Simulation of Multiple Line Rail Sections

Devendra Shelar
Computer Science and Engineering,
Indian Institute of Technology Bombay, Powai, Mumbai 400076, India
devendrashelar7@gmail.com
Priya Agrawal
Industrial Engineering and Operations Research,
Indian Institute of Technology Bombay, Powai, Mumbai 400076, India
priya.a@iitb.ac.in
Rangaraj N.
Industrial Engineering and Operations Research,
Indian Institute of Technology Bombay, Powai, Mumbai 400076, India
narayan.rangaraj@iitb.ac.in
Ranade A.
Computer Science and Engineering,
Indian Institute of Technology Bombay, Powai, Mumbai 400076, India
ranade@cse.iitb.ac.in

Abstract

In this paper, we discuss a simulation-based approach to determine a strategy for the effective use of third line in a 3-line railway section. A railway traffic simulator developed at IIT Bombay has been used to experiment with different scheduling strategies. The simulator provides a detailed picture of the running of multiple trains on a rail section, considering timetables of fixed schedule trains, dynamic assignment of paths of unscheduled trains, detailed infrastructure modelling (stations, signals and block sections) and detailed train running characteristics.We describe a typical railway section consisting of two unidirectional lines and one bidirectional line (also called as the third line).

Numerical experiments have been performed considering different positioning of the third line relative to the other lines as this affects the traffic scheduling and track allocation. We have demonstrated the analysis using the Tiruvallur Arakkonam section in Southern Railways, where we have modelled the section layout and the traffic patterns. (of scheduled passenger trains as well as unscheduled freight trains). The performance measures used to quantify the section performance are weighted average traversal time and the maximum delay. The strategies that we analyse include fixed time interval reservation and variable time interval reservation based on traffic indicators. The approach is promising for analysing multiple line rail sections generally.

Keyword: Performance measures, Rail traffic simulation, Simulation.

1 Introduction

Indian Railways has a very wide and complex network and variety of routes across India. Across various regions, across various sections the Indian Railways comprise of single lines, double lines or more than two lines. In certain suburban networks there are also six parallel tracks set up. There are various performance measures that can be studied to analyse the track behaviour on a particular section. One can measure throughput (number of trains traversing the section per unit time), headway, average traversal time, maximum delay for a train etc. However, the sections comprising of three lines is of peculiar interest to this particular study. The three-line section comprises of two dedicated railway lines. one reserved for up direction and other for down direction. The third line can be used in both the direction. The question we will try to address is how a section controller can utilize the third line for better performance of the section across various performance measures.

As said above, in three-line sections, the third line can be used in both directions as opposed to the two main lines which can be used only in one direction each. Further, in a general section, the third line can be in the middle or one of the main lines can be in the middle. The purpose of study is to determine in what direction the third line be used given the traffic parameters in both the directions and the network configuration for the section. In particular, we will be analysing the performance of a Tiruvallur-Arakkonam section (abbreviated as TRL-AJJ section) in Southern Railways.

It is observed that during some intervals of time the train traffic is more in one direction than the other direction and during the other intervals of time it is vice versa. Hence, intuition suggests that the direction of the third line should be same as the direction in which there is more train traffic. We identified some ways as how to use the third line. We tried to determine the direction in which the third line needs to be used during the various intervals of time so as to reduce the overall delay of trains. Scheduling strategies for effective use of the third line were discussed.

We have used simulator developed by IIT Bombay. It was initially developed for IRISET (Indian Railways Institute of Signal Engineering and Telecommunication) that handles train scheduling on a linear section. The simulator finds out a conflict free, feasible schedule. The simulator also generates a velocity profile for the trains using which we can determine the location and velocity of the train at the given time. It handles two kinds of trains. scheduled and freight (unscheduled) trains. The loop allocation and the schedule of the freight train can be obtained given the source and the destination station and the departure time from the source station. The trains are scheduled as per their priorities and first come first serve criteria. The express trains have the highest priority while the freight trains have the lowest priority. The current work also aims to see whether this can be used for larger parts of the rail network, by using a combination of global and local scheduling principles.

