit hindrance*
Train moving from *Station* to *Stn_up* creating hindrance to other trains moving from *Station* to *Stn_up*.
4) *Up Exit - Down Entry hindrance*
Train moving from *Station* to *Stn_up* creating hindrance to other trains moving from *Stn_up* to *Station*.
5) *Down Entry - Down Entry hindrance*
Train moving from *Stn_up* to *Station* creating hindrance

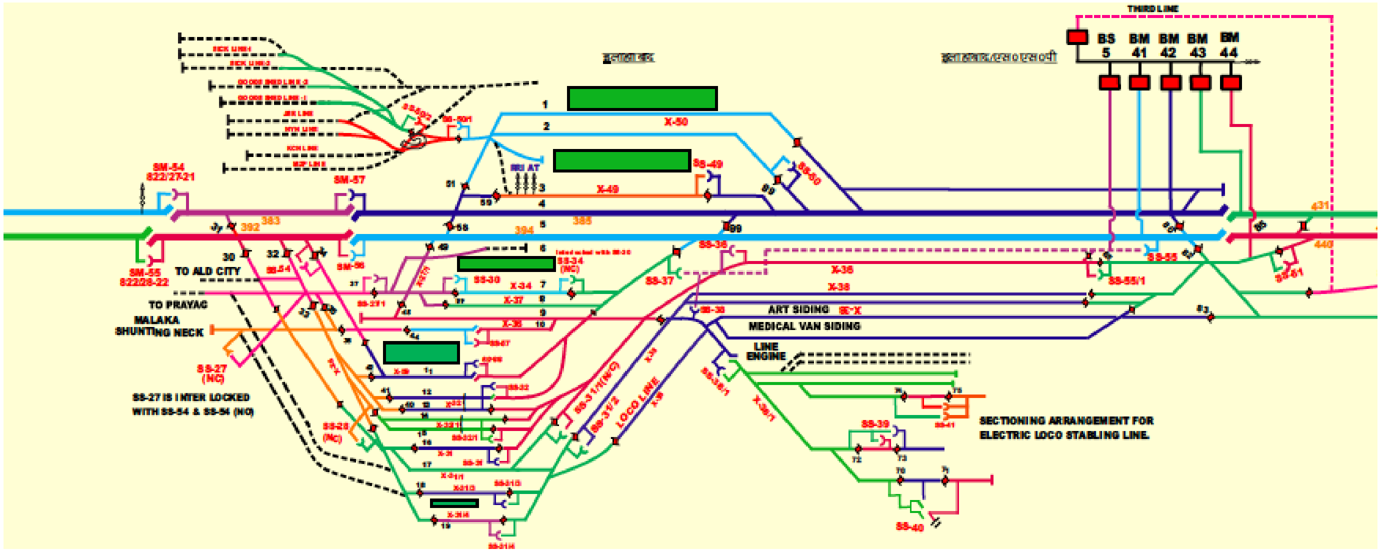

Fig. 2. Layout Allahabad

to other trains moving from *Stn_up* to *Station*.

6) *Down Entry - Up Exit hindrance*
   Train moving from *Stn_up* to *Station* creating hindrance to other trains moving from *Station* to *Stn_up*.
7) *Down Exit - Down Exit hindrance*
   Train moving from *Station* to *Stn_down* creating hindrance to other trains moving from *Station* to *Stn_down*.
8) *Down Exit - Up Entry hindrance*
   Train moving from *Station* to *Stn_down* creating hindrance to other trains moving from *Stn_down* to *Station*.

In the following section we focus on the example of Allahabad junction to highlight the questions one can ask using this approach.

IV. Example: Analysis of ALD station

A detailed analysis is done on one of the most congested junctions of Indian Railways, i.e. Allahabad (ALD) junction. For that firstly the layout of ALD station is carefully studied which is shown in the Table II.

