Simulation of Mix-traffic Railway Networks carrying Semi high speed passenger trains and High axle load freight trains

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Synopsis

Railway traffic is a derived demand. In India, it emanates from the requirement of the growing population which has already reached 1.3 Billion. This population generates demand directly on the passenger side and indirectly on the freight side. With this high and growing demand for railway services, there is a need to increase the speed of the passenger trains as well as a need to increase the axle load of freight trains. An increase in speed leads to a significant increase in the cost because a high speed passenger railway requires very high quality track. In sections that handle both passenger and freight traffic, the running time of freight trains could increase because of higher speed differentials and loss of capacity to permit overtaking higher priority passenger trains. Increase in axle loads may also increase traversal times on sections for safety and other considerations.

Managing mixed traffic with semi high speed passenger trains and heavy axle load freight trains is a challenging task. This can be achieved either by: improving operations over an existing railway or building an entirely new single purpose dedicated line. Adequate demand, sufficient funds for investment and topographical feasibility are mandatory for

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establishment of dedicated new lines. A new dedicated line is justified if its cost effectiveness is better than that of existing line with improved mixed traffic operations. To analyse these effects of the improvements in terms of capacity and running times, simulation is an economically viable and quick approach. For this purpose, a rail traffic simulator developed at IIT Bombay is demonstrated, which has modelled rail infrastructure and rail traffic in adequate detail, including rules of operation for mixed traffic. The simulator has been developed over the years for analysing mixed traffic capacity of long sections. Using simulation, we provide illustrative analyses of such situations on high traffic sections of Indian Railways. This study also illustrates how mixed traffic with large speed differentials and high heterogeneity of the trains have impact on capacity, number of over-takings, punctuality and traversal time of freight trains. There is some evidence of increase in capacity of the mix traffic network with improvement in operations, in addition to the option of building dedicated rail lines for different streams of traffic. Improvement in operations can be done through many measures such as enhancing the signalling infrastructure of the section, introducing fixed interval timetables for different streams of traffic and other strategies.

The tool is likely to be useful in an environment where there are a number of interesting possibilities for technology upgradation and system level investments in the next few years in India.

1. Introduction :

Indian nationwide rail network is a state-owned enterprise, operated by the Government of India through Ministry of Railways. It is fourth largest railway networks in the world comprising 115,000 km of track with operating route length of more than 65,000 km and 7,112 stations. It is one of the largest transportation and logistics network of the world which runs 19,000 trains, out of which 12,000 trains are passenger trains and 7000 trains are freight trains. In 2014 - 2015 Indian Railways had revenues of INR

1634.50 billion which consists of INR 1069.27 billion from freight and INR 402.80 billion from passengers tickets. As it can be seen that number of freight trains were half of that of passenger trains, whereas freight revenue is more than double of passenger revenue. This great inequality prevails in Indian Railways (IR) because IR is a state owned enterprise and a public transportation medium, so its first preference is always to serve the citizens of India and then comes profit generation. As the growth in the economy picks up in the years to come, IR will have a challenging task ahead because of line and terminal capacity constraints in transporting the incremental traffic.

With the very high and growing demand for railway services, there is a need to increase the speed of the passenger trains and axle load of freight trains on existing railway infrastructure. In sections that handle both passenger and freight traffic, the running time of freight trains will increase because of higher speed differentials and loss of capacity to permit overtaking higher priority passenger trains. Increase in axle loads may also increase traversal times on sections for safety and other considerations. So to satisfy these demand, either a new dedicated line for single purpose can be implemented or existing railway operations should be improved and optimized. But not in all cases, augmenting dedicated line is an option. Because it depends on combination of many factors such as investment, geography and adequate demand. So improved mixed traffic operations in some cases might be a better solution compared to dedicated lines. To examine and analyse the impact of such infrastructural changes on the section, Simulation tool has been devolved by IIT Bombay. This paper mainly deals with impact of capacity of the section with introduction of semi high speed passenger trains and high axle load freight trains.

NOTE: The experiments below are with some assumptions about operating characteristics of different train types and should be viewed only as indicative results. More analysis is needed with validated data. The paper illustrates the utility of simulation as a methodology in such analysis and possibly in decision making.

