Crew Planning for Commuter Rail Operations, a case study on Mumbai, India

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Abstract. We consider the problem of constructing crew duties for a large, real instance of operations for commuter train services in Mumbai, India. Optimized allotment of crew duties and enforcement of work rules ensures adequate safety and welfare of rail workers. Currently, within Indian railways, decisions related to crew allotment are made manually. The main objective is to use as few crew members as possible to execute upon the timetable. This improves the efficiency of the system by increasing the average working hours of work per duty. We also have several other secondary objectives. The presence of a large number of operational constraints makes the problem difficult to solve. Computational experiments are performed over the current train timetables and the results of our algorithm compare very favorably with the crew duty schedules in use. For the Western Railways train timetable of 2017-18, the crew duty sets required to perform the timetable was 382. The proposed algorithm achieves crew allotment with 368 sets, promising significant savings of manpower and money.

Keywords: Railways, Optimization, Crew Schedule Problem, Crew Allotment, Duty Preparation, Operations Research, Constraint Modelling, Metaheuristic, Resource Allocation, Work Load Balancing

1 Introduction

Large mass transit systems like Mumbai Western Railways are complicated not only because of the multitude of management considerations, labour laws, and union requirements, but also because requirements have been changing rapidly in the recent past. As mentioned in [1], staff is to be assigned for each of the 382 links in the 1,355 services that Western Railways runs daily using 89 rakes. This requires that timetables need to be modified frequently, thus requiring daily duties (hence, duty sets) and crew rosters to be changed quickly as well. Crew scheduling at the Mumbai Suburban Railways has been done manually with great skill for over 150 years. The changing times require a positive change in the approach of how we prepare these work duties for the system.

An optimal duty preparation strategy minimizes the number of sets required to match crew members with the services of the Western Railways. Least number of sets implies more working hours per set or more working distance per set. Tight packing of these sets with proper adherence to HOER (Hours of Employment and Period of Rest) rules ensures minimum operating slack and maximum use of valuable manpower.

This paper contributes in two ways. First and foremost, in a problem space in which algorithms and models tend to be highly specialized because every crew scheduling system is unique, it describes an approach that is simple, flexible, and hence has potential for adaptation to systems other than the Railways. Second, it adds to the operations research literature on crew scheduling by describing an iterative approach that uses time probabilistic curves to match duties to crew. The huge search space at a large complex system like the Railways makes it a very interesting matching problem for resource allocation.

2 Railway Terminology and Documents

The Western Railways line comprises of 37 stations going from Churchgate to Dahanu Road, out of which 15 are could be used for crew change.

As part of its operations planning, the Western Railways department does timetabling and crew scheduling. Both these tasks are documented in 2 books, namely Suburban Working Time Table and Schedule Book for Suburban Guards and Motormen, reference [2] and [3].

A rake refers to the complete physical train that comprises of all allocated coaches. A rakes movement throughout the day is broken into services. The crew comprises of a guard and a motorman, whose duties are defined in the schedule book. The schedule book consists of a collection of sets. Each set contains the on-duty and off-duty time, start and end station, the assigned lobby, set working hours and distance, list of services to be done as work of the set, and rest hours provided to driver after completing the set.

These sets are divided into 2 lobbies, Borivali and Churchgate. The sets belonging to a particular lobby are packed in continuation forming a loop. The sets are divided into 2 categories:

Working Sets : These are the sets which have allocated services to be manned by a crew member. They are divided into following 3 categories:

- Day working sets
- Night working sets: Sets with on-duty time after 22:00
- Halting working sets: Always occur in pairs, one set defining evening duty and the other defining morning duty with a short rest in between.

Waiting Duty and Shunting Duty Sets : A shunting duty set requires the motormen to take rakes to/from a stabling depot such as a yard or a car shed.

3 Problem Formulation

To create an efficient strategy for crew allotment, the overall problem has been decomposed into the following 2 stages:

Set Generation : To break the rake cycles into some workdays. This is essentially a matching problem for resource allocation.

Set Linking : Set linking requires us to combine single workdays to form a sequence of sets, satisfying the rest considerations.

4 List of Constraints

Hours of Work and Period of Rest Rules (HOER), reference [4], is the official document of the Government of India and the Western Railways containing a list of operational rules. Our algorithm takes into account all these constraints for duty allocation. The set generation constraints are listed below:

1. Total working hours in a set must be less than 8 hours
2. The rest between the sets of a halting pair should be at least the maximum of 5 hours or 2/3rd hours of first part of halting pair
3. Total working time of a halting pair should not be more that 14 hours
4. The morning part of a halting pair should have less working hours than the evening part
5. The on-duty and off-duty time should be at least 15 minutes before and after work with the minutes rounded to nearest multiple of 5
6. The time gap meal breaks should be about 40 minutes. Time interval for lunch is 12:00-14:00 and that for dinner is 20:00-22:00.
7. In the morning and evening peak hours, all services should be provided with overlapping crew for quick and punctual reversal of the train. Work overlap is given every time a service departs in the opposite direction within 8 minutes for a 12-car load and within 10 minutes for a 15-car load.
8. For a halting pair, the crew must not be rested at the crews allocated lobby.
9. No relief to be provided en-route for any train.
10. Night sets should also be utilized for shunting duty.

