A heuristic based approach for freight path generation in a mixed traffic rail network

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***Abstract*—Freight trains have a relatively lower priority on mixed traffic rail networks and are scheduled during the time windows left over by passenger trains. Hence, generating good quality freight paths on a shared rail network is challenging. This paper reports a heuristic based approach for freight path generation on the six principal routes known as Golden Quadrilateral + Diagonals (GQD) of Indian Railways. The main tool used for freight path generation is the mixed-traffic railway simulator built at IIT Bombay. The simulator undertakes detailed Java simulation for train-by-train velocity profile generation and provides the user with traversal details for multiple trains over some time period. The potential crew change points on each route are identified and a set of freight paths are generated between each pair of such points along with four end-to-end paths. The proposed approach is found to perform well in terms of the number of freight paths generated and the average traversal speed. A comparison of the generated paths with existing paths on a congested section reflects the same. The main advantage of the proposed simulator-based heuristic is its scalability to a large network which consists of around 9850 route kilometers and 1527 passenger stations.**

Keywords—freight path generation, heuristic method, mixed-traffic railway simulator, zero base timetabling, Indian Railways

I. Introduction

Huge investment for rail infrastructure and increased transportation demand force railway operators to run both passenger and freight services on the same rail network using shared resources. In such a mixed traffic rail network, freight trains often have lower priority than passenger trains, and are scheduled during the time slots left over by passenger trains. This sharing of the infrastructure by both services often leads to congestion and unavailability of resources, especially on busy routes. Indian Railway is a good example of this scenario where freight services are scheduled after passenger services, using a shared set of resources. This work reports a heuristic based approach adopted for generating good quality freight paths in the six routes within the Golden Quadrilateral + Diagonals (GQD) of the Indian Railways undertaken as part of the Zero Base Timetabling (ZBTT) project at IIT Bombay, in collaboration with Indian Railways. The six GQD routes are the principal routes of Indian Railways that connect the metro cities of New Delhi, Mumbai, Chennai and Kolkata.

Indian Railways is one of the largest railway networks in the world with a total of 1,26,366 track kilometers and operates 13,169 passenger trains and 8,479 freight trains on a daily basis [1]. Both the passenger and freight trains share the same track resources on most of its routes (apart from certain dedicated freight corridors). The revenue from freight operations is more than double that of passenger services (earnings from passenger and freight services for the financial year 2019-20 stands at INR 510.67 billion and INR 1114.72 billion respectively). The higher revenue obtained from freight operations helps the organization in running passenger train services at a subsidized rate. This indicates the importance of freight operations and it is necessary to make it more efficient to support the whole railway system. Primary step in this direction is to generate more good quality freight paths (paths with an average speed of 45 kmph and above) on high demand routes. The fact that the current average speed of freight trains in the Indian Railways network is around 25 kmph [1] points to the urgency of the matter.

The ZBTT project between Railway-Board, Centre for Railway Information Systems (CRIS), Zonal Railways and IIT Bombay undertook the generation of passenger train timetables on the GQD routes of Indian Railways from scratch (de-novo), with an objective of achieving faster run times, rationalized halt patterns, compaction of schedules, and wider and uninterrupted freight corridors [2]. Commonly, freight services are scheduled in an ad hoc manner rather than based on fixed timetables. However, we attempt to generate a bunch of scheduled freight paths on the GQD routes following a heuristic procedure using the mixed-traffic railway simulator built in-house. Through this systematic process, the average traversal speeds of freight trains are expected to be increased from the existing level. The superiority of the proposed freight paths is ascertained by comparing them with the existing freight paths in one of the congested sections of Indian Railways. Also, we propose a methodology that has been scaled up to a large network and is replicable on a practical level.

The remainder of the paper is organized as follows: Section 2 provides a review of literature on freight train scheduling. Section 3 explains the current problem in more detail and Section 4 describes the proposed heuristic based methodology for freight path generation. Section 5 presents the results in brief and provides a comparative analysis of the proposed methodology in terms of the quality of freight paths generated and its scalability. Section 6 concludes the work with scope for further research.

II. Literature review

Freight train scheduling in a mixed traffic rail network has been addressed in the literature. In [3], the authors consider joint routing and scheduling of the passenger and freight trains with an objective of minimizing the sum of travel times for freight trains and total tardiness for passenger trains. The work reported in [4] calculates feasible routes for

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each freight train in a congested railway network with mixed traffic. The objective here is to minimize the sum of congestion costs, running times, and length. Further, [5] propose a heuristic for routing and scheduling freight trains in a passenger rail network. The common aspect in these works is that the freight train operations are planned without disturbing existing passenger train paths. On the other hand, [6] propose a model to schedule passenger and freight trains simultaneously on an inter-city rail network by considering the carbon emission related factors. However, a prioritization is done here between passenger and freight trains on the network. Freight train scheduling has also been addressed without considering the complexities of interaction between passenger and freight services. The work in [7] considers freight train scheduling in a single/double track freight train railway system as that of Canadian Pacific Railway.

