A Graphical Tool for Planning and Real-Time Operation of Freight Trains

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Abstract. Indian railways are one of the four largest railway systems globally and transport more than a billion tonnes of freight each year. However, several of the routes share the tracks with passenger trains. Passenger and freight trains operate at distinct speeds, and a slow-running freight train is often stopped to pass a faster passenger train. This leads to a reduction in the average speed of the freight train. In this context, a pre-processing tool to assist in the operational planning of freight trains using a trajectory-based graphical approach was developed to insert feasible rail movements in real time. The proposed method and its effectiveness are demonstrated using real-world data, which shows that the proposed method can greatly reduce delays and provide significant benefits for real-time applications.

Keywords: Graphical method, Freight, Railways, Trajectory.

1 Introduction

Railways are a popular mode of transport in India. It is safe, economical, reliable, and efficient for the passengers. The Railway authority provides a large capacity for the movement of people and goods and requires relatively low maintenance. It operates at higher speeds when compared to road transport due to the dedicated right-of-way. Also, its capacity can be easily increased by adding more coaches. With India's growing population and road traffic, the need for better utilisation of railways arises [1].

In the freight segment, Indian Railways (IR) transports various goods for different sectors across the length and breadth of India. IR has started new initiatives in freight segments to upgrade existing goods sheds, attract private capital to build multi-commodity multi-modal logistics terminals, change container sizes, operate timetabled freight trains, and fine-tune the freight pricing/product mix [2].

The mixed running on IR creates problems in real-time operation and management of traffic. Passenger and freight trains operate at distinct speeds, and a slow-running freight train has to be stopped frequently to pass a faster passenger train. This leads to a reduction in the average speed of the freight train. So, it is essential to develop an operational planning tool for freight trains that can be used to manoeuvre them in real-time and also insert new trains into an existing train timetable.

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2 Literature Review

For real-time operation, train operators must schedule and plan feasible freight train trips in the existing railway network, which can be highly complex and vastly time-consuming due to many constraints and operational factors. Lack of decision support tools for planning new freight trips and real-time fine-tuning of their manoeuvres leads to operational risks in planning. This section briefly reviews the literature published on the operational planning of rail networks.

Kraay et al. [3] considered a scheduling and pacing problem that minimises fuel consumption and travel delays. Branch-and-bound and a rounding heuristic were proposed to solve the scheduling and pacing problem. Carey [4] extended the previous model by embedding a route selection mechanism in the mathematical model, and further expanded the model to consider two-way tracks. Carey and Lockwood [5] described a mathematical model to dispatch trains on a single one-way line with sidings and stations. A heuristic was proposed to solve the problem by dispatching trains one after the other. Higgins et al. [6] formulated a non-linear mixed-integer program to solve the scheduling problem on a long single-track line. The objective was to minimise both fuel consumption and overall tardiness. Caprara et al. [7] presented a study on passenger railway optimisation, which focused more on the European environment where passenger trains dominate. Lawley and Richard [8] presented a time-space network flow model for scheduling bulk deliveries and maximising demand satisfaction while minimising waiting times for loading. Mu and Dessouky [9] developed an optimisation-based heuristic for scheduling freight trains that could minimise delay but only for moderately sized networks. Mu and Dessouky [10] extended their work by proposing a switch table dispatching policy for a double-track segment. This methodology enabled the faster train to pass a slower train by using the track travelled by train in the opposite direction, provided it is empty. Jiang et al. [11] tried scheduling passenger trains in a highly congested network by increasing the dwelling time of trains at some stations and allowing them to skip some stops by proposing a heuristic algorithm.

Although these approaches are helpful to find optimal and sub-optimal solutions for complex optimisation problems in rail network planning and scheduling, this requires the decision-makers to have a good grasp of operations research-based mathematical modelling and optimisation, which restricts their use in real situations. These methods suffer from two major drawbacks: (1) Mixed-integer problems with a constraint for every train will take unreasonable time to solve. (2) Whenever some trains cannot keep up with the schedule, the entire problem must be rescheduled for the current network state. Furthermore, real-life cases can involve problem-specific and system-related constraints, which may be challenging to model in a closed form, making it infeasible to solve. To overcome these issues, a trajectory-based graphical approach is proposed, which can act as a pre-processing tool to be used by decision-makers with little background in rigorous mathematical and optimisation background for simple routes and to address local issues and fine-tune train manoeuvres in real-time.

3 Algorithm

The proposed method uses train trajectories to identify the potential trajectory of the train of interest. The existing schedule of the trains, their stop stations, start and stop time at the stations, and the distance between stations is used to create virtual trajectories of the trains along the route. The speed of a train has been assumed to be a constant value between two stations due to a lack of information on variations in the speed of trains as they traverse between two stations. The length of a train is used to ensure a safe gap between the trains. The operational restrictions such as speed limits planned maintenance of tracks in the network, and the number of platforms at the station will be considered for accurate manoeuvring of the desired train. For operational planning of new trains along the route, the trajectories of the existing trains are plotted based on the schedule. For real-time fine-tuning of the trains, the real-time positions of the trains are plotted along with the background trajectories based on the schedule. The application of this method is demonstrated in the next section using a real-world case study.

