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A NEW SCHEDULING APPROACH TO TRAIN PLATFORMING PROBLEM

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Summary: The aim of the paper is to introduce a decision-making tool for assignment of trains to platforms. Train platforming problem is formulated as special case of parallel machine scheduling problem in which jobs and parallel machines are synonymous with trains and tracks. Objectives of the model are to minimize total delay of trains and to maximize number of trains (station capacity) and to maximize number of connecting trains assigned to the same platform.

Key words: track, model, platform, track occupation diagram (train platforming problem), parallel machine scheduling problem, railway transport, railway station.

INTRODUCTION

Railway plays a big role for freight and passenger transportation. Investments in railway transport increase considerably, especially in European countries. Railway operation is consisted of a set of complex and difficult decision-making processes. One of the most important processes is traffic control in railway station. Operational conflicts of trains can be reduced by making of an effective occupation diagram (plan) of station tracks. This decision-making process is managed by a station dispatcher. Possible operational conflicts in this area (waiting of train for a station track) are caused by two reasons. The first is represented by irregular situations in operation (e.g. a case of number of delayed trains) and the second reason by possible human-factor mistakes (in decision-making). These two

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reasons can cause that the whole process can be possibly ineffective. An efficient decision making tool can be needed for assignment of incoming trains to station tracks (platforms).

The aim of this study is to provide a remarkable improvement in assignment process of trains to tracks. Development of modelling approaches and solution techniques can be a base for this improvement.

There was published increasing amount of information sources focused on operational scheduling of railway stations in recent years. Basic overview is provided by following text.

A significant categorization of scheduling and dispatching is mentioned by Törnquist (1). This distinction is consisted of tactical scheduling, operational scheduling and re-scheduling. The author of (1) classified the studies based on type of problem, solution method and type of evaluation.

The work of Chakroborty and Vikram (2) is focused on the train platforming problem with three special features: delays, allocation of non-preferred platforms and last minute reassignment of platforms. The scheduling period is divided into phases with the length of two hours. There is presented a linear mixed integer programing formulation for a busy railway station in India in (2). Optimal results are obtained for problem with up to 110 trains and 9 platforms.

Linear mathematical model for obtaining of an efficient track occupancy plan has been suggested by Krempl [3]. The objective of the model is to minimize total occupation time in the railway station.

Bi-criterion mathematical model with the aim to determine the platforms to serve has been suggested by Jánošíková and Krempl in (4). First objective is to minimize the deviations from arrival and departure times stated by the timetable. The second one is to maximize the desirability of the platform for the train assignment. Lexicographic approach and local branching algorithm are applied. Jánošíková et al. (5) have also developed a multi-objective mathematical model focused on assignment plan of arriving trains and duration of waiting for connecting trains. In addition, the proposed mathematical model has the same specific criteria which are highlighted in (6).

Bažant and Kavička (6) have performed two-layered artificial neural network for solving of assignment problem of platform tracks to delayed arriving trains. To obtain most suitable solutions, authors took into consideration specific criteria including technical and technological preferences.

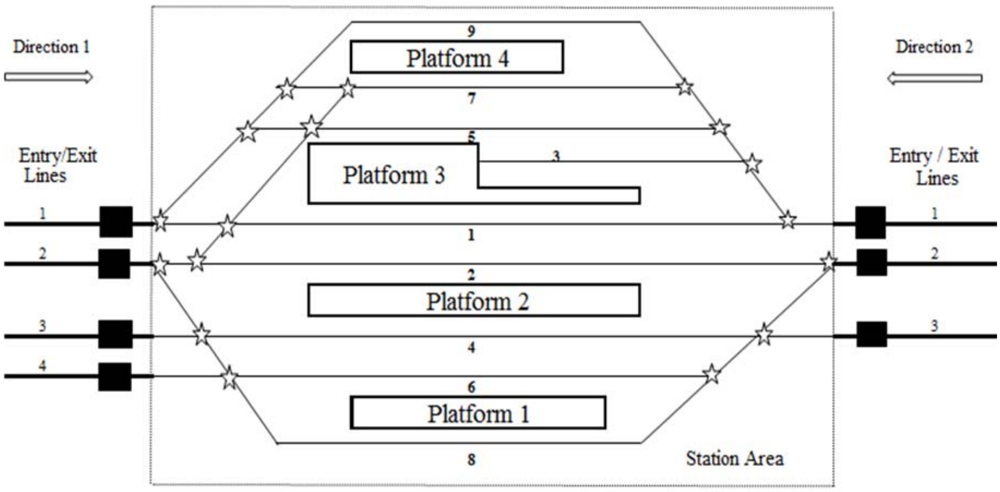
Parallel machine scheduling problem is generally applied to train scheduling problem in literature. To solve train platforming problem, classical mathematical models were presented. To our knowledge, there is no study that handled train platforming problem as parallel machine scheduling problem. In this paper, parallel machine scheduling approach for dispatcher's decision-making process is presented. This model has special constraints like resource constraints and machine eligibility restrictions.

The remainder of this paper is organized as follows. Considered problem is characterized in detail in next section 1. Methods able to be utilized for solving of train platforming problem are mentioned in the section 2. Conclusions are summarized in the final section.

1. PROBLEM STATEMENT

It is necessary to provide a description of operational processes within a railway station before the problem will be stated and mathematized. The problem is solved on the base of conditions of railway system in the Czech Republic (Prague).

Train platforming problem represents decision-making process of dispatchers in railway station. This process includes assignment of trains to station tracks such that they can arrive to the station and depart from the station. Some terms are explained with the help of an example of railway station topology which is illustrated in Figure 1.