Another aspect related to freight train scheduling is the planning of crew required to operate the services. Railway crew planning is a vast research area in itself. A review of the existing models, methods, and applications in the area of railway crew scheduling is provided in [8]. In [9], the authors propose an integer programming formulation and analysis by integrating line planning, timetabling and vehicle scheduling to realize a robust public transport supply. Also, [10] proposes an eigenmodel and iterative algorithms for solving an integrated planning problem. The work in [11] focus on minimizing the cost of assigning crews by considering the various rules and regulations for crew assignment including the rest time required between tasks and the limit on the number of working hours. Most works on railway crew scheduling are application-oriented and include country-wise specifications [8]. In this work, the requirement of crew change is incorporated into the freight path generation stage by planning the freight paths between potential stations that can act as crew change points.

A scan of literature reveals that integer programming based methods, column generation and different types of heuristics and meta-heuristics have been employed for freight train scheduling as well as railway crew scheduling [8,3]. The main disadvantage of these methods is scalability and when a network wide scheduling is required for a more comprehensive planning, they are found inadequate. The largest instance reported in [3] consists of 266 track segments and 88 junctions (331 nodes and 319 arcs) while in practice the planning is to be expanded to several thousands of track segments and junctions. We try to address this aspect of scalability and propose a heuristic methodology using a network wide simulator to generate good quality freight paths in a mixed traffic rail network over multiple routes.

III. Problem Description

In this work, we focus on the six GQD routes of Indian Railways that connect the metro cities of New Delhi, Mumbai, Chennai and Kolkata. These principal routes carry about 58% of freight traffic and 52% of passenger traffic and account for around 15% of the network, approximately 9100 route kilometers [12]. A schematic diagram of these six routes can be seen in Fig. 1. We number these routes as follows:

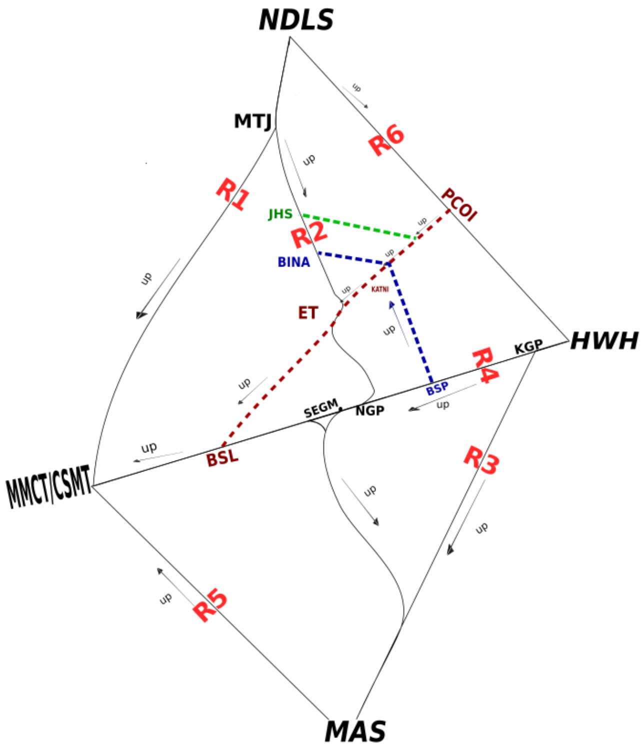

Fig. 1. GQD routes of Indian Railways under consideration

(Railway station codes: BSL - Bhusaval Junction; SEGM- Sevagram Junction; NGP - Nagpur Junction; BSP - Bilaspur Junction; KGP - Kharagpur Junction; ET - Itarsi Junction; BINA - Bina Junction; JHS - Jhansi Junction; MTJ - Mathura Junction; PCOI - Prayagraj Chheoki Junction)

Route 1 (R1): New Delhi (NDLS) - Mumbai (MMCT)

Route 2 (R2): New Delhi (NDLS) - Chennai (MAS)

Route 3 (R3): Kolkata (HWH) - Chennai (MAS)

Route 4 (R4): Kolkata (HWH) - Mumbai (CSMT)

Route 5 (R5): Chennai (MAS) - Mumbai (CSMT)

Route 6 (R6): New Delhi (NDLS) - Kolkata (HWH)

Freight train movement on a given section of a route has an origin and a destination on the route. Generally, there are no scheduled halts except for (a) Precedence - overtaking by passenger trains, if needed, due to a higher priority, and (b) Crew change – when the crew operating the train are close to, or have finished their duty hours. In this work, precedence is taken care using the passenger train timetables and simulation of freight paths. In long-haul services, crew change is planned at intermediate stations where adequate infrastructure (running lines for trains and running rooms for staff) are available.

