A simulation-based tool for crew planning in rail freight services

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Abstract. This paper addresses railway crew planning associated with a set of scheduled freight services. We consider the Igatpuri (IGP) - Bhusaval (BSL) section of Indian Railways as a test case. A discrete event simulation-based tool is developed to analyze the crew allocation procedure followed in practice. The proposed simulation model incorporates rules and guidelines related to working and rest times of crew. Simulation experiments are carried out to determine various performance measures like crew utilization, number of paths delayed due to crew unavailability, average number of crew resting/waiting at an outstation, and number of deadheadings. Based on the performance measures, a suitable crew deployment pattern is determined for operating the given freight paths. We find that an evened-out crew deployment pattern can reduce the overall crew requirement.

Keywords: Railway crew planning, Discrete event simulation, Indian Railways, Freight planning, Decision support tool.

1 Introduction

Crew planning is an important task in railway operations and crew expenses constitute around 30 percent of total railway operational expenses (Suyabatmaz and Sahin, 2015). Improper management of crew results in service delays and affects the overall system effectiveness. Any train service (passenger/freight) can only be realized with the proper allocation of crew to operate that service. While passenger train services are based on a predetermined timetable, freight services are a combination of ad hoc and scheduled services. This work develops a simulation based tool for crew planning required to operate a set of scheduled freight services. The capabilities of the simulation tool is illustrated using a set of scheduled freight paths in the Igatpuri (IGP) - Bhusaval (BSL) section of Central Railway (a part of Indian Railways).

A typical crew set for operating a freight train consists of a Loco Pilot, Assistant Loco Pilot and Guard. The maximum time that a crew can operate a train is limited and since freight services can be scheduled over long distances, it is inevitable to have crew changes in between the source and destination. Each crew will have a headquarter (HQ) and when they move away from their HQ, they are to be provided adequate resting facilities at the outstation. There are numerous rules and guidelines associated with railway crew allocation and this, along with the variation in freight path characteristics, make the planning process complex.

The present work uses discrete event simulation to analyze the crew planning procedure in the IGP-BSL section for a given set of freight paths. The simulation model imitates the crew allocation procedure followed in practice by incorporating the work and rest related rules and guidelines. The crew configuration (number of crew deployed at various stations where crew change happens) is varied and the simulation model is run to calculate performance measures like crew utilization, delay in freight paths due to crew unavailability, number of deadheadings, and average number of crew at outstation. Based on these performance measures, an appropriate crew configuration can be identified.

The remainder of the paper is organized as follows: Section 2 provides a review of literature on railway crew planning. Section 3 explains the current problem in more detail and Section 4 describes the proposed simulation-based methodology for railway crew planning. Section 5 presents the results followed by a discussion on the same. A comparison between the current crew configuration and the proposed one is also included. Section 6 concludes the work with scope for further research.

2 Literature review

Railway crew planning has been studied widely over the years. Heil et al. (2020) provide a review of existing models, methods, and applications in the area of railway crew scheduling. The article notes that research in railway crew scheduling gathered momentum in the 1990s motivated by potential cost savings from the application of Operations Research techniques.

The recent work by Hanczar and Zandi (2021) presents a mathematical formulation for railway crew scheduling considering the rules and regulations applicable in a European context. The model incorporates a roundtrip policy for crew members joining from various cities. Variation in rest time rules based on the location of duty is not reported though. Neufeld et al. (2021) propose a hybrid column generation approach for the railway crew scheduling problem with attendance rates. The special characteristic of the problem is that only a certain number of trains are to be covered by the crew members instead of the whole set.

Bizhaem and Tamannaei (2017) focus on reducing multiple covered trips and the deadheadings happening as a result of it (the article names this transfer of crew as "transition") in addition to cost minimization. Further, Rählmann et al. (2021) address tactical level crew scheduling for freight rail services under uncertain demand. Here, duty frames that can cover duties in uncertain scenarios are prepared and the main goal is to generate robust and recoverable duties. Fuentes et al. (2015) focus on minimizing the cost of assigning crews by considering various rules and regulations for crew assignment. Also, Schöbel (2017) proposes an eigen model and iterative algorithms for solving an integrated planning problem.

An overall scan of literature reveals that integer programming based methods and different types of heuristics have been commonly employed for the development of crew schedules. However, a few works have also focused on analysing the crew planning procedure using simulation based approaches (Chahar et al. 2011, Dalal and Jensen 2001, and Guttkuhn et al. 2003).