TABLE II
ALD Station lines

Line num.	Purpose
1	Common line with passenger platform
2	Common line with passenger platform
3	Common line with passenger platform
4	Main up line
5	Main down line with passenger platform
6	Dock line from Naini, Allahabad City and Prayag with platform
7	Common line with passenger platform
8	Common goods line
9	Engine line
10	Common line with passenger platform
11	Common line with passenger platform
12	Stabling line
13	Common line
14	Common line
15	Common line
16	Common line
17	Engine line
18	Common line with passenger platform
19	Common line with passenger platform

A. ALD Station infrastructure

At ALD station, there are 19 lines that are used for handling the traffic through the station. These 19 lines have infrastructure usage policies and hence usage of some lines is restricted to specific purposes only. As per the station working rules, the running lines direction of movement and holding capacity are as below. The working rules are possibly inaccurate and not the latest, but the rules are typical for a busy and congested junction.

We construct the hindrance matrices with the following infrastructure restriction policies being adopted.

Line 4 : No Down movement allowed

Line 5 : No Up movement allowed

Line 9 & Line 17 : Not used in the simulation since these are used as Engine Lines. They are not used for any kind of traffic other than the movement of the engines.

Line 12 : Not used in the simulation since this is used as Stabling Line.Therefore this line is not available as per station layout for the routine train traffic.

Line 6 : No Up mmovement towards the station SFG allowed. the only movements possible are Up movements from NYN,PRG,ALY side and the reversal thereafter.

In the hindrance matrices, the movements are accordingly modeled. for example, neither the 4NYN movement is allowed, nor the movement NYN5. For the lines; other than the restricted ones mentioned above;both side movement is allowed from any side of the junction.

Therefore, the corresponding rows/columns are not shown in one of the hindrance matrices, shown in Table IV (on the last page). There would be seven other hindrance matrices, as desribed in the previous section (IIIA).

B. Assumptions while creating hindrance matrices for ALD

A detailed analysis is done on the infrastructure of the station to calculate these hindrances. The assumptions that we make for the analysis are as follows.

1) 25 kmph average speed of passenger trains when entering/ exiting the lines other than platform lines.
2) 10 kmph average speed of passenger trains when moving on platform lines.
3) When a train is exiting from the line, no movement is started from other lines for exiting at the same side.

An example for the hindrance matrix, i.e. DownExit-UpEntry hindrance matrix for ALD station is shown in the Table IV.

The first column indicates which resource is being used and the first row shows which resources get hindered because of the resource in first column being used. The zero in the matrix in the matrix indicates allowed simultaneous movements in the yard.

V. Simulating freight trains

Using the above hindrance matrix values and the passenger timetable, an algorithm is executed to find the hindrances created by passenger trains for each line/loop. There are 5 types of hindrances created by these scheduled passenger trains, as below:

1) Trains halt at the loop line
2) Hindrance created to trains entering in up-direction
3) Hindrance created to trains exiting from up-direction
4) Hindrance created to trains entering in down-direction
5) Hindrance created to trains exiting from up-direction

Once the above hindrances are calculated, one can use this for new freight paths and freight train delays (in passing through the junction) in various ways. One of the experiment that we perform is described below. A freight train is fired at each minute for the entire day and the movement modeling is based on the following assumptions.

Assumptions

1) 5 minutes are required for a freight train to decelerate to halt at the station,
2) 20 minutes are required for a freight train at the ALD station for different activities like crew change,
3) 7 minutes are required for a freight train to exit the station once it start accelerating,
4) Only the 4th and 5th lines are used for freight traffic for up and down movements respectively

Using the above, the simulation yields a time duration regarding when the train actually enters into the ALD station and at what time the freight train exits the station: this is based on existence of a free path and ensuring that the freight train does not cause hindrances to scheduled trains (that are to perhaps arrive *after* the freight train enters). This is obtained using the Python simulation.

Note: we check not only the existence of free path (as computed using the simulation), but also that no hindrances to scheduled passenger trains are created by the freight train's entry. This is a significant feature of the simulation.

Further, while simulating, care is taken that while entering the station, no enter hindrance is present in that particular direction and after that minimum time interval is present at the halting line without creating any hindrance to the passenger trains scheduled at that particular line. Also while exiting it is made sure that there is no exit hindrance in that direction for the particular line. The details are in [10].