We generate a bunch of sectional freight paths (16/12 paths based on the traffic density in the section) between each pair of potential crew change points which are around 250 kilometers apart. Further, four end-to-end paths are also generated on each of the six GQD routes under consideration. For the end-to-end paths, a larger distance of around 400 kilometers is left between the crew change points in anticipation of high-speed uninterrupted services. Thus, the proposed heuristic encompasses an integrated procedure for freight path generation with crew change considerations.

For generating freight paths, freight trains with three different velocity profiles are considered. They include trains with a maximum speed of 60 kmph (loaded, covered wagon type), 75 kmph (empty, covered wagon type), and 100 kmph (container type). The mix of trains on each route is determined based on the demand. However, the commonly used mix is as follows: 50% of 60 kmph trains, 30% of 75 kmph trains, and 20% of 100 kmph trains.

IV. Methodology

We propose a heuristic based approach for generating good quality sectional and end-to-end freight paths in all the six GQD routes under consideration. The steps involved are as follows:

- Generate Bare-Run-Times (BRTs) for freight trains between various stations in a route using the simulator - This provides an estimate of the minimum traversal time taken by a freight train to cover a route while respecting the Permanent Speed Restrictions (PSRs) imposed on various blocks, and also the acceleration/deceleration characteristics of the train. However, passenger trains are not simulated during this exercise and the corresponding congestion in the network is not captured.
- Incorporate the scheduled maintenance blocks in all block sections (usually 3 hours long)
- Identify freight corridors (duration greater than 30 minutes) in each route by extracting free time slots between sections (scheduled maintenance blocks and time windows representing passenger train paths are not breached)
- Fire freight trains in the identified freight corridors; number of trains to be fired is decided based on the length of the corridor with a safety headway between the trains - at least 10 minute headway is maintained between the trains
- On a section, the desired mix of trains with different speed profiles (spread over all corridors) is maintained
- Fine tune the freight paths by changing the firing order of trains, gap between firing, and the proportion of trains in each corridor

We use the mixed-traffic railway simulator built at IIT Bombay [12] for freight path generation. The simulator undertakes detailed Java simulation for train by train velocity profile generation and provides the user with traversal details for multiple trains over some time period. In addition, pre- and post-processing codes are also incorporated for accepting inputs, report generation and output analysis. The simulator uses a travel-advance, greedy-heuristic with asynchronous train movement and high priority trains are scheduled from first to last stations followed by low priority trains. The occupancy information of high priority trains are respected and the simulator generates a feasible, conflict-free timetable. The simulator incorporates the following sectional infrastructure and train characteristics into it.

Sectional infrastructure:

- All stations on a route
- Block sections between stations
- Loop lines at stations
- Maximum permissible speed and permanent speed restrictions on all track sections
- Safety and signaling arrangements (for headway between trains)

Train characteristics:

- Maximum speed of train
- Acceleration/deceleration characteristics
- Origin-destination details of train
- Priority of various trains (for ensuring precedence)

The simulator is scaled up to operate on a network level and the freight paths can be generated on all the six routes in a single run. This is a significant advantage offered by the proposed simulator based heuristic methodology.

V. Results

The overall statistics of the freight paths generated on each of the six GQD routes is provided in Table I. The objective of the exercise is to generate an average of 16 good quality sectional freight paths and four end-to-end paths in each of the six routes. The target traversal speed is 45 kmph. As can be seen in Table I, this target is comfortably achieved for all the six routes. Further, the simulator also provides the option of carrying out a what-if analysis for other probable/hypothetical scenarios. In this direction, we tried generating freight paths by removing low priority stopping passenger trains from the network and with improved acceleration/deceleration values. These results are provided in Table II. It can be found that there is a clear improvement in the number of sectional freight paths generated and the speed of overall paths. This indicates that there can be a trade-off made between low priority passenger trains and high demand freight trains, when required.

