

A REVIEW OF TIMETABLING AND RESOURCE ALLOCATION MODELS FOR LIGHT-RAIL TRANSPORTATION SYSTEMS

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Abstract

This paper surveys the relevant operations research literature on timetabling and resource allocation problems with a special attention paid to the transportation systems. The purpose of this review is to define the critical objectives, determine the key components and identify the key issues for developing a comprehensive mathematical model for timetabling of light rail transit vehicles in sequence with the assignment of drivers as an available resource. In doing so, the implications of the emerging timetabling research is discussed, components of the mathematical models proposed are reviewed, and the extent they reflect real business practices are analyzed. Finally, fundamental issues and primary elements of a simple model in association with general timetabling and resource allocation problems are presented.

Keywords: *Timetabling, resource assignment, light-rail transportation, quantitative models*

1. INTRODUCTION

This research focuses on public transportation, since it is important to raise the capacity of public transportation and quality of service at reasonable cost, in order to prevent problems caused by individual means of transport such as pollution, congestion and social discrimination [1].

The most essential schedule of transportation systems is the timetable [20]. Constructing a timetable is part of the overall transit planning process, a choice of service frequency for each route, and allocations of vehicles and crews to routes [25]. For example a train timetable defines the planned arrival and departure times of trains to/from yards, terminals and sidings, and train scheduling plays a vital role in managing and operating complex railroad systems [33]. Several approaches have been used to solve timetabling problems up to now. Simulation [21], [30], linear programming [29] and metaheuristics [20] are used for railway timetabling. Evolutionary algorithms have been applied with very good results to various types of timetabling problems [2], [10], [15], [8], [4]. Also, metaheuristics have become increasingly popular in the field of automated timetabling [20],[22].

In this paper, the scope is preparing a model for timetables and assignment of resources (trains and operators) for light rail transit vehicles. Timetabling and crew scheduling are major planning problems for railway companies at operational and short-term level [19]. This paper is concentrated on, only operational level timetabling and resource assignment problems. Moreover, only models and techniques used in passenger transportation which is completely different from freight transportations are focused on.

2. LITERATURE REVIEW

Timetabling is the process of assigning events, and resources, to timeslots subject to constraints [33],[6]. Most of the time-tabling problems belong to the class of NP-hard problems, as no deterministic polynomial algorithm exists [10]. Large variety of solving techniques has been tried out in literature for solution of timetabling problems [7].

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Personnel scheduling problems involve the allocation of staff to timeslots and possibly locations [32]. Personnel scheduling covers many areas, such as the nurse rostering [5], transportation staff scheduling [33], educational institute staff scheduling [24] and airline crew scheduling [14].

2.1. Timetabling

The tasks of public transportation are to meet the increasing demands of all kinds of passengers by high quality of service based on limited number of vehicles [11]. Up to now, for the solution of timetable scheduling problems, simulation [21], [30], simulated annealing [27], genetic algorithms [2], tabu search [10], hybrid genetic algorithms [11], linear programming [29], integer programming [16], heuristics [18] and mixed-integer programming [31] methods have been used.

On the other hand, the studies made for personnel scheduling studies are generally based on fixed schedule assumption and make resource scheduling accordingly [23], [11], [3], [17], [16], [13]. These personnel scheduling problems involve the allocation of staff to timeslots and possibly locations.

There is limited literature which solves timetable scheduling and resource assignment problem interactively. There are three studies which propose timetabling together with consideration of resource constraints. (1) Cowling et al. [12] developed a hyper-GA for scheduling geographically distributed training staff and courses. They aimed to maximize the total priority of courses which are delivered in the period while minimizing the amount of travel for each trainer. (2) Sigl et al. [28] determined the quality of timetable by earliness of scheduled classes. Here, a genetic algorithm is employed to schedule classes as early in the morning as possible, while minimizing the number of holes in a student's schedule. Minimizing the number of conflicts is achieved by number of conflict by a large number K and then selecting the best individuals in a population according to smallest fitness value. Instructors and rooms are considered as hard constraints. (3) Walker et al. [31] developed a recovery model which involves two related processes: (a) determination of a revised or amended train schedule; (b) involving the adjustment or repair of the associated driver duties. Their model's objective is to minimize deviation from the existing schedule while incurring as little cost increase as possible. Their research is mainly about short-term level timetabling. For this purpose, an integer programming model is developed to resolve disruptions to an operating schedule in the rail industry. The model constrained with two distinct blocks, with separate variables and constraints. These blocks are coupled by piece of work sequencing constraints and shift length constraints which involve variables from both blocks.

In this paper, the timetabling problem is modeled simultaneously with resource assignment problem. The constraints and demand structure is different and specific to the problem area, which is light-rail transportation.

3. FUNDAMENTAL ISSUES OF PROPOSED MODEL

Modeling focuses on an operational-term timetabling of light-rail transit considering double track, with a number of intermediate stations in between. The operational and physical constraints are defined to reflect the real world applications. Therefore, in addition to literature driven criteria, model development stage has also employed information provided by the operators of the light-rail transportation system of Istanbul.

The purpose is set as: "to develop optimal timetables and personnel schedules for light-rail transit". The system is composed of two sub-problems: the timetable problem and personnel scheduling problem. A model, with an objective of minimizing average passenger travel time and minimizing number of trains required, is developed.