2 Literature Review

Rangaraj et. al. (2003) have given the detailed description of the simulator that we have used for our experiments. The input and files are described and the algorithm used for scheduling is described in detail. Abril et. al. (2007) have discussed some techniques for railway capacity analysis and a simulation based tool, MOM, to perform the same. The parameters used are new or existing lines, train mix, regular time tables, traffic peaking factor, priority, track interruptions, train stop time, maximum trip time threshold, time window and quality of service, reliability or robustness. They have defined capacity as the ratio of time period and headway. Barber et. al. (2008), have discussed simulation approach for robust timetabling. Simulation disruption is performed and the conflicts are resolved using it. These methods are used in MOM. Homer et. al. (1999), have discussed strategic planning model for railway system. It evaluates On-Time performance measurement for freight cars at ultimate destination. Fadadu (2010), in his report has analysed investment to construct by-pass at a junction, which is a bottleneck in a considered part of the network. The simulator developed by IIT Bombay is also used in this. Construction of by-pass or a flyover is suggested based on the analysis of the traffic patterns. Raghuram and Rao (1991) have described experiment design and implementation for line capacity planning of a section of running freight trains. The effects of variation in the number of tracks, signalling mechanism, train speed and starting times for trains have been analysed.

3 Problem Description

3.1 *Objective*

The main objective of the study is to propose a scheme for operating the third line in the Tiruvallur-Arakkonam section. These stations are abbreviated as TRL and AJJ respectively. The down direction of the section is from TRL to AJJ or the up direction is from AJJ to TRL direction. The TRL-AJJ section consists of 3-railway lines namely the up main line, down main line and a 3^{rd} line which can be used in both the directions. We need to determine how to operate the 3^{rd} line so that the capacity of the section can be optimally used. An indirect, but useful measure of performance in this context is the average traversal time for trains using the section.

3.2 *Description of Section*

The particular TRL-AJJ section has the up line in the middle. The principle which we attempt to discuss here can be extended to similar sections anywhere. These sections could have the 3^{rd} line in the middle or the down line in the middle. In TRL-AJJ section there are two main intermediate stations Kadambattur and Tiruvalangadu (abbreviated as KBT and TI respectively). There are other intermediate stations at which only the local trains halt. Also, these stations have only as many loops as the number of railway lines, namely 3. At the stations KBT and TL, there are 5 loop lines, each. Hence, there is scope for change of railway tracks by trains and overtaking etc. at these stations. The following diagram shows the line arrangement at the TRL- AJJ section.

4 Input Modelling

The traffic patterns that are given to the simulator can be specified in various types. It can either be regular traffic pattern or irregular traffic pattern.

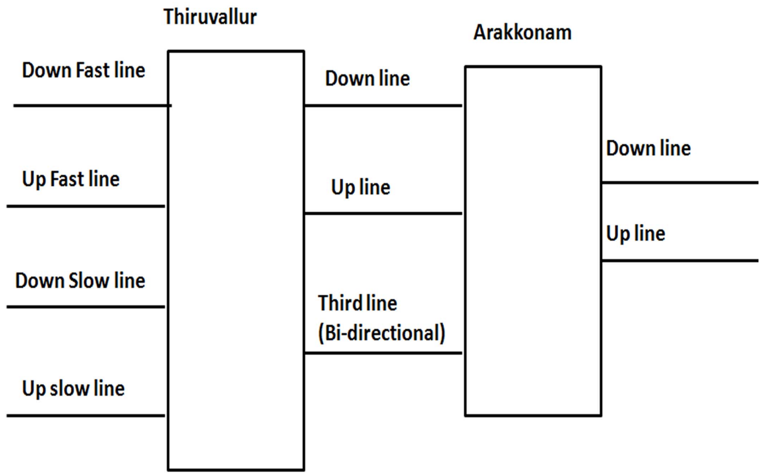

Figure 1: Line arrangement of TRL-AJJ section

4.1 *Regular traffic*

In this type the arrival and departure time for every train is specified at each station. But delay might occur because of various reasons like maintenance of tracks, engine failure or climatic conditions. While simulation, external delays can be added and analysed as part of the future work.