1.1 IITB Simulator:

IITB railway simulator is a JAVA based tool developed over the years on the IIT Bombay campus for analysing and studying railway networks and operations. In short, it generates valid movements of trains for given inputs using a specified block signalling method. It handles train scheduling on a linear section and generates a conflict free, feasible schedule which also includes complex scenarios like overtakes, originating and ending trains in between of the section, etc. It is a planning tool which can be used to understand the effects on making some infrastructural and operating strategy changes on the capacity.

1.2 Semi High Speed:

From [1] & [3], the Gatimaan express category of trains is taken as one of the semi high speed train options which has maximum speed of 160 km/hr. From [4], we infer that Gatimaan express will be run using WAP-5 locomotives. To find an approximate acceleration and deceleration parameters of the WAP-5 Locomotive, data from [7] has been employed. The reference [7] provides some experiments on different locomotives of Indian railways with standard passenger rakes. From one such experiment, WAP-5 locomotive takes approximately 312.1 seconds to accelerate to the speed of 110 km/hr. To reach such speed in such time, constant acceleration of 0.0979 m/s^2 (~ 0.1m/s^2) is required. This value has been assumed for deceleration also for simplicity. So, in summary, we use an acceleration and deceleration value of 0.1 m/s^2 and a max speed of 160 kmph for semi high speed train.

1.3 High Axle load:

Two important freight locomotives used in India are [5]:

1. **WAG-9** is a type of electric locomotive used in India. These are essentially the same as the WAP-7 units, with some differences in gearing and the control software to make them suitable for freight operations. The rated top speed is 100km/h. Rated axle load is 20.5t [6].
2. **WAG-9H** is a heavier variant of the WAG-9 and consequently higher TE. Everything else was just as in the WAG-9 class, except for some application software changes. They are the only freight dedicated three-phase AC locomotives in India. Axle load is 22.5t [6].

WAG-9H can be considered as high axle load freight trains in our study. Since both are similar to WAP-7 Locomotive, their acceleration and deceleration values can be calculated using [7]. WAP-7 Locomotive takes approximately 240 seconds to accelerate to the speed of 110 km/hr. To reach such speed in such time, constant acceleration of 0.127 m/s^2 is required. Since these calculations are made for passenger wagons, for freight wagons there will be reduction in acceleration. Therefore WAG-9h or WAG-9's acceleration can been assumed as 0.1 m/s^2 (80% of 0.127 m/s^2). The only difference is the maximum permissible speed. From [2], it is noted that higher operating speeds can be achieved through reduced axle loads. So WAG-9H Locomotive which is of higher axle load will be having lower maximum speed than WAG-9 Locomotive. Maximum safety speed of WAG-9 can be considered as 75% of Rated speed (75 km/hr = 75% of 100km/hr). Maximum safety speed of WAG-9H can be assumed less than that of WAG-9.

Freight trains with WAG-9 locomotive are considered as Medium axle load freight trains. Similarly freight trains with WAG-9H locomotive are considered as High axle load freight trains.

Construction of Test Cases:

The Allahabad-Mughalsarai Section of Allahabad Division is highly congested and delays are observed in passenger train running on most days. Because of its geographical location, this line is quite congested, and handles a significant amount of both Passenger as well as Freight traffic. There is a need to create more paths for additional trains. Even though there is a proposal of dedicated freight corridor in this section, it has been considered in this study as a typical example of a significant section which currently handles mixed traffic. With the detailed infrastructural data, test cases can be constructed on any sections. In this study, different test cases were built on this MGS-ALD section. All the test cases have few common basic infrastructural parameters and also few varying parameters. Basic Sectional details which are mentioned below were used from [8]:

1. 22 Stations from Mughalsarai (MGS) to Allahabad (ALD) were considered.
2. Exact functional loops of the stations were considered as per Table 2.
3. For location of blocks and stations, the following table 1 is considered:

Name	Start Km	End Km	Up Loops	Down Loops	Common Loops	Up Blocks	Down Blocks
Mughalsarai	0	2.97	2	2	4	1	1
BH-K	5.09	5.56	1	1	Nil	2	2
Jeonathpur	7.56	9.32	2	3	Nil	4	4
Ahraura Road	13.56	15.09	2	2	Nil	6	6
Kailahat	21.68	23.38	2	2	Nil	7	7
Chunar	31.32	33.97	2	2	2	2	2
Dagmagpur	39.21	40.79	2	2	Nil	1	1
Pahara	47.15	48.74	2	2	Nil	1	1
Jhingura	54.62	56.21	2	2	Nil	2	2
Mirzapur	62.56	64.91	2	2	Nil	2	2
Vindhyachal	70.38	72.09	2	2	1	1	1