Chahar et al. (2011) report the development of a strategic crew planning tool based on discrete event simulation to investigate the impacts of crew rules and train service changes. Performance measures like crew utilization and on-time performance of freight trains are studied. Dalal and Jensen (2001) use simulation to evaluate the work-rest patterns for scheduling train crews at Union Pacific Railroad in the United States. Further, Guttkuhn et al. (2003) use discrete event simulation to determine the impacts of factors like traffic pattern, labour rules, government regulations and optional crew schedules on overall operational efficiency and crew allocation. In the same direction, the present work aims to investigate the effects of various crew deployment patterns on performance measures like crew utilization, number of delays due to crew unavailability, requirement of resting rooms and number of deadheadings. The specific rules and guidelines associated with crew allocation in Indian Railways are incorporated to have a realistic analysis of the crew planning process.

3 Problem description

We consider rail freight operation in the Igatpuri (IGP) - Bhusaval (BSL) section in the Bhusaval Division of Central Railway as a test case. It is a part of the principal route connecting the major cities of Mumbai and Kolkata in India. The freight trains operating between IGP and BSL typically have a crew change at the intermediate station Nandgaon (NGN). This is because the freight paths available between IGP and BSL require longer time than the maximum permitted working time of the crew. However, when faster paths are available, crack services are run between IGP and BSL without a crew change in between. The stations IGP, NGN and BSL are shown in the rail map provided in Fig. 1.

There are various working and rest time related rules that are applicable while allocating crew to a duty. Each crew member has a headquarter (HQ) and the rest rules vary when they take up a duty at the HQ and at an outstation. The various work and rest related rules applicable for crew duty allocation are listed below.

- Maximum running time for a crew in a single stretch: 9 hrs
- Maximum time from sign on to sign off (time for preparatory work before and after the duty): 11 hrs
- Maximum duty time in a fortnight: 125 hrs
- Minimum duty time in a fortnight: 104 hrs
- Crew should return to their HQ within 72 hours from an outstation
- After a duty, the crew should have:
  - 16 hrs of rest in case the crew is returning to HQ from an outstation
  - 8 hrs of rest if the duty is from the HQ to an outstation
  - A rest of (0.5 x traversal time + 1 hr) if the traversal time is less than 4 hrs
- Continuous night duties should be limited to 4 (last duty - return to HQ)
- Preferred periodical rest - 4 periods of 30 consecutive hours

In this work, we focus on the rules related to continuous running times and rest. Further, to ensure each crew member returns to their HQ within 72 hours, higher priority is given to the crew waiting a return to the HQ during crew duty allocation.

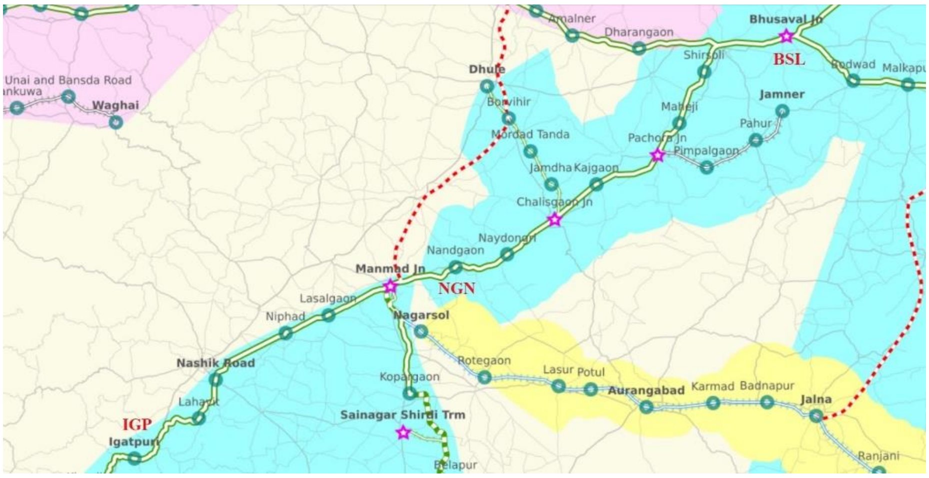

Fig. 1. Rail map of the IGP-BSL section under consideration (Atlas, indiarail-info.com)

4 Methodology

We propose a simulation-based tool incorporating the principle of discrete event system simulation. The entity of interest is the crew available in the system at any instance and major activities include the allocation of crew to various services, stipulated rest after a duty, and deadheading, if required. The state of the system changes during the following discrete time events:

- When a crew is allocated to a service
- When a crew completes the stipulated rest and becomes available for the next duty
- When a crew is deadheaded to HQ

The proposed tool imitates the actual crew allocation procedure and crew movement happening between various crew change points (IGP, NGN and BSL) in the section. The crew allocation related rules and guidelines are built into the logic and an allocation policy (higher priority for outstation crew) is implemented.