4.2 *Irregular traffic*

The traffic pattern of unscheduled trains is said to be irregular. Some of the variations are listed below:

- The departure times of the unscheduled trains from the source station can be determined based on a fixed headway or a variable headway. Both of these strategies are discussed further in section 6
- We can analyse past traffic for a particular period and fit a theoretical probability distribution to it.
- The departure times of trains can be based on the values obtained from a random number generator.
- Based on the current trends of traffic, the future traffic i. e. the approximate number of trains can be predicted and simulation can be done for the it.
- The speed, acceleration, deceleration of the train can be varied.

  In this paper we have experimented for the change in headway of freight trains and the real sample data. The analysis of the remaining strategies is part of our future work.

5 Strategies Used

5.1 *Nature of suggested policy*

Let us first define a set of parameters to measure the performance of the section. Let the measure of traffic in the up direction be N_u and that in the down direction be N_d which captures the intensity of traffic and usage in each direction over a certain time horizon.

5.2 *Traffic indicators*

The traffic indicators N_u and N_d are computed as follows. Determine a time horizon T (e.g. two hours) from current time.

- *Definition 1:* N_u is the weighted sum of trains in the up direction that are in the section or will be in the section during the time interval $[0,T]$. The current time is 0.
- *Definition 2:* N_d is the weighted sum of trains in the down direction that are in the section or will be in the section during the time interval $[0,T]$. The current time is 0.
- *Definition 3:* K is the measure of threshold difference between the up-traffic and down-traffic that would suggest sufficient directional dominance in the down direction.
- *Definition 4:* L is the measure of threshold difference between the up-traffic and down-traffic that would suggest sufficient directional dominance in the up direction.

We now put down the following aims that we would like to prove by simulation of the TRL-AJJ section with the help of the simulator.

- If the third line is currently operating in up direction, change over to down IF $N_d - N_u = K$ (i.e. continue in up direction if $N_d - N_u < K$)
- If the third line is currently operating in down direction, change over to up IF $N_u - N_d = L$ (i.e. continue in down direction if $N_u - N_d < L$).

In other words, move to a different regime if there is sufficient directional dominance of traffic. The parameters K and L and the method of computation of the traffic indicators N_u and N_d will be described below. Let the up trains considered for scheduling be $u_1, u_2; ...; u_m$ with priorities $p_{u_1}; p_{u_2}; ...; p_{u_m}$. Also, let the down trains considered for scheduling be $d_1; d_2; ...; d_n$ with priorities $p_{d_1}; p_{d_2}; ...; p_{d_n}$.

- The traffic measure N_u in the up direction is given by:

$$N_u = \frac{p_{u_1} + p_{u_2} + ... + p_{u_m}}{m} \quad (1)$$

- The traffic measure N_d in the down direction is given by:

$$N_d = \frac{p_{d_1} + p_{d_2} + ... + p_{d_n}}{n} \quad (2)$$

Now, let us define the traversal time of a train. A train once into the section of interest can either halt at an intermediate station which is the train's destination station or exit the section completely. Therefore, the traversal time of the train is defined either to be the time taken for train to halt at its destination station in the section (if any) or the time taken by train to exit the section completely adhering to the schedule specified by the simulator, since its arrival into the section. For e.g. if a train tr enters the station at time ta and halts at its destination station or exits the section at time te then the traversal time t_{tr} for train is:

$$t_{tr} = t_e - t_a \tag{3}$$

We can further define a weighted average traversal time for all the trains considering the specific time window. Let's say that $tr_{u_1}; tr_{u_2}; ...; tr_{u_m}$ be the traversal times for the up trains and $tr_{d_1}; tr_{d_2}; ...; tr_{d_n}$ be the traversal times for the down trains. The priorities of the trains are mentioned earlier. Then the weighted average traversal time for these trains is defined as:

$$WATT = \frac{\sum_{i=1}^{m} p_{u_i} * tr_{u_i} + \sum_{i=1}^{n} p_{d_i} * tr_{d_i}}{m + n} \tag{4}$$