Vindhyachal	70.38	72.09	2	2	1	1	1
Birohi	74.97	76.38	2	2	Nil	2	2
Gaipura	82.38	84.56	2	2	Nil	5	4
Jigna	89.38	91.09	2	2	Nil	6	6
MandaRoad	97.5	99.38	2	2	Nil	6	6
Unchdih	105.74	107.15	1	1	1	6	5
MejaRoad	114.03	115.91	2	2	Nil	9	9
Bheerpur	125.56	127.03	2	2	Nil	7	7
Karchana	134.5	136.03	2	2	Nil	6	7
Chheoki	143.21	144.71	2	1	2	1	1
Naini	145.15	147.26	1	2	Nil	4	4
Allahabad	151.97	155.38	2	1	13	-	-

Table : Infrastructural Details

4. Blocks and station signal location were calculated by their Overhead Equipment (OHE) number.
5. Every Block's maximum speed is set as 160 km/hr except the one which is adjacent to MGS & ALD stations (30 km/hr).
6. Permissible Speeds at Allahabad and Mughalsarai have been taken as: - 30 kmph for mainline; 15 kmph for all other loop lines.
7. Permissible Speeds at Allahabad and Mughalsarai have been taken as: - 100 kmph for mainline; 15 kmph for all other loop lines.
8. Passenger train's scheduled timetable were used as in [8]. Only Friday running trains were considered, since maximum no. of trains traverse on Friday.
9. Totally around 108 passenger trains (56 up & 52 down) were considered.
10. Following type of trains (Table 2) has been considered:

S.No	Train Type	Acceler -ation (m/s^2)	Deceler -ation (m/s^2)	Maximum Speed (km/hr)
1	Semi High speed trains (Gatimaan express type)	0.1	0.1	160
2	Rajdhani and Duronto type trains			130
3	Medium speed Passenger trains			110
4	Low speed passenger trains			100
5	Medium axle load freight trains			75
6	High axle load freight trains			60

Table : Train Characteristics

11. Gradients were not considered.
12. Maintenance interval for block were not considered.
13. Permanent speed restrictions were considered from [8].

Case 1 (Actual section without modification):

This case is to simulate the actual operations of the section. So for passenger trains, train type of 2,3 and 4 of Table 2 were considered. For freight train, train type 6 has been used. Initially scheduled passenger trains are simulated asynchronously in the simulator. The following results were obtained:

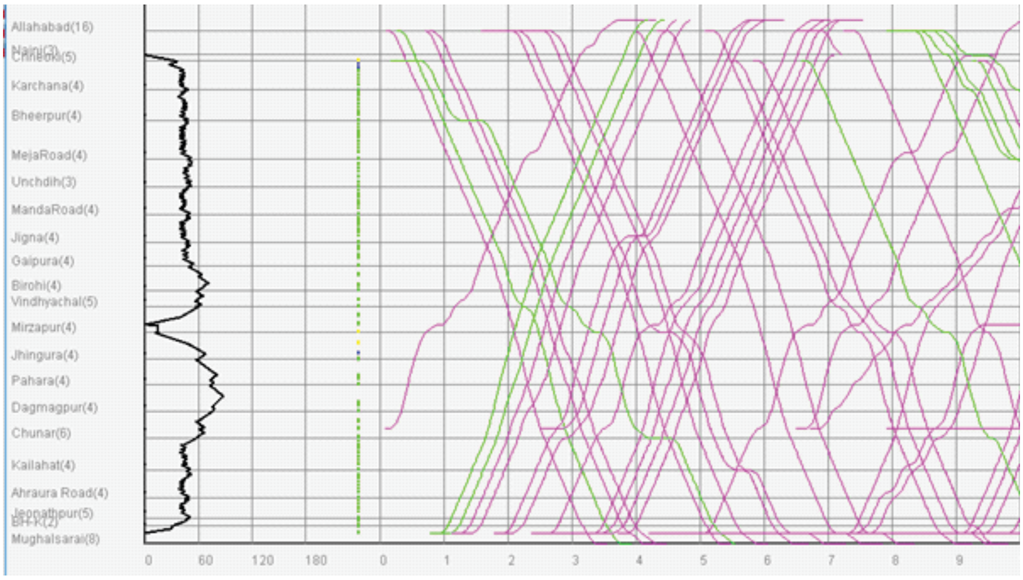

Fig 1 : Snapshot of scheduled passenger trains of test case -1

After scheduling passenger trains, capacity is evaluated. Two definitions of capacity has been defined:

1. **Raw Capacity:** No. of freight trains of uniform characteristics which can run safely in the section in 24 hr time window. But this measure does not include traffic of scheduled passenger trains.

   For this trains of type 5 (of Table 2) is considered. Raw capacity (similar to Scott's formula) is found out to be:

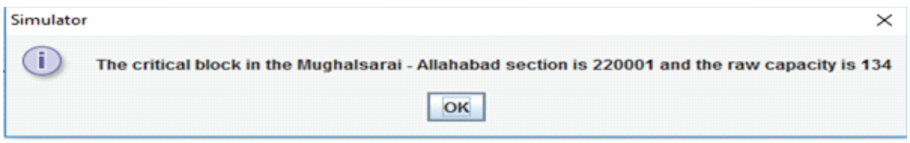

Fig 2 - Raw Capacity of Test Case-1

2. **Mixed Capacity:** This definition of Capacity also considers the scheduled passenger traffic. Mixed capacity estimates the number of freight trains (in a 24 hour period) that can be run on a section which handles passgenger traffic achieving a reasonable traversal time of freight trains (of twice the free running time) without affecting passenger schedules. This is a better measure than raw capacity.

The mixed capacity computation for case 1 of ALD-MGS section is as below:

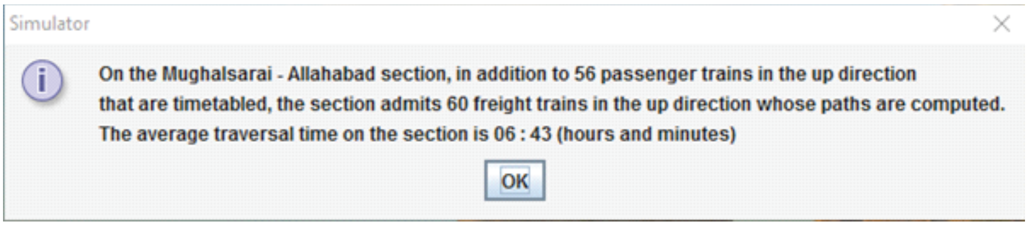

Fig 3 : Mixed Capacity of Test Case 1

Case 2 (Rajdhani type trains (130 km/hr) were replaced by semi highspeed trains (160 km/hr)):

With the same data as that of Test case 1, except that the Rajdhani type trains (Type 2 of Table 2) were replaced by semi high speed trains (Type 1 of Table 2). Therefore, their speed has been increased by increasing from 130 km/hr to 160 km/hr. This modification will impact the mixed capacity as below:

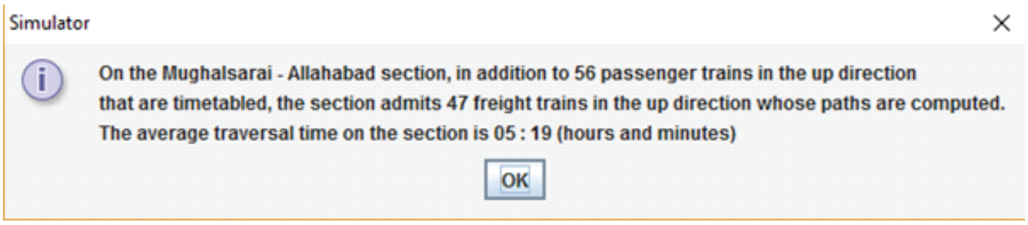

Fig 4 : Mixed Capacity of Test Case 2

Case 3 (Medium axle load freight trains to be replaced high axle load freight trains):