The above is one example of an experiment: we analyze this below.

VI. Experimental results

Figure 3 shows the congestion of all 19 lines at ALD station due to scheduled passenger train timetable. The blue bar in Figure 3 indicates the available time (i.e. no kind of hindrance to any further to-be-scheduled trains) at the respective line for other movements and the orange bar indicates the hindrance created by halts at the particular loop. Figure 4 indicates the result obtained after firing freight trains at each minute in up direction. The y-axis and x-axis are in minutes. The y-axis indicates the halt required if the freight train is fired the time-minute (of the day) on the x-axis. The x-axis indicates the firing time for the entire day. In the graph, it is visible that at some points the *ActualHalt* $<$ *HaltWithFiring* which indicates that it is not possible to enter into main up line of the ALD station at that time because of a scheduled train creating hindrance. We observe that some good time windows for freight trains to arrive in the up direction movement as follows:

1) 1:05 am to 2:15 am,
2) 5:30 am to 6:30 am,
3) 12:30 pm to 3:15 pm.

Figure 5 is the result obtained after firing freight train at every minute in the down direction from SFG to NYN via ALD. For better understanding of terms '$ActualHalt$' and '$HaltwithFiring$', a snapshot of the result is shown in the TABLE III using which the terms are explained. From the Table III, it can be seen that if the train is fired at 115 or 116

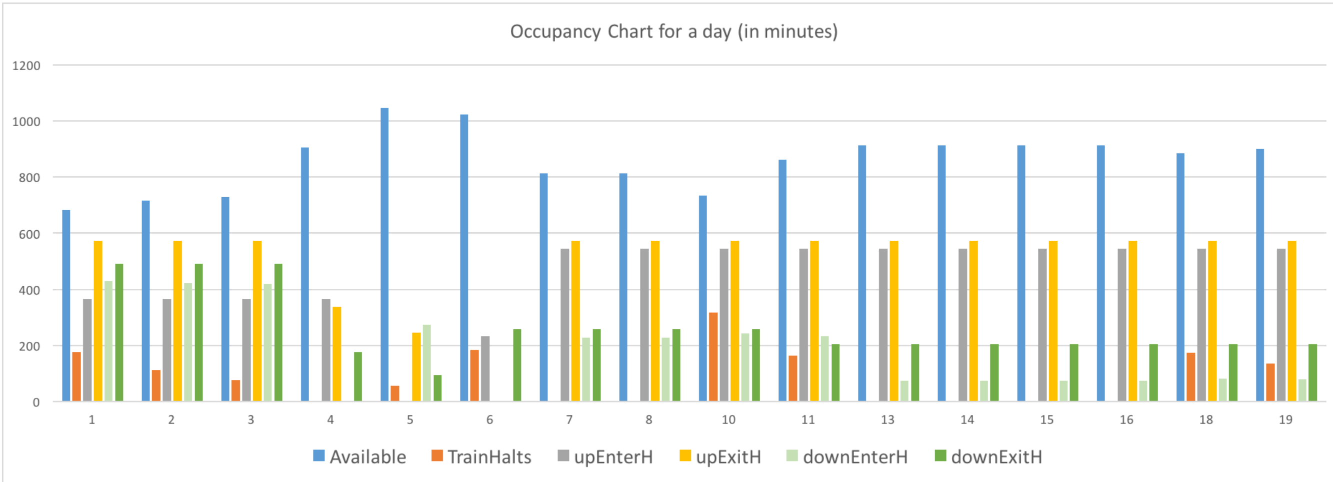

Fig. 3. Consolidated hindrances created at each line by passenger trains (for ALD's 19 platforms): minutes (out of 1440) vs platforms