3.1 Model Parameters

- Number of vehicles: Total number of vehicles available for timetabling [32].
- Vehicle capacity: Passenger capacity of vehicle.
- Trip start and finish hours
- Number of machinists
- Maximum daily working hour of machinists
- Maximum duration that a machinist can be on train.
- Headway time: Minimum time difference between the departure of train from a station and arrival of next train to the same station [32].
- Minimum dwell time of stations: Minimum dwell times changes for each station
- Maximum dwell time of stations: Maximum dwell times changes for each station

- Minimum run time: Minimum time that a train needs to cover distance between two stations because of speed limits [26].
- Inflow of passengers: Number of passengers coming to a specific station between specific time intervals.
- Outflow of passengers: Number of passengers leaving a specific station between specific time intervals.
- Constant multipliers for average travel time and train number.
- Number of machinists: Available maximum machinist number as full time/part-time.

3.2. Model Variables

- Train index: Train index increases for each trip [32].
- Station index: Station index shows the sequence of stations according to path of trains [33].
- Trip start time of train: Time that a train start its trip.
- Arrival time of train: Arrival time of a train to a specific station [33].
- Departure time of train: Departure time of a train from a specific station [33].
- Run time: Travel time of train between two stations [20].
- Passenger travel time: Duration of a passenger's time on train [9].
- Number of passengers at station: Number of passengers at a specific station for a specific time interval.
- Number of passengers on train at a station: Number of passengers on train at a specific station for a specific time interval.
- Binary variable for assignment of machinists: This variable takes value 1 if machinist is assigned to a train, 0 otherwise.
- Trip duration: Duration of trip for each train.
- Total working hour of each machinist: Total duration of machinist at work.
- Total driving hour of each machinist: Total duration of machinist on train for each day.
- Required machinist quantity for each day: Machinist quantity changes according to number of trips scheduled.

3.3 Model Constraints

Previous literature discussed in the above sections have suggested certain constraints specific to rail transportation models. In addition, interviews with IBB light-rail system operators have proposed consideration of specific criterias.

1. Number of passengers on train at a specific time interval must be smaller than the maximum passenger capacity of train.
2. The departure time of first train from the first station must be greater or equal to start hour of trips.
3. Arrival time of final train to the final station at final trip must be smaller than finish hour of trips.
4. The time difference between departure and arrival of a train at a specific station must be greater than minimum dwell time and must be smaller than maximum dwell time.
5. A train's arrival time to a station must be greater or equal to the time of departure from the previous station plus headway time.
6. Travel duration between two stations must be greater than minimum travel duration between stations according to speed limits.
7. Travel time of a passenger is equal to run time of train between stations plus time difference between arrival time of passenger to the station and arrival time of train to the station.
8. Total working hour of each machinist must be smaller than maximum daily working hour.
9. Total driving hour of each machinist must be smaller than maximum daily driving hour.
10. When a machinist is assigned to a trip it could not be assigned to the following trip on the same train.
11. Total trip duration for each trip is equal to time difference between arrival time of train to final station minus departure time of train from the first station.
12. Total driving hour for each machinist is equal to sum of total trip durations times binary variable about assignment of related machinist.

13. Total working hour of each machinist is equal to total driving hour of each machinist plus walking durations to the trains plus rest hours such as lunch, coffe breaks.
14. Total Passenger quantity on train, at specific station for a specific time interval equal to passenger quantity on train at previous station plus inflow of passenger to the station minus outflow of passengers from the station.

3.4 Critical Objectives

The time a passenger spends waiting is a very critical element for evaluating passenger service level. Typically, a railway passenger faces different types of waiting due to different causes. For instance, when connections are not properly scheduled, a passenger will have to wait a long time between trains. Trains running behind schedule will also create waiting times. During rush hours most of the trains meet with some considerable delay. Thus, an actual travel time take during rush hour is typically longer than the ideal running time [29].

The objective of the model is to minimize the average travel time of passenger(s) and minimize number of trains.

- Objective: Minimize average travel time of passenger(s) times constant multiplier 1 plus number of trains times constant multiplier 2.

3.5 Assumptions

1. The Demand data is measured at certain time-intervals so the trip frequency is determined at this frequency.
2. Waiting time at platforms are decided according to number of passengers. There must be upper and lower limits for waiting times at stations.
3. The vehicles must stop at all intermediate stations. The dwelling time among every station might not be same. The length of dwelling time depends on predicted volume of passenger flow (Chang and Chung, 2005).
4. It is assumed that machinists should not make two consecutive trips.
5. It is assumed that passengers arriving to the stations will take the first train

4. CONCLUSION AND FUTURE WORK

It is obvious that, nowadays, efficient public transportation is a critical task for metropol. Yet, previous research that considers resource assignments in timetabling is limited. This paper has developed a model that includes the critical objectives and key components specific for timetabling of light rail transit vehicles. Simultaneously, assignment of machinist has also been considered. It has been revealed that light-rail transportation has its own set of constraints such as headway and dwell times. In addition, there are other human factors such as machinist rest hours and unavailability for consecutive rides. It was uncovered that the objective function should include both the service level objective (minimizing passenger travel time) and the operational objective (minimizing the number of trains).

Future research should focus on solving the model, validating the model via simulation and verifying the results.

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