Given a general scenario, the average traversal time when the 3^{rd} line is used only in the up direction and when it is used only in the down direction are bound to be different. Let us call these times as $WATT_u$ and $WATT_d$ respectively. On the basis of the average traversal times $WATT_u$ and $WATT_d$ we compute the values of K and L as shown below. These definitions of K and L are specific only for 3-line sections which have the up line in the middle.

There are two major cases based upon the values of N_u and N_d.

- $N_u \geq N_d$: In this case, we claim that $WATT_u > WATT_d$ as shall be shown in the results of the experiment later.

- $N_u < N_d$: In this case, there are two sub cases:
  - $WATT_u > WATT_d$: This would be the case when N_u is not much less than N_d.
  - $WATT_u \leq WATT_d$: This would be the case when N_u is much less than N_d.

Then, let

$$K' = N_d - N_u \tag{5}$$

The smallest such value of K' is K. Mathematically defined as

$$K = \{minN_d - N_u | WATT_u \leq WATT_d\} \tag{6}$$

L is defined similarly.

When the difference between the traffic measures N_d - N_u becomes as greater than or equal to K we will want to change the direction of the 3^{rd} from up to down. However, once the traffic sets in the section and direction of 3^{rd} line is in down direction, if N_u which is initially less than N_d, gradually becomes greater than N_d, because of existing traffic changing the direction of 3^{rd} line may not reduce the $WATT$. Hence, we change the direction of 3^{rd} line only when the difference $N_u - N_d$ becomes greater than the threshold L. i.e. when N_u - $N_d > L$, change the direction of the line from down direction to up direction to reduce $WATT$.

Some claims about the values of K and L can be made as follows:

- If the third line is in the middle, we would expect $K = L$
- If the up line is in the middle, we would expect $K > L$
- If the down line is in the middle, we would expect $K < L$

6 Suggested Control Policy

6.1 *Fixed time strategy*

6.1.1 *Varying the headway of freight trains*

The indicative values of K and L (and T) are suggested through a simulation exercise on the TRL - AJJ section. The time window for the experiment was taken to be one hour. We scheduled 4 down passenger trains each with priority 4 for the experiment. We vary the parameters u (upHeadway in minutes) and d (downHeadway in minutes) for the freight trains which are of priority 8 each. The priorities are defined on scale 1-10. We normalize the priorities by dividing it by 11 which is $maxPriority + 1$. The freight trains start coming into the section since the beginning of the time window at a regular interval of headways. That is the first freight trains in both directions reach the beginning of the section at 0000 hrs. Since the time window is of duration 1 hour, the number of trains fired in up direction and down direction are given by n_u and n_d as follows:

$$n_u = \frac{60}{upHeadway} \tag{7}$$

$$n_d = \frac{60}{downHeadway} \tag{8}$$

Further the weighted traffic in up direction and down direction will be as follows:

$$N_u = n_u * \frac{8}{11} \tag{9}$$

$$N_d = \frac{n_d * 8 + 4 * 4}{11} \tag{10}$$

Similarly, the weighted average travelling time (WATT) is obtained.

In this strategy, the time window for experiments was taken 1 hour. The values K and L would vary depending upon the position of the 3^{rd} line with respect to the up main line and the down main line.

