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A feasible timetable generator simulation modelling framework for train scheduling problem

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ABSTRACT

An important problem in management of railway systems is the train scheduling/timetabling problem. This is the problem of determining a timetable for a set of trains that do not violate track capacities and satisfy some operational constraints. In this study, a feasible timetable generator framework for stochastic simulation modelling is developed. The objective is to obtain a feasible train timetable for all trains in the system. The feasible train timetable includes train arrival and departure times at all visited stations and calculated average train travel time. Although this study focuses on train scheduling/timetabling problem, the developed simulation framework can also be used for train rescheduling/dispatching problem if this framework can be fed by real time data. The developed simulation model includes stochastic events, and can easily cope with the disturbances that occur in the railway system.

1. Introduction

Management of railway systems is increasingly becoming an important issue of transport systems. One of the important problems in management of railway systems is the train scheduling/timetabling problem (*TrnSchPrb*). This is the problem of determining a timetable for a set of trains that do not violate track capacities and satisfy some operational constraints. Several variations of the problem can be considered, mainly depending on the objective function to be optimised, decision variables, constraints and complexity of the relevant railway network.

A general most common *TrnSchPrb* in the literature considers a single track linking two major stations with a number of intermediate stations in between [5]. It is assumed that $S = \{1,\ldots,s\}$ represents the set of stations, numbered according to the order in which they appear along the rail line. In particular, 1 and s denote the initial and final stations, respectively. Analogously, it is assumed that $T = \{1,\ldots,t\}$ denotes the set of trains which are candidate to be run in a given time horizon. For each train $j \in T$, a starting station f_j and an ending station l_j ($l_j > f_j$) are given. Let $S^j = \{f_j,\ldots,l_j\} \subseteq S$ be the ordered set of stations visited by train j. A timetable defines, for each train $j \in T$, the arrival and departure times for the stations $f_j, f_j + 1,\ldots,l_j - 1, l_j$. The running time of train j in the timetable is the time elapsed between origin station and destination station of the train [5]. This general *TrnSchPrb* can be more sophisticated by adding some real life behaviour of rail systems or relaxing some assumptions made related with the railway system under consideration.

The *TrnSchPrb* has been studied by researchers and so far many efforts have been spent to solve the problem. In early years, due to the limitations of computers' abilities and the complexity of the problem, the problem was relaxed by unrealistic assumptions and generally deterministic models were studied. Depending on the increasing computer capabilities more realistic models were developed. Although simulation for modelling has been used in some articles, none of them includes a

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comprehensive framework. This has been the main motivation for us to develop a feasible timetable generator simulation modelling framework.

In this study, a feasible timetable generator framework for stochastic simulation modelling is developed for obtaining a feasible train timetable for all trains in a railway system. This framework includes train arrival and departure times for all stations visited by each train and calculated average train travel time. A general stochastic simulation modelling framework is developed and depicted step by step in order to guide to researchers who aim to develop a simulation model of railway transportation systems. By using this framework all the railway transportation systems can be modelled with only problem/infrastructure specific modifications and feasible solutions are easily obtained. In order to avoid a deadlock, a general *blockage preventive algorithm* is also developed and embedded into the simulation model.

In Section 2 a literature review on the *TrnSchPrb* is given. A feasible timetable generator simulation modelling framework is demonstrated in detail in Section 3. A hypothetic problem and the proposed simulation model are also introduced in this section. In Section 4 the obtained results are discussed. Concluding remarks and future work directions are exhibited in the last section.

