Priority Based Train Scheduling Method Using ACO in Indian Railway Perspective

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Abstract. The aim of this paper is to solve a train scheduling problem (TSP) with different train priorities and travelling at different speeds in the Indian railways (IR) perspective. Initially, a mathematical model for a TSP is developed and then the Ant Colony Optimization (ACO) technique is applied to resolve the problem. A real-world train timetable problem is presented to make a comparison between the manual solutions method used by the Indian Railway (IR) and the solution obtained from ACO and CPLEX solver to check for quality and accuracy in terms of total travel time. The result shows that there is a 6.827% improvement in travel time using ACO over manual solution. A collision free train schedule is determined based on the obtained train sequence.

Keywords: Indian Railways Train Scheduling, ACO, Information Flow System in Indian Railways

1. Introduction
Indian Railway operates in passenger and freight transportation as a major contributor. Approximately 8116 million passengers have travelled through the Indian railway in recent years contributing to a turnover of 462.80 billion INR. in the year 2018-19[1]. The rank of IR infrastructure i.e. the number of trains and length of tracks is 4th in the world. Unpredicted events like technical breakdown, equipment failures, sudden increase in passenger demand, track accidents, changed weather conditions causing disruption to segments track, varying speed trains running on tracks, different train types, train bypassing, siding, etc. causes the lateness of the train, triggering a knock-on effect in entirely railroad lines & connections, and hence generating the need of continuous scheduling. In this era of automation and IoT scheduling problem can be remarkably improved by using computational techniques. Further, the Indian Railway system has a heterogeneous nature (i.e. different types of train run on the same track). On the basis of speed, trains[2], [3] are classified as Mail, Passenger, Express, and freight, etc. As the whole territory of IR divide into control areas (zones) and these control areas further divided into division or control sections. A railway line connecting these different zones that have different control sections, containing single multiple tracks on which all types of trains run between the stations. Due to the limited capacity of tracks between the stations, it is important to have a fast and corrective way of scheduling trains. Initially scheduling in IR is done according to the First Come First Serve policy. Shortest Job First method was also implemented with different train priorities. For the last five decades,
Researchers have examined various parts of the train planning issue & TSP. For solving train scheduling problem many techniques are used such as Mathematical programming, discrete event simulation, and metaheuristic approaches, etc. A simulated annealing (SA) technique has been used by [4] for TSP. Van Wezel et al.[5], [6] implemented a Genetic algorithm (GA) to develop train timetables and TSP. Gorman [7] developed a hybrid method, consisting of GA and tabu search for solving the problems of routing and TSP. A neural network has been used [8] for routing in a railway system. The key to this article is (a) framework for real-time operational practices in Indian Railways for TSP (b) ACO based approach for solving train scheduling problem in IR (c) validation of model on a real railway network. The rest of the paper is organized as follows. Section 2 describes the basic concepts related to TSP. In Section 3, we give a detailed description mathematical model. Section 4 is devoted to the comparative study of computational results of different techniques implemented on the real IR network. Section 5 concludes and provides future directions.

2. Problem Definition
Planning is an ever-interesting research topic, whether we are talking about manufacturing, goods or services. The TSP is one of the challenging problems in the railway system. At present most of the scheduling is done manually by human operators (called dispatchers) in IR. Due to the limited computational capability of a humankind, it is difficult to combat the complex nature of the scheduling problem and provide optimal solutions quickly. On the basis of infrastructure details, a network can be categories in to three parts. The first one is microscopic having a high level of detail, whereas mesoscopic representation has moderate. This paper considers the macroscopic (low level) representation of the IR network. A network contains nodes (station) & lines (segments) joining nodes. Generally, several tracks (loops) are established at almost every station where overtaking or crossings can be done in an effective manner. A segment can permit one-way traffic movement or two ways. consist of three stations joined with segments. Generally, In IR every station contains multiple tracks (loops) as shown in station2. In this work smaller details of infrastructure consisting of signaling distance, interlocking etc. are not considered. The railway planning operation depends upon the following inputs: commodity and demand data, number (no.) of trains, halt, and speed of trains, priority etc.[9]. In Indian railways priority of a train generally is based on their speed. Usually, a cargo train had a lower priority than a passenger train. During the scheduling process in IR, the higher priority train gets more importance in comparison with lower priority trains in term of resource usage. In the case of a single-track railway line, a segment can be only occupied by one train at a time. Simply, the no. of trains occupying tracks at a station should be equal or less than the no. of existing tracks at that station.

3. Mathematical Model
Railway scheduling is a very complex problem, it is necessary to state entirely the model’s restrictions, assumptions and inputs. The model in this paper studies a single railway line TSP on which trains are going in both directions. This model is similar to that of Higgins [10] with slight modifications for achieving the infrastructure requirements. In this model, it has been assumed that the trains will be dispatched from the first and last stations only. The situation of crossing and overtaking of trains can
only be performed at the stations or sidings. On the basis of directions, the train is named as UP and DOWN. UP train movement is form right to left while down train traverse from left to right. Further it has been assumed that each train will fit on any track. Below the definitions and symbols used in this paper to design and implement the model are described.