- If the third line is in the middle, we would expect $K = L$
- If the up line is in the middle, we would expect $K > L$
- If the down line is in the middle, we would expect $K < L$

6.1.2 *Scheduling as per sample operating data*

Some sample operating data covering 8 days was available for the TRL-AJJ section. A part of this data(24 hours duration) is used as the representative data. The assumptions made about operating practices for this particular are as follows(the details could vary from section to section in practice):

- The 3^{rd} line is not used by suburban trains because for this section, because for this section, the platforms are not available for on the third line at every station. Hence, the long distance trains which do not halt at the intermediate stations use this line.
- For the up long distance trains the 3^{rd} line is if higher priority than the UP line whereas for the down long distance trains the down line is of higher priority.

The 3^{rd} line is reserved in a particular direction for a fixed time interval. The time interval can typically range from 2 hours to 12 hours. The experimental results have been shown in section 7.1.2.

Table 1: Fixed time strategy results

up Headway	down Headway	N_u	N_d	$WATT_u$	$WATT_d$	Direction of 3^{rd} line
5	5	3.270	5.810	17.403	19.482	up
5	6	3.270	5.273	16.132	18.366	up
6	5	2.727	5.810	17.570	18.442	up
7	5	2.455	5.810	17.948	17.820	down
8	5	2.182	5.810	18.023	17.440	down
9	5	1.909	5.810	18.075	17.221	down
9	8	1.909	4.727	15.000	15.011	up
10	13	1.636	3.909	13.201	13.123	down
10	14	1.636	3.909	13.023	12.921	down
11	7	1.636	5.000	15.590	15.385	down
12	10	1.360	4.180	14.123	14.027	down
13	12	1.360	3.909	13.626	13.508	down
14	13	1.360	3.909	13.428	13.147	down
15	16	1.091	3.636	13.367	13.367	-
16	15	1.091	3.636	13.510	13.266	down

6.2 *Variable time*

In this strategy, the traffic intensity is calculated every hour. If the traffic intensity is more than the calculated K and L values(as described in section 6.1) then the direction of the third line is changed. The underlying assumptions are same as discussed in section 6.1.2. The experimental results for this strategy have been discussed in section 7.2.

7 Experimental Results

7.1 *Fixed time strategy*

7.1.1 *Varying the headway of freight trains*

The approach used in the experiments related to table 1 is that, if for certain period of time we find the up traffic heavier than the down traffic above a threshold, we dynamically change the direction of the third line from down to up direction (if required). That is we keep monitoring the values for the traffic and determine the direction of the third line. (The values obtained in Table 1 are as per the calculations shown in section 6.1.1)

The static allocation of direction for third line, we do a pre-analysis of traffic and fix a schedule for the third line. Say for example, for half an hour the third line is in up direction followed by half an hour for which the third line is in down direction, followed by one hour for which third line can be used in both the directions.

Unscheduled trains are fired for an interval of 1 hour. We can see that the direction of the third line is changed when the difference between the traffic measures N_d - N_u becomes as greater than or equal to K we will want to change the direction of the 3^{rd} from up to down.

In the table 1 we have not specified the results for all the up headways and down headways.This is because, as the down head way increases, or the down traffic decreases, the usage of third line changes from down direction to up direction. However, if we reach a stage where $WATT_u$ and $WATT_d$ both are equal, that means even if we further reduce

Table 2: Fixed strategy results for real data

Time slots	N_u	N_d	$WATT_u$	$WATT_d$	Direction of 3^{rd} line
0-6	7.727	3.818	13.032	16.799	up
6-12	5.727	4.182	8.78	17.671	up
12-18	4.636	8.727	11.801	14.127	up
18-24	5.727	8.818	8.189	11.839	up

Table 3: Variable strategy results for real data

Time slots	N_u	N_d	$WATT$	Direction of 3^{rd} line (per hour)
0-6	7.727	3.818	13.712	down, down, up, up, up, down
6-12	5.727	4.182	10.760	down, down, up, up, up, up
12-18	4.636	8.727	14.172	down, down, down, down, down, down
18-24	5.727	8.818	10.391	down, up, up, up, up, down

the down traffic, the $WATT$ values will be the same whether the third line is used in the up direction or the down direction. The reason behind this is that the traffic in both the directions is so less in these cases that the third line is not at all used.