The basic flow of logic in the simulator is given below:

- Start time advancement (time and day)
- Choose a freight path when its starting time matches the simulation time
- Determine the longest path (< 8 hours) that can be charted based on the traversal time from the source (selecting the destination of the path)

  - These can be crack paths from IGP-BSL (or BSL-IGP) or shorter paths
  - If no path is < 8 hours, choose the shortest available path
- Update the crew availability matrix by checking the rest ending times of crew
- Allocate crew for the chosen path using the following priority rule:
  - Priority 1 - Crew awaiting a return to the destination of the path chosen (HQ of the crew) - supports the return of crew to their base station within 72 hours
  - Priority 2 - Crew having HQ at any other station but awaiting return in the same direction of travel
  - Priority 3 - Crew having HQ at the source station of the path
- If crew is not available, delay the path until crew becomes available (update the departure and arrival times of the crew accordingly)
- If a crew is allocated, update the crew availability matrix by deducting the number of crew available at the source station by one
  - Crew allocated with a duty becomes unavailable for a time period which equals the sum of the traversal time to the destination and the stipulated period of rest after the duty
- Record the time when the crew completes the duty and rest (becomes available for the next duty at the destination of the path)
- At the end of the day (time =1440 minutes) update (rollover) the remaining paths (paths extending to the second day) and the matrix recording the rest ending times
- Update the day count and repeat the procedure
- Terminate the algorithm at the end of n days

The basic variable that is being tracked and updated during the simulation run is the crew availability at each instance. It is recorded as a vector as given in Table 1. The main column title denotes the location of the crew at a particular instance and the second level column title represents the HQ of the crew. For example, in Table 1, the value 5 (third row, second column) represents the number of crew available at IGP who have their HQ at NGN.

Table 1. Sample crew availability matrix

IGP			NGN			BSL		
IGP	NGN	BSL	IGP	NGN	BSL	IGP	NGN	BSL
12	5	6	4	7	3	4	4	9

The simulation is run over a period of time by varying the crew configuration and the following performance measures are determined:

- Average crew utilization - indicates the appropriateness of the number of crew deployed

- Number of freight paths delayed due to unavailability of crew and total delay - indicates crew shortage/improper deployment strategy
- Number of deadheadings - reflects the imbalances in freight paths in both directions
- Average and maximum number of crew resting/waiting at a crew change point - indicates the requirement of resting rooms at various crew change points

The proposed simulation model is a deterministic model and there are no random variables/randomness involved. The inputs used in the model are the start and arrival times of the scheduled freight paths and the various crew configurations that are to be tested. Appropriate warm-up periods are considered during each simulation run to avoid any bias in the results due to the system starting from a zero state.

5 Results and discussion

The simulation model was run by varying the crew configurations and it was found that with a total of 34 crew and a crew configuration of 8-12-14 (IGP-NGN-BSL), the scheduled paths can be operated without facing any delay due to crew unavailability. As the next step, different crew configurations (keeping the total at 34) are compared based on the delay of freight paths. These results are given in Table 2. It is to be noted that the number of crew at a crew change point is increased/decreased by only a unit value in each scenario and the total number of crew is maintained at 34.

Table 2. Crew configurations and delay in paths

Sl. No.	Crew configuration (No. of crew at:)			Total crew	Avg. no. of paths delayed per day	Avg. daily delay in paths (minutes)	Crew utilization (percentage)
	IGP	NGN	BSL				
1	8	12	14	34	0	0	
2	8	13	13	34	1	136.33	
3	9	12	13	34	0	0	
4	9	11	14	34	2.33	218.79	60.86
5	9	13	12	34	0.67	128	
6	10	12	12	34	1.5	4	
7	10	11	13	34	1.97	487.87	

From Table 2, we find that configurations 1 and 3 result in zero delay of freight paths due to crew unavailability. Next, we compare these two configurations based on the average and maximum number of outstation crew resting/waiting at a crew change point. This parameter is of interest since it determines the number of resting rooms that needs to be arranged at a crew change point to accommodate the outstation crew.

A minimum value among these two possible configurations may be preferred in case there is a shortage of resting rooms.