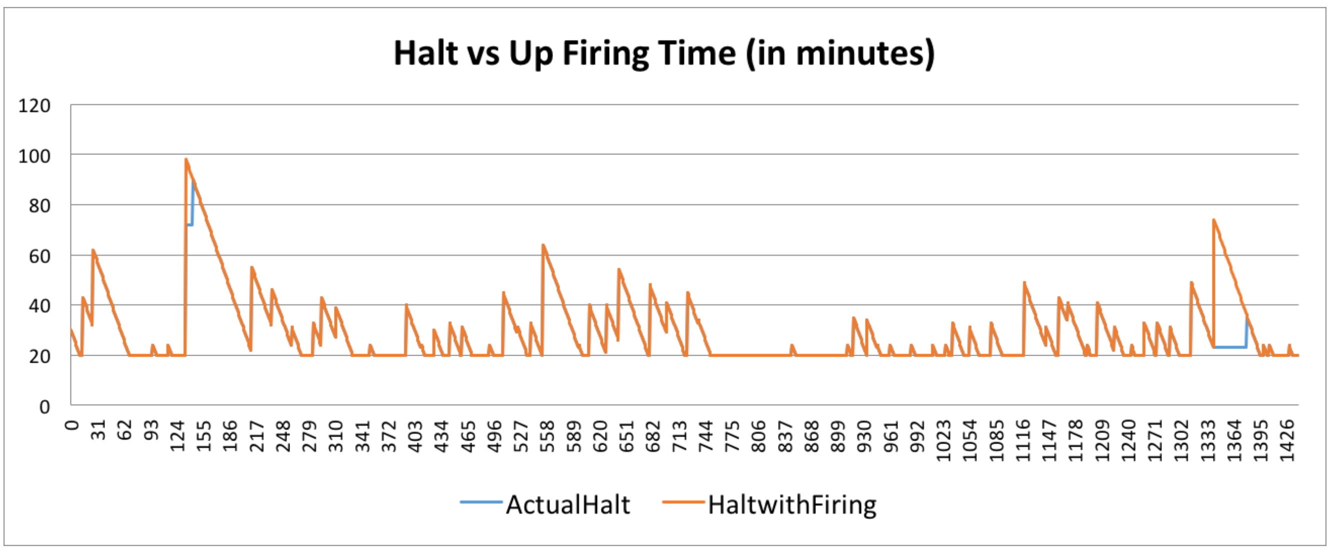

Fig. 4. Halt (in min) v/s firing time (in min of day) of Up-freight trains

TABLE III
SNAPSHOT OF TIMINGS FOR DOWN FREIGHT TRAINS THROUGH ALD

FiringTime	EnterTime	ExitTime	ActualHalt	HaltWithFiring
115	115	147	20	20
116	116	148	20	20
117	160	192	20	63
118	160	192	20	62

minute of the day i.e., at 1:55 am or 1:56 am, the train can enter the station at the same time. But if the train is fired at 117 minute of the day, it will result in delay of entry of train in ALD junction because of an already scheduled passenger train. This results into extra 43 minute $HaltWithFiring$ compared to $ActualHalt$.

Some of the good time windows for despatching freight trains in the down direction are as follows:

1) 12:50 pm to 2:50 pm,
2) 4:10 pm to 6:10 pm.

If the global network analysis indicates that this junction is a bottleneck resource, such time windows can be used to do backward scheduling and as a dispatching guidelines for effective management of traffic. This seems to be relevant in the case of ALD junction as part of ALD divisional operations.

VII. CONCLUDING REMARKS AND FUTURE WORK

We explain the development of a Python-based simulation tool for analyzing operations at a railway a junction. The simulation is useful for identifying freight paths, quantifying