The set linking constraints from the document are mentioned below:

1. Total hours worked in a week must not exceed 52 hours.
2. A minimum rest of 12 hours is necessary after completion of a set, except for rest in between a halting pair
3. A minimum rest of 30 hours must be given after completion of a night set
4. Schedule will be prepared with sets allotted to Churchgate and Borivali lobby
5. A night must not be linked in succession to another night set. Similarly, a pair of halting sets must not be linked in succession to another halting pair.

6. All the sets not in sequence can be kept as out of rotation sets

While the above points are mentioned in the HOER Railways document, there are certain considerations that arise out of field expertise, operational knowledge and practicality of schedule preparation. These are operational constraints that also need to be enforced:

1. The trains are also required to be taken to/from a stabling depot which requires understanding of the rail map
2. After the completion of a service of a rake, the crew should preferably work the next service of the same rake.
3. In a set, at least 1 break of 30 minutes is required, preferably at Churchgate
4. For the morning part of a pair of halting sets, a 35 minutes break must necessarily be given when the crew reaches Churchgate
5. The working hours in the morning part of a halting pair should be capped to 5 hours 30 minutes
6. The evening part of a pair of halting sets should start as late as possible
7. All shunting sets must be first used to work the rakes to/from stabling points
8. Waiting duty and shunting duty sets need to be created as per requirement
9. The number of halting sets is limited by the number of available beds
10. The night sets must not be given a large number of services, 2 is preferred
11. Geographical information about the stations must be taken into account to define how much time a crew would take to change platforms at a station
12. The maximum allowable number of services in a set is 5
13. For a night set, the off-duty time should be at or after the start of the first morning service from the sets end station
14. No normal set should start early morning
15. A long service that goes all the way between Dahanu Road and Churchgate needs to broken at Virar resulting into 2 services

5 Objectives

The allocation must aim to achieve the following objectives, given in order of decreasing weight-age.

1. Tight packing of services
2. Tight linking of sets
3. Sets should start and end close to headquarters
4. Balanced workloads
5. 2:3 ratio of number of sets for Churchgate and Borivali lobby

6 Crew Allocation Scheme

We need an efficient, flexible and quick heuristic to solve a large search space matching problem. All constraints need to be modelled into the algorithm, reference [5]. Resource allocation will be done constructively, a time weighted probabilistic function will create multiple allocation schemes and a work load balancing function will further improve the results. This is an iterative approach of creating work duties, a metaheuristic that is largely greedy initially with a self-correcting mechanism. Creation of large number of allocation schemes, all of which have the constraints enforced, gives us a large subspace of possible solutions with a hope of finding a good enough solution.

Described below are major decision points that are implemented into the algorithm to create a work duty (or set) of services. Each decision point has numerous constraints built into it. After the creation of a set, the future services are picked via a time weighted probabilistic function.

1. Iterate over services until all of them have been allocated to a set
2. Select a service, earliest among available, and start generating a set with it
3. Given the starting service, check for next service from the same station after the required break period. Iterate over every possible next service after checking for platform and break time constraints. Use a time weighted probabilistic function to create multiple set allocations
4. Keep adding services to a set until the number of services in the set reach the maximum value of 5, or all available services violate the 8 hour limit

The above steps generate a good enough solution. To further improve the results for secondary objectives, we require a self-correcting mechanism that performs work load balancing as described below:

1. Shuffle: Sets with large number of services are combined with sets with smaller number of services to generate new sets with fair work distribution
2. Merge: Two sets with a small number of services can be merged as one to reduce set count

The post-processing algorithm essentially balances the number of duties as per workload and maximizes start and end of duties near the assigned crew headquarters as best as possible.

The set linking stage is analogous to traveling salesman problem (TSP) where each working set is a city and break between each working set is the distance between cities. Hence the problem is NP-hard. But, the additional rules which provides an upper bound on the number of hours of work per fortnight, adds to the complexity of the problem. Hence the set of feasible solutions is not convex. Therefore, a cyclic re-allotment has been implemented to achieve a feasible solution. This algorithm initializes linking of sets randomly. A checker function loops around this linking for every 14 days window to identify part of the linking where the count of total working hours fails to lie inside a specified upper and lower bound. For violations reported by the checker function, the linking is broken until that the remaining link satisfies the constraints. These removed sets are returned to the pool of non-linked sets. Further, the algorithm greedily adds non-linked sets to the link to improve working hours. These steps are iterated until every part of link satisfies the constraints. This algorithm gives near optimal results in fairly less computational time.

7 Results and Conclusion

Computational experiments are performed over the current train timetables and the results of our algorithm compare very favorably with the crew duty schedules in use. The manual generation of crew duty by the experts takes 2-3 months to compile one schedule, which includes a lot of trial and error. This procedure is automated by the algorithm. The iterative approach of creating work duties by a constructive method and work balancing proves to be an efficient, flexible and quick heuristic to solve a large search space matching problem. From the comparison shown in Table 1, we can observe that the algorithm gives an improved average working hours with lesser number of total sets.
The algorithm allows to evaluate changes in policy like adding new depot. Change in depot can help to improve on the TAP costs. Further modifications on the algorithm can allow it to be used to roster crew schedule daily rather than one schedule to be used for year long planning.

Table 1. Comparison of duty sets generated by the tool vs manual preparation

Statistic	**Proposed**	**Manual**
Number of Halting Sets	129	192
Number of Day Working Sets	209	161
Number of Night Working Sets	30	29
Total Sets	368	382
Average distance	135 km	125 km
Average Working Hours	6:29	6:16 (CCG depot) 6:23 (BVI depot)

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