Table 3. Average and maximum number of crew resting/waiting at various crew change points - Configuration 1 (8,12,14)

Home base of the crew	Average, maximum number of crew waiting at:		
	IGP	NGN	BSL
IGP	3.25, 4	2.68, 7	1.06, 4
NGN	1.65, 2	5.64, 10	4.70, 7
BSL	1.46, 2	0.90, 3	4.94, 7

Table 4. Average and maximum number of crew resting/waiting at various crew change points - Configuration 3 (9,12,13)

Home base of the crew	Average, maximum number of crew resting/waiting at:		
	IGP	NGN	BSL
IGP	3.42, 5	2.69, 6	0.89, 3
NGN	1.98, 3	5.65, 10	4.37, 6
BSL	1.78, 3	0.83, 2	4.69, 6

The highlighted cells in Tables 3 and 4 represent the average and maximum number of outstation crew resting/waiting at various crew change points. On comparing the number of outstation crew, the requirement of resting rooms at BSL is higher for Configuration 1 compared to Configuration 3. However, the opposite is true in case of resting room requirement at IGP (Configuration 3 needs more resting rooms compared to Configuration 1). For NGN too, Configuration 3 can be preferred. In short, the results provide more basis for the crew planner to decide on a suitable crew configuration depending on the resting room availability at various crew change points.

As the next step, the number of crew at various crew change points are increased by around 10% and its effects on various performance measures are investigated. A total of 38 crew is considered and the simulation is run for various crew configurations. The configurations tried are: (11-13-14), (11-14-13), (12-13-13), (12-12-14), (13-12-13), and (11,12,15). We could find that there was no delay in freight paths for any of the crew configurations. This indicates that when there is a certain buffer in terms of the available crew, small changes in crew deployment does not affect the system performance significantly. However, it is to be noted that the crew deployment pattern is still relevant in terms of the average number of outstation crew resting/waiting at various crew change points. This will, in turn, determine the number of resting rooms required at these stations.

Another interesting observation is regarding the number of deadheadings. The results show that the number of deadheadings is influenced by the number of excess crew available in the system (than the bare minimum of 34 here) in addition to the commonly anticipated causes like imbalances in the number and timings of freight paths in both directions. There are no deadheadings reported when the total number of crew employed are 34 and 38. However, when the number of total crew was increased to 41 (20% excess of the bare minimum of 34) and 44 (30% excess of the bare minimum of 34), the number of daily deadheadings was found to be 3 and 7.5 respectively.

The current crew configuration (number of loco drivers available on a particular day) for IGP-NGN-BSL is roughly in the ratio 5:14:81. On carrying out simulation experiments using this ratio of crew configuration, we find that we would require 39 crew (crew configuration: 2-5-32) to operate the given freight paths (without encountering any delay in freight paths). This indicates that if the deployment is more evened out in a proportion close to 24:35:41 (like 8-12-14), the given paths can be operated with a lesser number of crew (34), as already seen. However, additional crew might be required to adjust for fluctuations in traversal time and demand encountered in a practical scenario. Also, the location related constraints are to be considered while making decisions related to crew re-deployment.

6 Conclusion

This work proposes a simulation-based tool for railway crew planning considering a set of scheduled freight paths. The work and rest time related rules applicable for the crew are built into the simulation model and experiments are run using different crew configurations as the input. Performance measures like crew utilization, number of paths delayed due to crew unavailability, average number of outstation crew resting/waiting, and the number of dead headings is determined. These measures help the crew planner to evaluate the impacts of various crew deployment patterns and choose an appropriate deployment strategy.

Our experimentation shows that if we have only a 10% excess crew, then small changes in the deployment pattern do not affect the overall delay-based measures of performance. This indicates that a trade-off should be made between the cost for excess crew and the desired robustness of the system. Further, it was observed that the number of deadheadings is also influenced by the number of excess crew in the system, in addition to the generally anticipated factors like imbalances in the number and timings of freight paths. A comparison of the current crew deployment pattern with the proposed one indicates that a more evened out deployment can reduce the overall crew requirement.

In this work, we assume that the given freight paths follow the given schedule strictly without any delays. However, since rail freight operations are subject to delays and demand uncertainties, it is worth incorporating these uncertainties in the analysis. The proposed simulation-based tool can be modified to incorporate these uncertainties and more experimentation can be carried out to gather further insights. The authors see this as an immediate future work and plan to proceed in this direction.

Acknowledgements

The authors thank Mr. K N Singh, the Chief Freight Transportation Manager, and other employees of Central Railway for providing the data and insights for this work.

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