4 Real-world Case Study

4.1 Details of the Rail Corridor under Study

The origin and destination stations taken for the study are MGR Chennai Central (MAS) and Howrah (HWH), respectively. The route length is approximately 1661 km. States that lie along the route are Tamil Nadu, Andhra Pradesh, Orissa, and West Bengal. It faces significant geographical challenges as it traverses through the eastern coastal plains and major rivers such as Mahanadi, Godavari, and Krishna. Major stations on this route are Kharagpur, Balasore, Cuttack, Bhubaneswar, Brahmapur, Vizianagram, Vishakhapatnam, Rajahmundry, Eluru, Vijayawada, Nellore, and Gudur, as shown in Fig. 1.

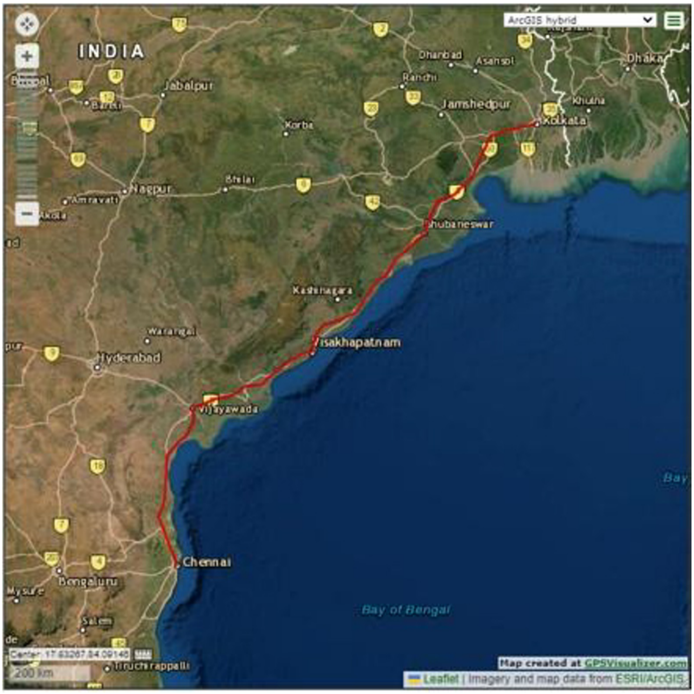

Fig. 1. Chennai-Howrah route map

A Python script is created that generates the route array between the origin and destination station and the milepost distances as output. As the second stage of output, it also extracts the trajectories of all trains that traverse the rail route between MAS and HWH. As per the script, the trajectories obtained are for seven days of the week in which daily trains are superimposed on the trains which run only on specific days of the week. The plots for the day of Thursday and Saturday were selected for finding the number of feasible routes for a freight train, one of which have been shown here in Fig. 2.

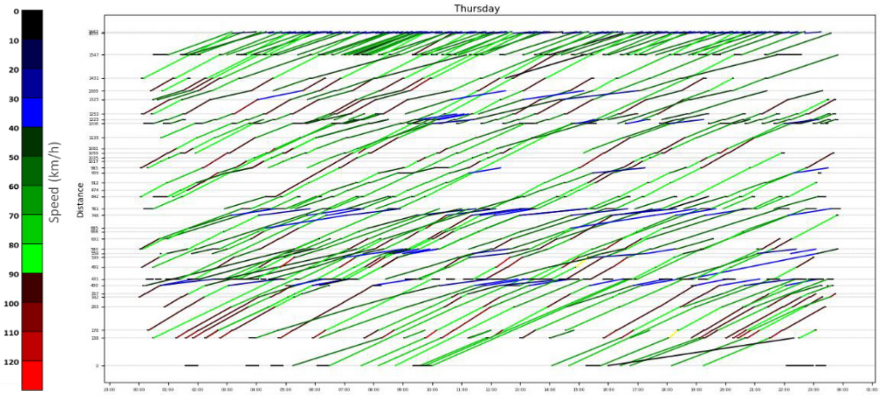

Fig. 2. Trajectories of trains for Thursday on the MAS-HWH rail route

4.2 Steps to find Feasible Solutions

A maximum speed of 120 km/h was assumed for the freight train. It was assumed that a freight train could cross a passenger train only at the stations where the passenger train stops. In between two stations, a freight train needs to follow the leading rain until it gets an opportunity to pass it at a crossing or station while maintaining a safe distance from the leader. At certain junctions where two trains cross each other, it is suggested that by providing a slight offset to the schedule of one of the trains, the freight train will get the chance to pass at a higher speed without causing much delay. The constraints on travel speed, the following behaviour, overtaking behaviour, and waiting time for determining feasible solutions are as follows:

$$v \le v_{max} \tag{1}$$

$$x_{i+1} \le x_i - \Delta \ \forall \ x_{s_j} \le x_{i+1} \le x_{s_{j+1}} \tag{2}$$

$$x_{i} = x_{i+1} \ \forall \ \mathrm{s} \in \{route\ stn\} \tag{3}$$

$$w \ge w_{min} \ \forall \ t_{stop} \ge t_{max} \tag{4}$$

In the above constraints, $v_{\max}$ is the maximum permissible speed, x_i is the position of the leader train, $x_{(i+1)}$ is the position of the follower train, s indicates the station, Δ is the minimum headway, w is the waiting time, w_{min} is the minimum waiting time, t_{stop} is the time since last stop, and t_{max} is the maximum permitted time since last stop. Using the above constraints, the process of new trajectory identification is shown in Fig. 3.

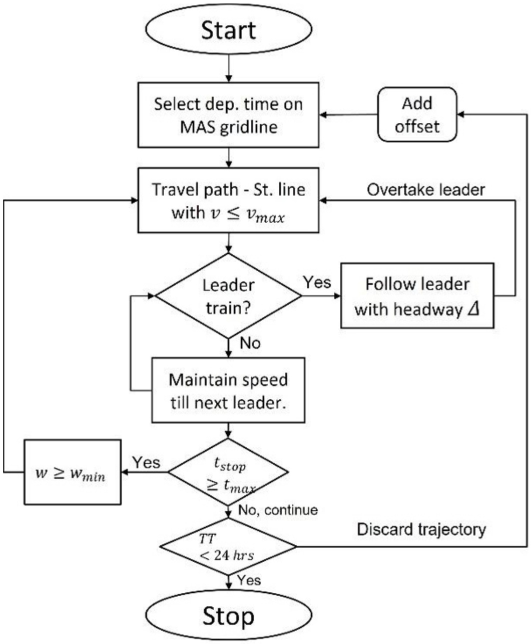

Fig. 3. Flowchart showing steps to find feasible solutions.

4.3 Results

After plotting the trajectories, total travel times were calculated for the trains by finding their projection on the X-axis between the origin station and the destination station. The waiting times were excluded from the total travel time to calculate the running speed of the train. The mean and standard deviation of the speeds were found. The results are tabulated in Table 1.

Table 1. Feasible paths of freight trains

Parameter of the Freight train	Train 1	Train 2	Train 3	Train 4
Total travel time(hrs)	23:20	22:40	23:40	23:10
Total running time(hrs)	22:00	21:30	22:35	21:40
Total stopping time(hrs)	01:20	01:10	01:05	01:30
Number of stops	3	2	3	4
Mean Section Speed (km/h)	81.12	76.56	79.61	78.07
Standard Deviation of speed (km/h)	24.38	22.75	22.95	19.28

From the results in Table 1, it is evident that the standard deviation of freight train 4 is lower compared to other possible paths (19.28 kmph), which signifies that this train does not accelerate and decelerate much during its journey time. This leads to lower operating costs compared to a trajectory with more deviation in speed. Freight train 1 runs at the highest mean speed of 81.12 kmph, so it can be preferred for cases where time-sensitive cargo needs to be transported.

If the freight train's speed is kept non-uniform with a significant standard deviation, then the opportunity of going faster at stations where other passenger trains stop and the chance of going slower to allow a passenger train to pass to reduce its delay is used efficiently. We can conclude that there exists a trade-off between operating cost and delay in the journey when it comes to having a high deviation in speed. A good balance of the trade-off between operating costs and delays can bring substantial profit for the railways.

4.4 Real-Time Fine-Tuning

The same tool can be used for real-time fine-tuning of the trains based on real-time deviations from the schedule. The trains that are delayed can be brought back on schedule by identifying the potential sections where the speed can be increased by not impacting other trains' schedules. At any given point, the current trajectories of all deviant trains can be used against the trajectories of the other trains (running on schedule), to identify the opportunities to move the desired train back to the schedule. The same algorithm used in figure 4 can be used with only a small variation, where the current position in time and space of the deviant train is used as the origin, and the rest of the trajectory can be predicted. The boundary conditions are also changed, and the iteration stops when the train reaches back to its original scheduled trajectory before it reaches its destination. Thus, the proposed method has applications for both planning new freight trains as well as fine-tuning the trajectories in real time.

5 Discussions

The paper proposed a simple graphical method for planning and real-time operation of trains. The method is simple, computationally cheaper, and can be easily implemented by non-technical staff. Unlike the traditional methods that require heaving computing infrastructure for optimization, this method can be easily implemented on desktop computers with minimal computational infrastructure.

However, one of the critical components of this methodology is that it is highly sensitive to changes in the train schedule. Therefore, any changes have to be regularly updated to ensure accurate planning of trajectories. Also, the method is flexible to incorporate change due to the planned maintenance of tracks. This can be easily incorporated by changing the capacities of the sections to reduce the number of tracks available. Current efforts continue in the direction of considering trains that travel in the opposite direction and use a single track for crossing the opposing trains.

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