2016 INFORMS RAS Problem Solving Competition

Routing Trains through a Railway Network: Joint optimization on train timetabling and maintenance task scheduling

RAS Problem Solving Competition Committee

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DISCLAIMER: Thank you for your interests in this problem solving competition activity. The problem described here represents one of challenging issues in railway operations management. We have simplified a real world problem for this competition. More general problems and related literature is available on the competition web-site under the section "Related Literature". Good luck for the competition!

1. Introduction

Train timetabling is a classical problem in railway operations management. A train timetable specifies a physical network route and detailed arrival time and departure time stamps for each train at passing stations. Train timetabling is a challenging task in a saturated railway network, especially when it consists of complex stations where there are a number of crossings and switches.

Maintenance of tracks is important for ensuring tracks are in appropriate states for running trains. Conducting maintenance tasks needs a blockage of tracks which means that there is complete capacity breakdown of the tracks and no train is allowed to run on the tracks during the maintenance time duration.

Train timetabling problem has been studied for many years. For survey papers, please refer to Assad (1980), Cordeau et al. (1998), Hansen (2010), and Harrod (2012). Also numerous papers address maintenance task scheduling problem, e.g. Budai et al. (2006), Peng et al. (2011), and Lidén (2015). It should be noted, that the problem introduced in this document has its real world challenges which have not been completely met in the literature.

This year's RAS problem solving competition addresses the real world problem that how to route trains through a complex railway network? Main challenges of the problem come from complicated infrastructure capacity and interactions between train timetabling and maintenance task scheduling.

This document is organized as follows: Section 2 presents definitions of relevant terms and problem assumptions, followed by explanations on problem input and output, optimization objective function and constraints in Section 3. Structure of input and output data files is given in Section 4. Finally a toy problem is given in Section 5.

Note: Please read the problem description and "toy problem" very carefully. Participants must use the given objective function and all constraints must be respected.

2. Relevant definitions and assumptions

2.1 Relevant definitions

Below definitions are based on descriptions given by UIC code 406 (2004), Pachl (2009) and Meng et al. (2015).

(1) Railway network

Railway network is a macroscopic concept. It is used to describe the layout of railway facilities. A railway network consists of stations, segments, tracks and so on. Fig. 1 illustrates a simple railway network consisting of 6 stations and 6 segments.
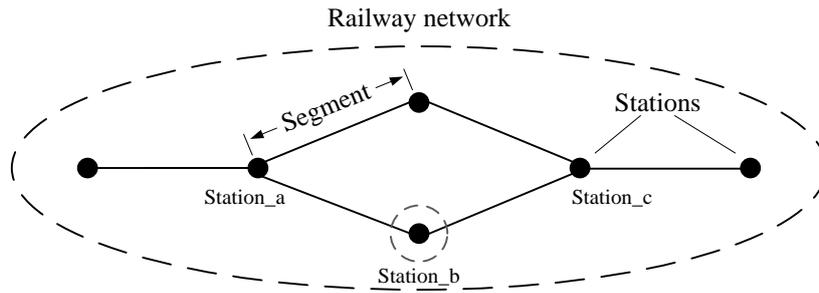
Fig. 1 A simple railway network

(2) Station

Railway station is a railway facility where trains may stop to load or unload passengers or goods, and overtaking, crossing or direction reversals are possible. Apart from main track(s), it often has siding track(s) to facilitate trains passing or overtaking.

(3) Segment

Segment is the track(s) between two stations, which can be divided into block sections for the purpose of safe train separation. A block section (in a fixed block system) means a section of track, which a train may only enter when it is not blocked by other trains. A segment may consist of one track (single-track), two tracks (double-track) or more tracks (e.g. triple-track). In this document, we only consider segments with two tracks.

(4) Line

Line is a series of stations and segments in between.

(5) Track

Tracks are the roadways of a railway system. A track consists of the rails, ties, plates between rails and ties, fasteners, ballast and so on. Main tracks are the tracks that can be used for regular train movements, except for train stopping. Siding tracks are the tracks other than main tracks, which can be used for regular train movements, e.g. train stopping, passing and overtaking.

(6) Node

A node can be viewed as a point where tracks join together. It can be used to model a beginning/ending point of a cell or a point inside a cell.

(7) Link

A link is the track between two nodes.

(8) Cell

A cell is a group of links. A cell is allowed to be occupied by at most one train at any given time. Please note that once one link in the group is occupied, it means all other links in the same group are occupied at the same time.

