Dr.METRO: a demand-responsive metro-train operation planning program

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Abstract

This paper introduces Dr.METRO, which is a demand responsive metro-train operation planning program. It involves several key functions for metro-train operation planning such as the data handling of passenger traffic, demand forecasting, train scheduling and the sequencing of a train-set operation.

It uses mathematical optimization techniques to solve the train scheduling problems and heuristic algorithms for the sequencing of a train-set out of the train schedule. Besides the optimization technique-based algorithms, it fulfils several useful graphic user interface (GUI) functions that are designed to be user friendly.

Dr.METRO is a software program developed to operate stand-alone with a compact and open structure. Its operating condition is IBM – a compatible PC and Windows framework. One of its merits is that a planner can use it separately from a formal business process in a company. So that he/she can prepare a train schedule according to his/her own creative concept and experience, not being restricted to organizational considerations. Dr.METRO helps them perform various quantitative analyses on schedule, sequence and monitor passenger traffic for better a train schedule and train-set sequence.
Keywords: Dr.METRO, train, schedule, sequence.

1 Introduction

This paper introduces Dr.METRO, which is a demand responsive metro-train operation planning program. Dr.METRO involves several key functions for metro-train operation planning such as the data handling of passenger traffic, demand forecasting, train scheduling, train sequencing for train-set operation.

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The key functions were selected after careful consideration of the processes of train scheduling and train-set sequencing from different companies in Korea. We identified standard functions and processes from several companies' business processes. The common functions and processes were selected as standard ones for Dr.METRO.

Many of the metro-train operating companies have operated on multiple lines and employed several thousand staff [1, 2]. These companies who are larger organizations in size have their own software systems for planning train operation developed by system integration (SI) projects. But a few small companies, who operate only one line and employ much fewer staff, have emerged in Korea recently. Most of the small operators are funded by Public-Private Partnership (PPP) projects, since they try to save the operating costs as far as possible. Therefore, they do not want to undertake the SI projects for train operation planning process. Some of them utilize side functions installed in the traffic control system instead. The number of the small metro-train operators is anticipated to increase for more than a decade [3].

Dr.METRO can be an option to this situation. It was developed to a stand-alone software program with compact and open structure. It operates under IBM – a compatible PC windows framework. Thus it is much cheaper than the software systems developed by the SI projects.

Another merit of Dr.METRO is that a planner can use it separately from a formal business process in a metro-train operation company. So that he/she can prepare a train schedule according to his/her own creative concept and experience. Dr.METRO helps them perform various quantitative analyses on schedule, sequence and passenger traffic for a better train schedule and train-set sequence with advanced mathematical optimization based and heuristic algorithms.

In deploying a mathematical optimization algorithm, we consider two mixed integer programming (MIP) problem solvers; IBM CPLEX and GUROBI. IBM CPLEX is well known to researchers as a MIP problem solver, but we chose GUROBI under consideration of costs. This paper presents a comparison between IBM CPLEX and GUROBI for train scheduling problem instances prepared to Seoul subway line 7.

The later part of this paper consists of; section 2, which presents the key functions of Dr.METRO, section 3 that presents the test results of solver engines to the train scheduling problem instances and lastly, section 4, which presents a conclusion and future work for Dr.METRO.

2 Key functions of Dr.METRO

Table 1 represents the key functions of Dr.METRO. The function of data handling is to input, edit, and delete data to (from) a database in Dr.METRO. The data is selectively collected to run the key functions. The data includes the essential components of infrastructure, operation and rail vehicle for building train schedule and train-set sequence.

Table 1: Functions of Dr.METRO.