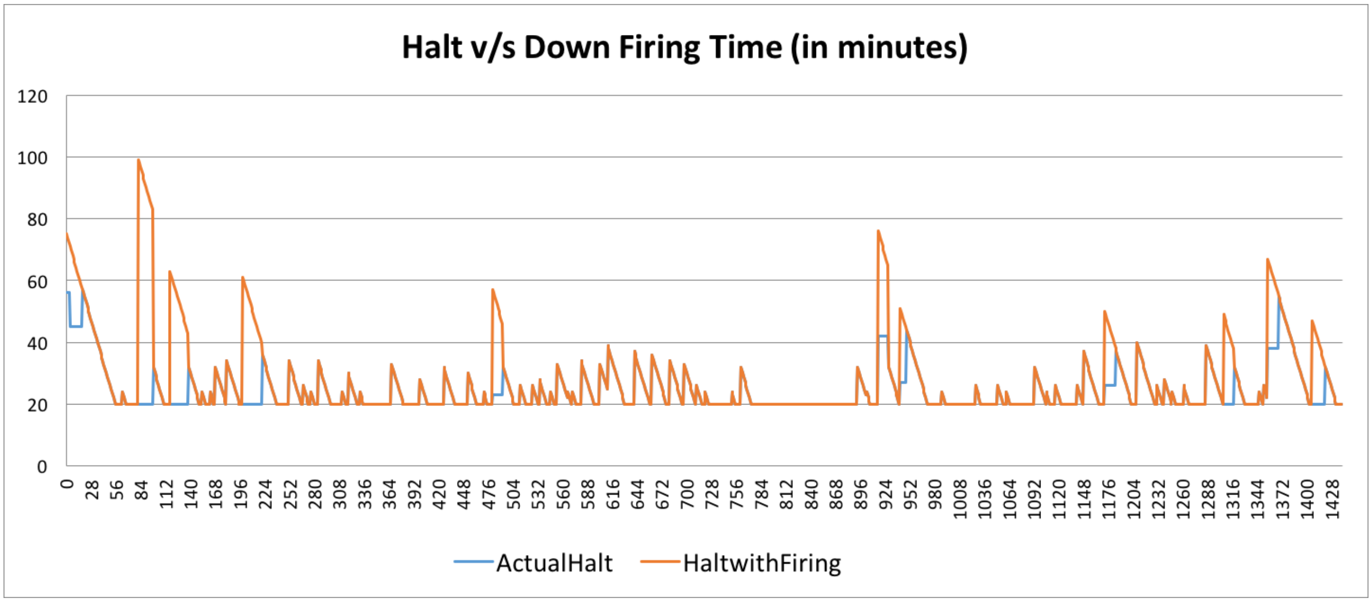

Fig. 5. Halt (in min) v/s firing time (in min of day) of Down-freight trains

availability of various resources and thus identifying bottlenecks in the infrastructure. The freight-train passage timings are useful for combining the junction simulation with a larger rail-section simulation: for example in [13], [17]. The key notion of the resource to resource hindrance matrix helps in this simulation and analysis.

Future work involves the introduction of other complex movements in the station. For example, we focused only on halts and 'through movements'. It is important to capture other movements like shunting movements that arise due to terminating and reversing trains, and due to loco-changes. The hindrance matrix approach has the potential for modelling these movements too. The effect of addition of a line in the station infrastructure on the throughput of the junction can also be addressed using the simulation.

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TABLE IV
EXAMPLE HINDRANCE MATRIX : DOWN EXIT - UP ENTRY HINDRANCE AT ALD STATION

	NYN1	NYN2	NYN3	NYN4	NYN6	NYN7	NYN8	NYN10	NYN11	NYN13	NYN14	NYN15	NYN16	NYN18	NYN19
1NYN	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
2NYN	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
3NYN	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
5NYN	0	0	0	0	6	6	6	6	6	6	6	6	6	6	6
6NYN	0	0	0	0	4	4	4	4	4	4	4	4	4	4	4
7NYN	0	0	0	0	6	6	6	6	6	6	6	6	6	6	6
8NYN	0	0	0	0	6	6	6	6	6	6	6	6	6	6	6
10NYN	0	0	0	0	5	5	5	5	5	5	5	5	5	5	5
11NYN	0	0	0	0	5	5	5	5	5	5	5	5	5	5	5
13NYN	0	0	0	0	6	6	6	6	6	6	6	6	6	6	6
14NYN	0	0	0	0	6	6	6	6	6	6	6	6	6	6	6
15NYN	0	0	0	0	6	6	6	6	6	6	6	6	6	6	6
16NYN	0	0	0	0	5	5	5	5	5	5	5	5	5	5	5
18NYN	0	0	0	0	5	5	5	5	5	5	5	5	5	5	5
19NYN	0	0	0	0	5	5	5	5	5	5	5	5	5	5	5