(9) Block section

A block section means a sequence of cells. In a station, it refers to the track between one home signal and one departure signal or between one departure signal and one boundary point. In a segment, it refers to the track between two passing signals.

(10) Boundary point

A node along which a home signal is located or a node specifying the boundary between a station and a segment.

(11) Main signal

Home or departure signal in a station.

(12) Passing signal

Signals in a segment.

(13) Track maintenance task

A set of jobs which are conducted within a time duration to ensure tracks and infrastructure are in good states for running trains. This is specified at the level of single cell involved.

(14) Track maintenance time duration

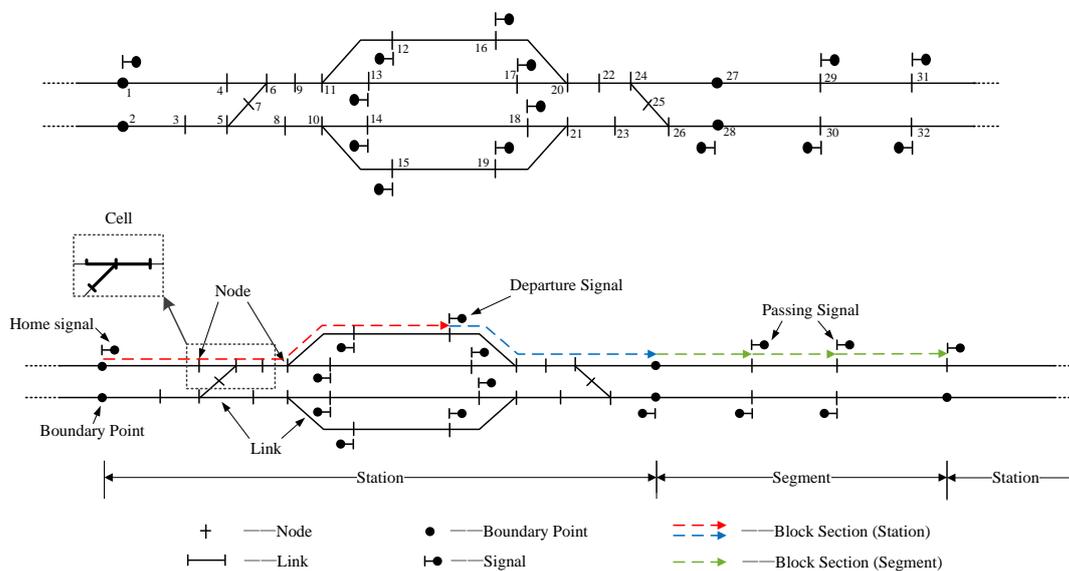The time period when track maintenance tasks are conducted.

Fig. 2 Illustration of Station_b in detail

Fig. 2 gives a systematic illustration of above terms, in which:

(1) Number 1-32 indicate nodes.

(2) Each link connects two nodes, so a link can be represented by a pair of nodes, such as (1, 4).

(3) Two types of cell are indicated:

    1) A cell just consisting of one link, e.g. cell [(1, 4)].

2) A cell consisting of several links, e.g. cell [(4, 6), (6, 7), (6, 9)]. In this type of cell, once one link (e.g. (4, 6)) in the group is occupied, it means all other links (e.g. (6, 7), (6, 9)) in the same group are occupied at the same time.

(4) Three types of block section are indicated.

1) Block section from home signal to departure signal (red dashed lines), also called as an "arrival block section": e.g. block section consisting of cell [1, 4], [(4, 6), (6, 7), (6, 9)], [(9, 11), (11, 12), (11, 13)], [12, 16].

2) Block section from departure signal to boundary point (blue dashed lines), also called as a "departure block section": e.g. block section consisting of cell [(16, 20), (17, 20), (20, 22)], [(22, 24), (24, 25), (24, 27)].

3) Block section from boundary point to home signal (green dashed line), also called as a "passing block section".

(5) Boundary points in Station_b include nodes 1, 2, 27 and 28.

(6) Two types of main signal are indicated:

1) Home signal: signals located along node 1 and 28.
2) Departure signal: signals located along node 12, 13, 14, 15, 16, 17, 18, and 19.

(7) Passing signal: signals located along node 29, 30, 31, and 32

2.2 Problem assumptions

In this document, the following assumptions are applied:

(1) One train is represented by a virtual dot for simplicity, and train acceleration and deceleration processes are not necessary to be considered (i.e. they are infinite).

(2) For a double-track railway segment between two stations, each track is modelled as a sequence of block sections, and for a single-track railway segment, the only track between two stations is modelled as one block section.