Functions	Sub-functions
Data handling	• Infrastructure – Node-arc network, track section, stations, meet-overtaking side, depot
	• Operation – Previous timetable, stop-pattern, headway, running time, dwell time
	• Rail vehicle – Type, composition, seat capacity, fleet size
Demand forecast	• Traffic – Smart transport card (STC) data
	• Forecast traffic demand for station-station by sensitivity analysis
Train scheduling	• Single pattern and skip-stop pattern train scheduling
	• TDE – Train diagram editor for train schedule
	• Congestion analysis for each train and track section
Train-set sequencing	• Train-set sequencing by heuristic algorithm
	• GCE - Gantt chart editor for train-set sequence

The function of demand forecast utilizes historical passenger traffic data obtained by smartcard. These days, smartcard systems are very common in most big cities over the world. Particularly, over 90% of passengers in Seoul and 50% of passengers in Korea use the smartcard for public transportation [4]. Dr.METRO takes advantage of the smartcard traffic data to identify passenger traffic patterns and forecast traffic demand.

The function of a train schedule is to provide a feasible train schedule to planners in the metro-train operators. Dr.METRO can provide a train schedule that consists of heterogeneous stop-patterns such as all-stop and skip-stop patterns. Figure 1 shows a snapshot of a train schedule to operate the express train with a skip-stop pattern together with the normal train with an all stop-pattern.

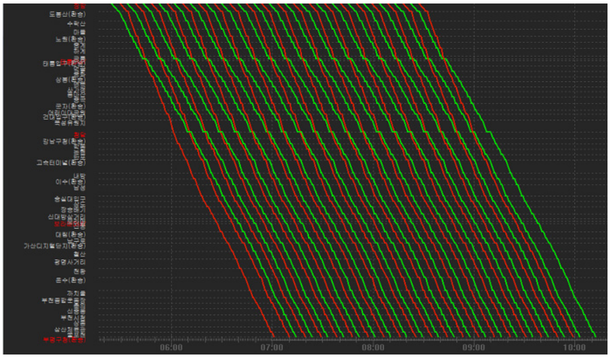

Figure 1: A snapshot of a train schedule.

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The standard stop-pattern indicates in which station express and normal trains should stop or pass. In addition, the pattern includes the run time for every station–station track section and the dwell time for every station. The function is quite useful to schedule the express train together with the normal train on the same line. The standard stop-pattern can be prepared by taking advantage of a commercial software program (e.g. Excel). A planner can complete the standard stop-pattern by importing to Dr.METRO.

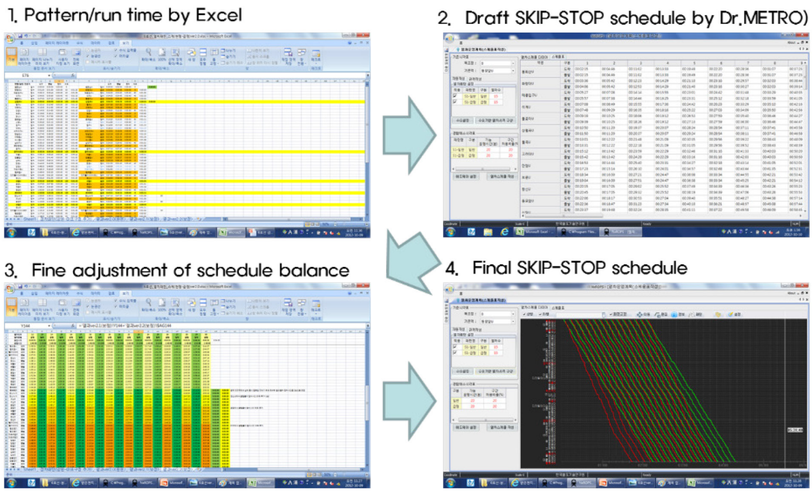

Figure 2: A process to complete a train schedule by Dr.METRO.

Figure 2 shows a train schedule process with Dr.METRO. As shown in Figure 2, a train schedule can be represented by both a train diagram window and a train timetable window. A planner can make fine adjustments to a draft train schedule, and then complete it in Dr.METRO.