7.1.2 *Scheduling trains as per the given time table*

The time slots considered for these experiments is 6 hours i.e. a set of 4 such experiments over a period of 24 hours. The results of the same have been shown in table 2. The 3^{rd} track is reserved in the up and down direction for all the for sets, $WATT_u$ and $WATT_d$ are calculated respectively.

7.2 *Variable time strategy*

In this section the time slots of 6 hours are considered and the direction of the $3^r d$ line is calculated based on the traffic intensity for each hour. In this case(while calculating $WATT_u$ the direction in the respective time slots are:

- {0-1,1-2,2-3,3-4,4-5,5-6} = {down, down, up, up, up, down}
- {6-7, 7-8, 8-9, 9-10, 10-11, 11-12} = {down, down, up, up, up, up}
- {12-13, 13-14, 14-15, 15-16, 16-17, 17-18} = {down, down, down, down, down, down}
- {18-19, 19-20, 20-21, 21-22, 22-23, 23-24} = {down, up, up, up, up, down}

(The above values are calculated as per the formulae in section 5.2). The directions are taken opposite while calculating $WATT_d$. The results are shown in table 3.

We observe from the table 4 that the fixed time strategy shows better results than the variable time strategy in all the time-slots. The reason is that changing direction of the third line causes a certain overhead which results from the flushing out of the trains actually running on the line.

8 Conclusion

The operational strategy for utilizing a resource like the third line in heavy traffic sections is not obvious. It depends on a number of factors like the location of the third line with

Table 4: Comparison of variable and fixed time strategies

Time slots	N_u	N_d	$Fixed_u$	$Fixed_d$	Variable
0-6	7.727	3.818	13.032	16.799	13.712
6-12	5.727	4.182	8.878	17.671	13.544
12-18	4.636	8.727	11.801	14.127	14.172
18-24	5.727	8.818	10.189	11.839	10.391

respect to the other two, the location of crossover points, the traffic density, the traffic mix and finally the performance measures of relevance to the rail operator. Simulation provides a good means for evaluating different strategies.

In this paper we have reviewed the performance measures like, traffic intensity and weighted average traversal time which are used as the decision making parameters for the 3 line railway section. Simulation also plays a major role in railway scheduling which has been done using the simulator developed by IIT Bombay

We experiment with the simple one of fixed time regimes and compare it with more complex strategies like variable time strategy involving some system state measures. More sophisticated control strategies using long run simulations can also be proposed and evaluated by other analytical techniques in future. The ones we have suggested have the advantage of being implementable with minimum additional infrastructure and training of personnel involved in the decision.

Based on our experiments we can say that the $WATT$ of fixed startegy is less than variable. More refined results can be obtained by analysing data for a variety of traffic and longer time which is a part of our future work.

References

[1] M. Abril, M. Barber, L. Ingolloti, M. A. Salido, P. Tormos, A. Lova A, “An assessment of railway capacity”, *Transport. Res. Part E, 2007.*

[2] F. Barber, L. Ingolloti, M. A. Salido, “A Simulation tool to evaluate the robustness of railway timetables”, *PSCS 2008.*

[3] Pratik V. Fadadu, “Network Level Investments to Improve Rail Capacity”, *M.Tech Project Report, Industrial engineering and Operations Research, IIT Bombay, 2011*

[4] Jack B. Homer, Thomas E. Keane, Natasha Lukiantseva, David W. Bell, “Evaluating Strategies to Improve Railroad Performance - A System Dynamics Approach”, *Winter Simulation conference, 1999*

[5] G. Raghuram and V. V. Rao, “A decision support system for improving railway line capacity”, *Public Enterprise,Vol-11(1), pp.64-72 (1991).*

[6] N. Rangaraj, A. Ranade, K. Moudgalya, C. Konda, M. Johri and R. Naik “Simulator for Line Capacity Planning”, *Sixth Asia Pacific Operations Research Society, Delhi, December 2003*