While estimating mixed capacity of the section, freight trains of type 5 (Table 2) are replaced by freight trains of type 6 (Table 2). With this modification, raw capacity turns out to be:

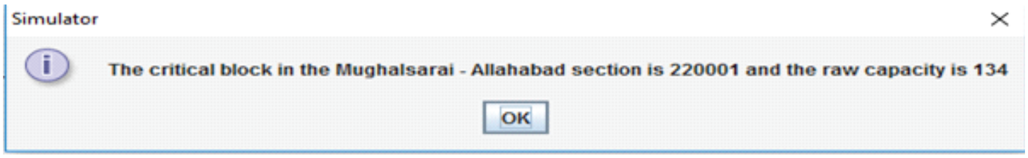

Fig 5 : Raw Capacity of test case 3

Mixed capacity for case 3 will be:

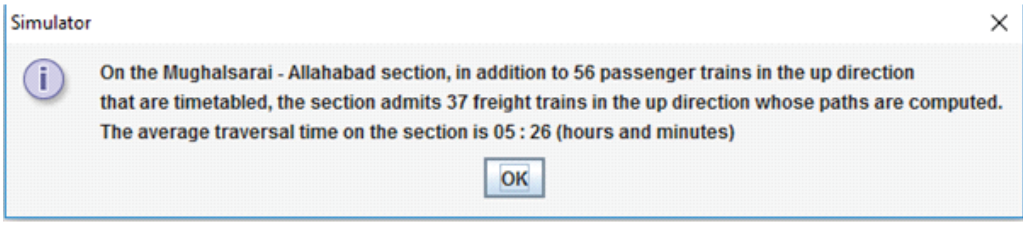

Fig 6 : Mixed capacity of Test case 3

Case 4 (Both modification of Case 2 and Case 3):

In this test case:

1. Train type 2 (of Table 2) has been replaced by train type 1 (of Table 2).
2. Train type 5 (of Table 2) has been replaced by train type 6 (of Table 2).

In this case, speed differentials of trains in the section has been increased to 100 km/hr (160-60). With this modification will impact the mixed capacity as below:

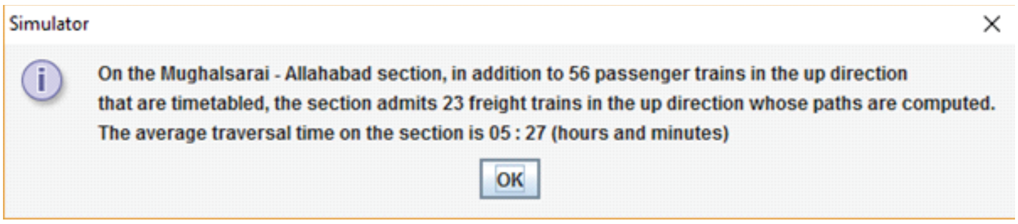

Fig 7 : Mixed Capacity of Test Case 4

Results and inferences:

The results of the 4 test cases are tabulated in the table below:

Case No.	Case Description	Raw Capacity	Mixed Capacity
1	MGS-ALD Section with normal condition	134	60
2	MGS-ALD Section with semi high speed trains		47
3	MGS-ALD Section with high axle load freight trains		37
4	MGS-ALD Section with semi high speed trains & high axle load freight trains		23

Although introduction of high axle load freight trains may affect the raw capacity, in the 4 test cases, the speed of these trains in the critical block (220001) is below 60km/hr (speed of high axle load freight train), resulting in a constant raw capacity for all test cases.

In the case of mixed capacity, with introduction of semi high speed trains and high axle load trains value of capacity decreases. With replacement of Rajdhani type trains (Max. speed = 130 km/hr) by semi high speed trains (Max. speed = 160 km/hr), loss of capacity is observed due to increase in number of overtaking by higher priority passenger trains. With introduction of high axle load freight trains, maximum speed of freight trains decreases which leads to decrease in capacity.

Extensions:

It has shown that there is inevitably some decrease in capacity of the section with introduction of semi high speed passenger trains and high axle freight trains. More analysis is needed to see how different operations strategies can be employed, so the capacity can be increased without implementing a dedicated line. The operations strategies will involve low to medium investment such as changing signalling regime, creating fixed interval timetable for different streams of trains and other techniques.

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