Besides the commercial spreadsheet program, Dr.METRO provides TDE to adjust the draft train schedule in the train diagram window directly. By using TDE, a planner can make modification of duplicating, shifting, inserting, removing as well as tilting train-graph, adjusting dwell time for some trains selectively.

Dr.METRO provides information on congestion for each train and track section. The congestion information can help planner to build train schedule in passenger side. The information is possible to provide by using specially developed algorithm for Dr.METRO. Thus a planner can improve his train schedule in a point of passenger ridership-pattern.

The last key function of Dr.METRO is train-set sequencing. It provides train-set sequencing plan for efficient rail-vehicle operation. A train-set sequence is a set of trains arranged to a sequence (e.g. up-ward train – down-ward train), so that each and every train-service included in a sequence is implemented by individual rail-vehicle. Dr.METRO considers various constraints out of operation rules and infrastructure conditions (e.g. maintenance requirements, minimum turnaround time in a depot) to provide feasible train-set sequencing plan.

Special heuristic algorithm was developed to minimize wasting time between sequential trains. Figure 3 shows a snapshot of a train-set sequencing plan prepared by Dr.METRO.

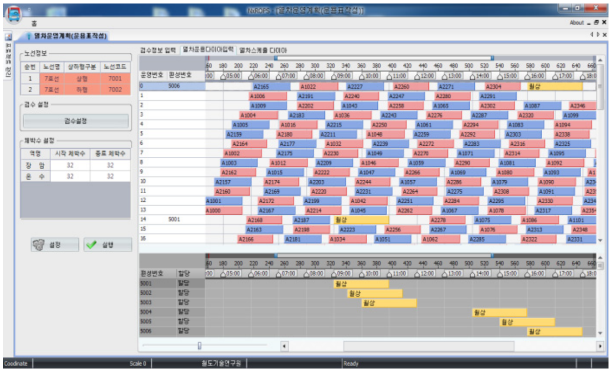

Figure 3: A snapshot of a train-set sequencing plan by Dr.METRO.

Dr.METRO provides a Gantt-chart editor (GCE) to adjust a draft train-set sequence plan. It is quite useful in reflecting planer's experience to the draft.

3 MIP solver for train scheduling problem

Dr.METRO provides a solution for a train scheduling problem model to Equations (1)–(12). In the MIP model, all capital letters are given parameters such as travel time (TRV) from first to last station (i.e. 1 m), run time (RUN) for each consecutive track section, dwell time (DWL) for each station, safety headway for departure and arrival (HD, HA). Others are decision variables; a_{is} and d_{is} are arrival and departure times of train-i at a station-s. $x_{ijs} = 1$, when train-i precedes train-j in a track section (s–s + 1), $x_{ijs} = 0$, otherwise;

$$\min \sum_{i \in T} (d_{ir}^{+} - d_{ir}^{-}) + \sum_{i \in T} (a_{im}^{+} - a_{im}^{-}) \tag{1}$$

such that,

$$a_{im} - d_{i1} \le TRV_i, \qquad \forall \mathrm{i} \in \mathrm{T} \tag{2}$$

$$a_{is+1} - d_{is} \ge RUN_{is}, \qquad \forall \mathrm{i} \in \mathrm{T}, \forall \mathrm{s} \in \mathrm{S}, \mathrm{s} \ne \mathrm{m} \tag{3}$$

$$\underline{DWL}_{is} \le d_{is} - a_{is} \le \overline{DWL}_{is}, \qquad \forall \mathrm{i} \in \mathrm{T}, \forall \mathrm{s} \in \mathrm{S} \tag{4}$$

$$d_{js} - d_{is} + M(1 - x_{ijs}) \geq HD, \quad \forall \mathrm{i} \in \mathrm{T}, \forall \mathrm{s} \in \mathrm{S}, \mathrm{i} < j, s \neq m \tag{5}$$