Parameters and Decision variable

- \( n \) : No. of trains
- \( m \) : No. of stations
- \( B \) : A sufficiently large number
- \( TD_{i,k} \) : Actual departure time of train \( i \) from station \( k \)
- \( X_{i,j,k} \) : Binary decision variables
- \( HT_{i,k} \) : Halt time of train \( i \) in station \( k \)
- \( TT_{i,k} \) : Travel time of UP train \( i \) between stations \( k = 1 \ldots m-1 \) and \( k+1 \)
- \( TT_{j,k} \) : Travel time of DOWN train \( j \) between stations \( k = 2 \ldots m \) and \( k-1 \)
- \( AA_{i,D} \) : Actual arrival time at station
- \( AA_{i,O} \) : Actual Departure time from origin station
- \( OPT_{\text{gap}} \) : Optimality gap
- \( \text{Saving}_{TT} \) : Total Travel time saving

Objective function

The objective function for the problem of interest (TSP).

\[
\text{Min } Z = \sum_{i=\text{train}} w_i (AA_{i,D} - AA_{i,O}) \tag{1}
\]

As an objective function paper focuses on minimizes the weighted sum of travel time of the UP and DOWN trains. At the end stations, halt time is zero, so this will give the actual arrival times of trains at their destinations. The flow diagram of infrastructure topology is represented in figure 1. And the timetables are described with the help of a graphical method termed as Train Graph. This train graph represents the time on one axis taken by the trains to travel from one station to another and on the second axis specify the number of stations and distance between the stations. The time distance graph is reversely represented by many countries i.e. on the minor axis travel time of train and major axis number of stations.

![Train Graph](image)

**Figure 2.** Train overtaking conflict b/w Train 3 & Train 4

In figure 2 train graph represents a schedule with four trains and four stations including headway (separation time between two trains i.e. Train 1 & Train 2) and overtaking conflict.
4. Computational Results

The results obtained from ACO are compared with those of the exact optimization method, manual method for TSP. In the present scenario, IR has been using a manual solution technique to produce a conflict-free train schedule. The mathematical model transforms into program code in MATLAB and CPLEX solver which is specially oriented to handle matrices. CPLEX solver is a well-suited tool for solving mixed-integer linear programming-based problems and is inbuilt with branch & bound method. For obtaining an optimal solution the search tree is considered. The nodes indicate the conflicts and branches solutions & order of search indicated with the help of numbers. As this problem is NP-hard signifies that it increases exponentially with the no. of conflicts. Two problems are studied, first one is the example problem and the second is Indian line railway network problem. The data are first described then, the computational results are discussed. Every train has provided departure time from its starting station. A train transverse on rail segments with specific speed. The Halt time for every train at each station is deterministic. This gives an initial schedule specifying train departure time, stoppage time with conflict.

![Figure 3. Schematic illustration of a test network](image)

The objective value ($z$) obtained from the above schedule becomes the upper bound value. Similarly, in MATLAB, the ideal solution is generated with conflict known as conflict detection block. After implemented all the constraints with the objective function the optimal value is obtained using CPLEX solver and conflict free schedule is created.

| Table 1. Train data for IR line |
|--------------------------------|
| **Train / Line data** | **Example problem data** | **Real network data** |
| Length | 297 Km | 71.40 Km |
| Line (Single Line) | A-B | ROK-PNP |
| Max. Permissible Speed | 60 Km/hr. | 50 Km/hr. |
| Total Station | 5 | 12 |
| Total Train | 3 (2 in UP & 1 in DOWN direction) | 12 (M/Ex. 2 in UP & in 2 DOWN direction) |
| Priority Weight | 1 for each train | 1 for Passenger & 2 for Ex. Trains |

The saving in total travel time is given as the difference between the travel times obtained from ACO and the manual method. All these methods are implemented on a real railway network at which 12 trains are running with different priorities. A simple example of a problem is also illustrated. Results Show a 3.070%, 6.827% improvement in ACO solution as compare to the manual solution.

\[
\text{%improvement} = \left( \frac{\text{Solution from manual method} - \text{Solution from ACO}}{\text{Solution from manual method}} \right) \times 100
\]
5. Conclusion

In this paper, a metaheuristic technique (ACO) was implemented for the Single Line TSP. The comparison results show that ACO solutions similar to the optimal solutions obtained by CPLEX for example problem, but correspondingly leave behind the manual method used by IR for scheduling of trains. For the real network problem, we found that the % improvement is better in CPLEX as compare to both ACO and manual method. The obtained results show significantly better performance with regard to the solution quality, computational time.

![Train Schedule Diagram](image)

**Figure 4.** Train schedule diagram

For future direction, there is a significant need for extension of metaheuristic techniques for dynamic train scheduling problems with dynamic variables, with unexpected events (passenger demands and link travel times). For future works, it is proposed to develop software to represent the unquantifiable constraints that dispatchers face in the scheduling of rail traffic; i.e. (train length, capacity constraints).

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