3 Problem definition

The problem has inputs and outputs as below:

(1) Input

1) A railway network with detailed topology information.

2) A set of train running tasks extracted from an ideal train timetable, where departure time windows at corresponding origin stations are given, also required stops with minimum dwell times are given for each train. Note that arrival or departure time windows at intermediate stations and destination stations are not required.

3) A set of track maintenance tasks with information where the tasks should be conducted and minimum maintenance time duration.

(2) Output

1) A train timetable specifying train routes on the railway network and corresponding arrival and departure time stamps at passing stations of each train.

2) A maintenance task schedule defining beginning time and ending time of each maintenance task, for each cell involved.

3.1 Objective function

Minimize total travel time of all involved trains.

3.2 Constraints (Operational rules)

(1) Departure time window constraints

Trains' departure times at their origin stations should be within given time windows.

(2) Minimum running time constraints

Running times of trains on tracks (cell) should be equal to or larger than the given minimum running times.

(3) Train stops constraints

Trains should have stops at stations where a stop is required. At stations, a train must stop at a siding track, in other words, train stop at a main track is not allowed. Trains may have extra station stops. Note that trains can traverse a cell at a slower speed than the free flow speed (and also stopping there if required).

(4) Minimum dwelling time constraints

If one train stops at a station (where a stop is required), it should stop at a siding track (cell) for a time period equal to or larger than the given minimum dwell time.

(5) Cell occupancy constraints

There should be at most one train occupying one cell at any time.

(6) Block section occupancy constraints

For departure and passing block sections, all cells in a block section are occupied and released at the same time. For arrival block sections, all cells in a block section are occupied at the same time, the cells except the last cell of the block section are released when the train arrives at the last cell and the last cell is released when the train leaves from it.

A train is not allowed to enter a block section which contains a cell under maintenance.

Once a train enters a block section, it has to traverse the whole block section.

Note: Sectional release is not considered in this activity. For simplifying the problem and without loss of generality, a minimum headway time before and after a train's running is not necessary to be considered in this activity.

(7) Block section selection constraints

One train needs to select one and only one block section to arrive at or leave from a station.

(8) Speed reduction constraints

In a double-track segment, when one cell belonging to one track is in a maintenance task, trains running on the other whole track (a sequence of cells) in the same segment (if there are) should slow down (e.g. running at 50m/h) for safety reasons.

(9) Speed restriction constraints

After maintenance task is finished on one cell, the first and second trains running on the cell should run at restricted (maximum) speeds (e.g. for the first train 30m/h, the second train 80m/h). Moreover, for adjacent/parallel cells of the cell which is right after maintenance, it's not necessary to restrict train running speeds.

(10) Maintenance task adjacency constraints

The time window of maintenance tasks on adjacent cells should be adjacent, in order to save relevant costs. In other terms: if two adjacent cells have a maintenance task, the maintenance tasks should be overlapping or contiguous.

(11) MOT starting time window constraints

The starting time of a MOT should be in a time window defined by the earliest and latest starting time.

(12) Completeness constraints

1) All trains and maintenance tasks should be scheduled.
2) A maintenance task cannot be split into pieces.

4 Structure for input and output data

4.1 Structure of input data

(1) Input_Node.csv file: This file gives data about relevant nodes in the railway network. A table is given as below detailing this file.

1
node_id

Column 1: Id of one node in the railway network.

(2) Input_Link.csv file: This file gives data of links in the railway network. A table is given as below detailing this file.

1	2	3	4	5	6	7	8
from_node _id	to_node _id	length_in _mile	speed_limit_in_ mph_FT	speed_limit_in_ mph_TF	link_capacity_in_train_per_time_interval (e.g. one train per minute)	dwelling_allow able_flag	bidirectional _flag

Column 1: Starting node i corresponding to link (i, j);

Column 2: Ending node j corresponding to link (i, j);

Column 3: Length of link (i, j), unit in mile;

Column 4: Maximum running speed for trains to drive through link (i, j), unit in mile per hour;

Column 5: Maximum running speed for trains to drive through link (j, i), unit in mile per hour;

Column 6: Capacity of link (i, j) per time unit;

Column 7: Type of link (i, j), 1-siding track in a station that allows for train stop, 0-otherwise;

Column 8: Bidirectional flag of link (i, j), 1-bidirectional, 0-unidirectional.

(3) Input_Cell.csv: This file gives data of cells. A table is given as below detailing this file.