Further, a comparison is carried out between the freight paths generated by the proposed heuristic and the paths charted by Central Railway (CR) on one of the congested sections (Igatpuri (IGP) - Bhusaval (BSL)) on Route 4 of GQD. This gives an indication of the improvement that has-

TABLE I. SUMMARY OF FREIGHT PATH STATISTICS

Route	**Freight path characteristics**			
	Average number of sectional paths generated	***Average speed of sectional paths (kmph)***	***Number of end-to-end paths generated***	***Average speed of end-to-end paths (kmph)***
R1	18.43	51.03	4	49.45
R2	17.25	49.03	4	58.07
R3	17.94	48.03	4	50.59
R4	17.54	47.89	4	48.63
R5	20.31	45.18	4	47.40
R6	20.13	50.48	4	49.76

TABLE II. SUMMARY OF FREIGHT PATH STATISTICS WITHOUT STOPPING PASSENGER TRAINS

Route	Freight path characteristics			
	Average number of sectional paths generated	*Average speed of sectional paths (kmph)*	*Number of end-to-end paths generated*	*Average speed of end-to-end paths (kmph)*
R1	20.50	54.87	4	57.26
R2	20	48.68	4	59.28
R3	21.31	49.84	4	54.1
R4	19.56	50.25	4	54.95
R5	19.25	48.04	4	48.55
R6	20.56	53.17	4	53.45

TABLE III. COMPARISON OF THE PROPOSED AND EXISTING FREIGHT PATHS

Section	Paths charted by CR	Paths generated by IITB simulator
IGP-NGN	4 paths > 45 kmph Avg. speed of best ten paths - 40.36 kmph	8 paths > 45 kmph; average speed - 62 kmph
NGN-IGP	6 paths > 45 kmph Avg. speed of best ten paths - 49.63 kmph	18 paths > 45 kmph; average traversal speed - 55.69 kmph
NGN-BSL	8 paths > 45 kmph Avg. speed of best ten paths - 53.55 kmph	8 paths > 25 kmph; average traversal speed - 41.72 kmph
BSL-NGN	4 paths > 45 kmph Avg. speed of best ten paths - 47.02 kmph	9 paths > 45 kmph; average traversal speed - 61.40 kmph

been achieved using the proposed heuristic based methodology. Table III gives the comparison of freight paths in the section IGP-BSL where Nandgaon (NGN) is the intermediate crew change point. It can be found that paths generated by the proposed heuristic outperform paths charted by CR in terms of number of paths and average traversal speed in three out of the four crew-change sections.

VI. CONCLUSION

Freight train scheduling in a mixed traffic rail network is challenging since higher priority for passenger trains result in unavailability of shared resources for freight services. This work proposes a systematic heuristic based approach for generating good quality freight paths on the six GQD routes of Indian Railway without disturbing the timetabled passenger paths. The main tool used for train path generation is the mixed-traffic railway simulator built at IIT Bombay. The proposed methodology is found to perform well in terms of the number and traversal speed of freight paths generated and scalability to a large network.

The proposed approach could generate a total of 48 end-to-end freight paths and 1923 sectional paths with average traversal speeds of 50.65 kmph and 48.23 kmph respectively. The benchmark target was 48 end-to-end and 1664 sectional paths with average speeds of 50 kmph and 45 kmph respectively. Further, the what-if analysis conducted to study the impact of generating freight paths ahead of low priority stopping passenger trains and with improved acceleration/deceleration values showed promising results. An additional 94 sectional paths were generated and the average traversal speed improved to 50.63 kmph. For end-to-end paths, the average speed improved to 54.60 kmph.

A comparison was done between the existing freight paths and those generated by the proposed methodology on a congested section (IGP-BSL) in Central Railway. The results show that the proposed methodology could generate a greater number of better quality paths in three out of four crew change sections considered. Further, one of the main advantages of the proposed simulator based heuristic approach is its scalability to a large network. We consider the largest network that has been solved using commonly employed integer programming based methods and other heuristics reported in literature [3]. The network comprises a 59 miles long rail track (double and triple track segments) from Los Angeles to Riverside, California with eight passenger stations. 84 freight trains and 89 passenger trains are scheduled on this network. The methodology we propose is implemented on a much larger scale where the network comprises around 9850 route kilometers with 1527 passenger stations. Around 8000 passenger trains are scheduled and 1878 freight paths are generated on this network.

The proposed simulator based heuristic methodology relies on trial and error based fine tuning of paths and does not have an inherent optimization routine as part of it. This can be one area of future research wherein the best mix and order of firing freight trains in a freight corridor can be ascertained using an optimization approach.

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