$$d_{is} - d_{js} + Mx_{ijs} \geq HD, \quad \forall \mathrm{i} \in \mathrm{T}, \forall \mathrm{s} \in \mathrm{S}, \mathrm{i} < j, s \neq m \tag{6}$$

$$a_{js+1} - a_{is+1} + M(1 - x_{ijs}) \geq HA, \quad \forall \mathrm{i} \in \mathrm{T}, \forall \mathrm{s} \in \mathrm{S}, \mathrm{i} < j, s \neq m \tag{7}$$

$$a_{is+1} - d_{js+1} + Mx_{ijs} \geq HA, \quad \forall \mathrm{i} \in \mathrm{T}, \forall \mathrm{s} \in \mathrm{S}, \mathrm{i} < j, s \neq m \tag{8}$$

$$d_{ir} - D_{ir} = d_{ir}^{+} - d_{ir}^{-}, \quad \forall \mathrm{i} \in \mathrm{T}, \exists \mathrm{r} \in \mathrm{S} \tag{9}$$

$$a_{ir} - A_{ir} = a_{ir}^{+} - a_{ir}^{-}, \quad \forall \mathrm{i} \in \mathrm{T}, \exists \mathrm{r} \in \mathrm{S} \tag{10}$$

$$a_{is}, d_{is}, d_{ir}^{+}, d_{ir}^{-}, a_{ir}^{+}, a_{ir}^{-} \geq 0, \quad \forall \mathrm{i} \in \mathrm{T}, \forall \mathrm{s} \in \mathrm{S}, \mathrm{i} < j, s \neq m \tag{11}$$

$$x_{ijs} \in \{0,1\}, \quad \forall \mathrm{i}, \mathrm{j} \in \mathrm{T}, \forall \mathrm{s} \in \mathrm{S} \tag{12}$$

Dr.METRO solves the MIP model with commercial solver. We considered two commercial solvers; IBM CPLEX and GUROBI optimizer. We prepared three problem instances taken from Seoul Metropolitan Rapid Transit Corporation (SMRT) for comparison test between the two commercial solvers. The test environment is PC (notebook) with Windows 7. Table 2 shows the results of the comparison between the two solvers for the three instances.

Table 2: Comparison between IBM CPLEX and GUROBI optimizer.

Time periods	Number of trains (Normal/Express)		IBM CPLEX			GUROBI Optimizer		
	Up	Down	Best Bound	Time (sec.)	Gap (%)	Best Bound	Time (sec.)	Gap (%)
07:00 –09:00	40 (27/13)	40 (27/13)	5.7e + 10	185	0.00	5.7e + 10	162	0.00
05:00 –19:00	70 (45/25)	70 (45/25)	1.5e + 09	1,725	0.01	8.5e + 08	623	0.0091
05:00 –24:00	123 (83/40)	123 (83/40)	-	Limit exceeded	-	1.5e + 09	Limit exceeded	0.1504

Both IBM CPLEX and GUROBI Optimizer outcome solutions for the first two instances and could not for the third one in the time limit (30 minutes). For the first two instances, GUROBI Optimizer provided better solutions in shorter time than IBM CPLEX.

We made conclusion no considerable difference exists between the two solvers in performance. But we selected GUROBI optimizer since it is much cheaper than IBM CPLEX in deployment license cost [5, 6].

4 Conclusions

A few number of small metro-train operators have emerged in Korea recently, and the number is anticipated to increase for several years. Most of them are funded by PPP projects, since they want to minimize the investment cost in operating trains. Dr.METRO can be a good option for this situation on both the performance and the cost sides.

Moreover Korean metro-train operators try to operate the express train in their existing line to provide the traffic service with short travel time. Dr.METRO can provide a solution to build the train schedule with the skip-stop pattern.

Dr.METRO equips advanced functions for forecasting passenger demand and analysing train congestion in train scheduling. It is possible to develop the functions by using smart transportation card data. The functions are quite useful for improving the quality of a train schedule, particularly from the passengers' perspective.

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