1	2	3
cell_id	from_node_id	to_node_id

Column 1: Id of one cell in the railway network;

Column 2: Origin node of one link in the cell;

Column 3: Destination node one link in the cell.

(4) Input_Block_Section.csv: This file gives data of block sections in all stations. A table is given as below detailing this file.

1	2	3
block_section_id	cell_sequence_number	cell_id

Column 1: Id of one block section in the railway network;

Column 2: Sequence number of one cell in the block section; Please note that the cells in one

Column 3: Id of one cell in the block section.

(5) Input_Train_Info.csv: This file gives data of trains in the railway network. A table is given as below detailing this file.

1	2	3	4	5	6
train_id	origin_node_id	destination_node_id	speed_multiplier	earliest_departure_time	latest_departure_time

Column 1: Id of one train in the railway network;

Column 2: Origin node id of one train;

Column 3: Destination node id of one train;

Column 4: Speed multiplier of one train in normal conditions, thus the actual free flow running speed for the train on the link is obtained by multiplying maximum free-flow running speed of the link and the speed multiplier of the train;

Column 5: Earliest departure time at its origin node;

Column 6: Latest departure time at its origin node.

(6) Input_Train_Required_Stop.csv: This file gives data of required stops for trains in the railway network. A table is given as below detailing this file.

1	2	3	4
train_id	station_name	require_stop	minimum_dwelling_time_in_minute

Column 1: Id of one train in the railway network;

Column 2: Name of a station;

Column 3: Whether the train is required to stop at the station, 0-No, 1-Yes;

Column 4: The value of dwelling time (unit in minute), if the train is required to stop at the station.

(7) Input_MOT.csv: This file gives data of maintenance tasks in the railway network. A table is given as below detailing this file.

1	2	3	4	5	6	7	8
mot_id	cell_id	earliest_starting_time	latest_starting_time	minimum_time_duration	speed_limit_in_mph_first_train	speed_limit_in_mph_second_train	speed_limit_in_mph_other_track_same_segment

Column 1: Id of the mot;

Column 2: Id of the cell which needs maintenance;

Column 3: Earliest starting time of the MOT, unit in minute;

Column 4: Latest starting time of the MOT, unit in minute;

Column 5: Minimum time duration of maintenance task, unit in minute;

Column 6: Maximum running speed of the first train running on all links regarding the cell

under maintenance after maintenance task, unit in mile per hour;

Column 7: Maximum running speed of the second train running on all links regarding the cell under maintenance after maintenance task, unit in mile per hour;

Column 8: Maximum running speed of trains running on the other whole track (a sequence of cells) in the same segment (if there are) during the duration of maintenance, unit in mile per hour.

4.2 Structure of output data

(1) Output_Timetable.csv: This file describes data of an output timetable. A table is given as below detailing this file.

1	2	3
train_id	node_id	arrival_time

Column 1: Id of the train;

Column 2: Id of the node the train passes by;

Column 3: Time stamp when train arrives at the node.

(2) Output_MOT_Schedule.csv: This file describes data of an output maintenance task schedule. A table is given as below detailing this file.

1	2	3
mot_id	starting_time	ending_time

Column 1: Id of the MOT;

Column 2: Time stamp when the maintenance task starts;

Column 3: Time stamp when the maintenance task ends.

5 Toy example

Input: All related input data of the toy problem is given in CSV files as attachments.

(1) Infrastructure: As illustrated in Fig. 3, we consider a junction station named Station_S with 58 nodes and 62 links. For detailed information, please see "Input_Node.csv", "Input_Link.csv", "Input_Cell.csv" and "Input_Block_Section.csv".
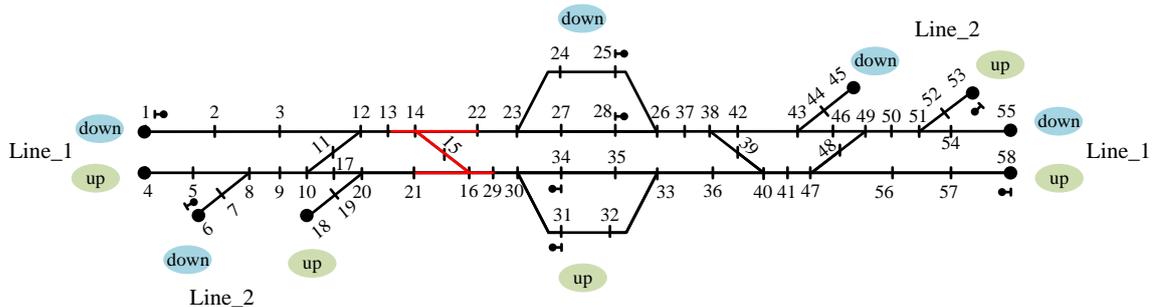
Fig. 3 Illustration of a partial railway network for the toy problem (place of MOT is marked in red color) around Station_S

(2) Trains: There are 2 trains to be scheduled. Train 1 goes from node 58 to node 18 in departure time window (30, 31); Train 2 goes from node 1 to node 45 in departure time window (1, 45). For detailed information, please see "Input_Train_Info.csv" and "Input_Train_Required_Stop.csv".