2. Literature review on train scheduling/timetabling problem

The existing studies about the *TrnSchPrb* aim at achieving a train timetable with arrival and departure times of all trains at the visited stations in the system. These studies generally begin with a planned *infeasible* initial (draft) timetable with many conflicts. After these conflicts were solved a *feasible* train timetable is composed, and the train operating authority runs the trains according to the timetable. In review papers; Assad [1], Cordeau et al. [9], Newman et al. [19] and Caprara et al. [6] some railway optimisation problems are considered, the *TrnSchPrb* is regarded in only one section, and none of these review papers concentrates solely on the *TrnSchPrb*. In papers that focus on the *TrnSchPrb* mathematical models are; Frank [10], Szpigel [23], Mees [18], Jovanovic and Harker [13] and Odijk [20]. On the other hand Higgins et al. [12], Brännlund et al. [2], Tormos et al. [24] and Liu and Kozan [17] are used heuristics and meta-heuristics as solution approaches.

Two study series draw our attention. The first serial includes four articles; Caprara et al. [4,5,7] and Cacchiani et al. [3]. The second one consists of Zhou and Zhong [27] and Castillo et al. [8]. Caprara et al. [4,5] concentrate on train timetabling problem relevant to a single, one way track linking two major stations with a number of intermediate stations between them. A graph theoretic formulation is proposed for the problem using a directed multigraph in which nodes correspond to departures or arrivals at a certain station at a given time instant. The objective is to maximise sum of the profits of the scheduled trains. Caprara et al. [7] extend the problem considered by Caprara et al. [5], by taking into account additional real world constraints. On the other hand, Cacchiani et al. [3] propose heuristic and exact algorithms for the periodic and non-periodic train timetabling problem on a corridor to maximise the sum of the profits of the scheduled trains. The heuristic and the exact algorithms are based on the solution of the relaxation of an integer linear programming formulation in which each variable corresponds to a full timetable for a train. This approach is in contrast with previous approaches proposed by Caprara et al. [4,5,7] so that these authors considered the same problem and used integer linear programming formulations in which each variable was associated with a departure and/or arrival of a train at a specific station in a specific time instant. Zhou and Zhong [27] focus on single track and propose a generalised resource constrained project scheduling formulation for train timetabling problem. The developed algorithm chronologically adds precedence relation constraints between conflicting trains to eliminate conflicts, and the resulting sub-problems are solved by the longest path algorithm to determine the earliest start times for each train in different segments. Castillo et al. [8] use an optimisation method to solve train timetabling problem for a single tracked bidirectional line, similar to the one presented by Zhou and Zhong [27] but more complex, and discuss the problem of sensitivity analysis. A three stage method is proposed to deal with the problem and a sequential combination of objective functions is used for solution.

In recent years, the authors, Zhou and Zhong [26], Liebchen [16], and Lee and Chen [15] have spent many efforts to optimise multi objective train scheduling problems.

In only a few papers a simulation model was developed for the *TrnSchPrb*. To our knowledge, Wong and Rosser [25] are the first authors who developed a simulation model for train scheduling problem. The output of the simulation model comprises a pictorial representation of the pattern of train movements as well as detailed statistics for each train. The problem is to determine where a crossing or overtaking should be allowed to occur, and the objective is to minimise the sum of weighted costs of delaying trains at passing loops where the weights chosen reflect the importance of each type of train. To improve the system performance, train starting times are varied, and one train at a time heuristic iterative procedure is used for improvements. Petersen and Taylor [22] presented a state space description for the problem of moving trains over a line, and an algebraic description of the relationships that must hold for feasibility and safety considerations was given. The line blockage problem at high traffic intensities was discussed under conditions that ensure the blockage not to occur. The objective of the study is to minimise the terminating times of the trains. Geske [11] focused on the railway scheduling problem and developed a constraint based deterministic simulation model with the objective of reducing the lateness of trains. Selecting alternative paths in stations was an optimisation task to reduce lateness and to find a conflict free solution. The results of the proposed sequentially train scheduling heuristic was compared with those of a genetic algorithm.

Above, a brief review of existing research related to the *TrnSchPrb* has been presented. While analytical results were obtained by exact algorithms, simulation models and meta-heuristics with approximate outcomes were also employed. The meta-heuristics were employed by the researchers in the relevant area after 1990s, multi objectives were optimised