(3) Maintenance of tracks: We have 1 MOT task with minimum time duration of 30 minutes. The influenced cells are marked in red color in Fig. 3. For detailed information, please see "Input_MOT.csv".

Remark: In this toy problem, for file "Input_MOT.csv", the column "speed_limit_in_mph_other_track_same_segment" does not apply as the MOT is in a station, rather than in a segment.

The committee has built up an integer programming model and solve the model using CPLEX solver. The optimal solution has an objective function value of 36 minutes. Table 1 gives a summary of the optimal solution. For detailed information, please see "Output_Timetable.csv" and "Output_MOT_Schedule.csv".

Table 1 Summary of optimal solution (unit of time is one minute)

Train	origin node	destination node	departure time at origin	arrival time at destination
Train_1	58	18	31	49
Train_2	1	45	40	58
MOT	**working place**		**starting time**	**ending time**
MOT_1	(13,14), (14,15), (14,22), (15,16), (21,16), (16,29)		0	30

Note: In the toy problem, for simplicity reason and without loss of generality, the running time for a train traversing a link is rounded up to an integer, which implies that the granularity of time is 1 minute. For example, regarding link (i, j) and train f, we assume value of "length_in_mile" is 1, value of "speed_limit_in_mph_FT" is 80, value of "speed_multiplier" is 1, the free flow running time from i to j is $(1*60)/(80*1) = 0.75$ min. After rounding up the value 0.75min, 1 minute is used as the free-flow running time for train f traversing from i to j. Please note that one may use a finer time granularity, e.g. half a minute or 1 second in their computations.

6 Practical problem

We use three adopted practical datasets for problem solving competition. Please download relevant datasets from the website. All three datasets have the same infrastructure and the only difference comes from MOTs. In each dataset, you have an illustration of the railway network with MOTs in both PDF and VSD formats.

7 Solution evaluation

All problems with different datasets need to be solved. The committee will develop a solution checker for examining feasibility of proposed solutions by participants. We will check feasibility of solutions using one second as the time granularity. Apart from timetables and MOT schedules, the participant are kindly required to provide a report which includes the methodology they use, the objective function value of their solution(s), computational time of the searching process.

Acknowledgments

References

Assad, A., 1980. Models for rail transportation. Transportation Research Part A, 14 (3): 205-220.

Budai, G., Huisman, D., Dekker, R., 2006. Scheduling preventive railway maintenance activities. The Journal of the Operational Research Society, 57(9): 1035-1044.

Cordeau J., Toth, P., Vigo, D., 1998. A survey of optimization models for train routing and scheduling. Transportation Science, 32 (4): 380-404.

Hansen, I. A., 2010. Rail Network timetabling and dynamic traffic management. International Journal of Civil Engineering, 8(1): 19-32.

Harrod, S., 2012. A Tutorial on Fundamental Model Structures for Railway Timetable Optimization. Surveys in Operations Research and Management Science, 17: 85-96.

International Union of Railways (UIC) Code 406. Capacity. 1st Edition, June 2004.

Lidén, T., 2015. Railway Infrastructure Maintenance - A survey of planning problems and conducted research. Transportation Research Procedia, 10: 574-583, doi:10.1016/j.trpro.2015.09.011.

Meng, L., Luan, X., Zhou, X., 2015. A train dispatching model under a stochastic environment: stable train routing constraints and reformulation. Networks and Spatial Economics, DOI: 10.1007/s11067-015-9299-1.

Pachl, J., 2009. Railway Operation and Control. VTD Rail Publishing, Mountlake Terrace (USA), 2nd edition, ISBN: 978-0-9719915-8-3.

Peng, F., Kang, S., Li, X., Ouyang, Y., Somani, K., Acharya, D., 2011. A heuristic approach to the railroad track maintenance scheduling problem. Computer-Aided Civil and Infrastructure Engineering, 26 (2): 129-145.