Source: Authors

Fig. 1 - Example of railway station topology

There are several points at which trains can stop within the station for boarding (and alighting) of passengers. These points are called platform tracks and can be of different type and length. The infrastructure of railway station is usually consisted of several platform tracks. Trains can enter the station by several entry lines, and leave by several exit lines (line tracks). Usually, each entry line can also represent an exit line and vice versa. Furthermore, each of these lines corresponds to a direction of travel (individual track of railway lines connected to the station). In this paper, the word “line” is used only for description of track out of station area and these tracks (lines) are marked in bold in Figure 1. The figure shows that there are seven entry/exit lines from/to a station and four platforms in this example. As it can be seen in the Figure 1, there are nine platform tracks in the station. Rectangles show home signals. If a train arrives at the signal and if all suitable tracks are occupied, the train is obligated to wait at the home signal. If one of the tracks is available and satisfies operational restrictions, the train can arrive to the platform. The occupation time at the platform track that the train spends on boarding is called as sojourn time. Exit of trains is controlled by exit signals located at each transport station track (platform track).

There are three significant considerations about assignment of platform tracks to trains in railway stations. (1) There might not be a railway connection between all platform tracks and entry/exit lines. Train can be assigned to such a platform track which is connected to adequate entry/exit line. For example, it is not possible to assign a train that comes from line 1 in direction 2 to the platform track 8. (2) Train length must be smaller than length of the platform track. (3) Dead-end platform tracks can be used only for trains departing and arriving from/in directions accessible from given dead-end track. Such train must be able to drive in both directions (or such additional shunting operations must be realized). Dead-end platform track 3 can be used only for trains arriving from entry line 1 and departing to the same exit line 1 (Figure 1). These limitations are called as eligibility restrictions.

Symbols of star (Figure 1) show switches allowing trains to go from one track to another. Train is usually going over certain number of switches and each individual switch is able to be used in different train routes. Naturally, each switch can be occupied by at most one train in a moment. Due to these facts it is necessary to exclude potential conflicts.

. On the other hand, there can be also more alternative routes between given pair of points (e.g. entry line and platform track). Each is created by different combination of switches. The other characteristics of the railway station and its operation concerned in this research can be given as follows:

- Trains arrive at the entry signal (home signal) according to timetable. However, delay of incoming trains must be taken into consideration. This situation effects arrival time to entry signal.
- Traditionally, each train has a different arrival and departure directions. However, in some cases, directions can be the same. It can occur for example in the case if considered

railway station is terminal (final) station of a train. Train waits for a while in the railway station and then departures back to the same direction.

Trains are classified into four types according to usage of railway station. First one is transit train. Transit train comes, stops for alighting and boarding of passengers and departs. In the case of defined pairs of trains it is necessary to create a connection (possibility to interchange). Originating train is defined as a train that is pulled out of the station. Non-stop train is label for a train which does not stop for boarding (alighting) of passengers and passes in station. The most of cargo trains are usually non-stop trains.

Motivation of this paper is solution of the train platforming problem in large railway stations. Inputs into model are: station layout (scheme) and arrival and departure times of trains located in considered time frame. The aim of the model is to assign these trains to platform tracks regarding station capacity, safety conditions (conditions of interlocking system) and several operation constraints. This assignment problem is multi-objective one. The first objective is to minimize the sum of delays of incoming (arriving) and outgoing (departing) trains. This delay may occur when an incoming delayed train is not able to enter the station because all suitable tracks are occupied by other trains (incl. track planned for this train, but in other – scheduled time). So, the train must wait at entry signal until any convenient platform track becomes free. To prevent increase of delay, this objective is handled. Second objective is to maximize the number of trains that can be assigned to platform tracks (maximization of station capacity). The last objective is to maximize number of connecting trains assigned to the same platform. Interchanging passengers are not obligated to go too far, to use underpass etc. and their comfort is improved in this case. It has positive effects on passengers and on the length of interchanging time as well (it can be seriously shorter).

2. SOLUTION METHODS

Proposed way of solution is introduced in this section 2. Firstly, parallel machine scheduling problem is explained in detail. Secondly, it will be shown that train platforming problem can be described in terms of parallel machine scheduling problem.

The parallel machine scheduling problem is a generalization of the single machine scheduling problem. The parallel machine scheduling problem belongs to the Theory of Scheduling. The problem is significant because it is a common phenomenon in real life and a sub-problem of multi-stage complex problems. It is one of the most studied problems in the literature focused on scheduling. This problem can be divided into three groups:

- identical parallel machines, if a job can be produced within the same duration (processing time) on all of the machines;
- uniform parallel machines, if a job is not produced within the same duration on each of machines, but time differences can be explained with a parametric relationship;
- unrelated parallel machines, if processing times display an irregular pattern of differences.

In scheduling problems, it is supposed that number of jobs and number of machines are finite. The number of jobs is denoted by n and the number of machines by m. Subscript j refers to a job while the subscript l refers to a machine. If a job requires more processing steps, then the pair (j,l) refers to the processing step of job j on machine l. The parameters related to job j are given as follows (7):

- processing time (p_j): p_j represents the processing time of job j,
- release date (r_j): r_j of job j may also be referred to ready date. It is the time when the job arrives at the system, i.e., the earliest time at which job j can start its processing,
- due date (d_j): d_j of job j represents the date when the job j must be finished. Completion of job after its due date is allowed, but a penalty is incurred in this case,
- machine eligibility restrictions (M_j): in the case of presence of machine eligibility restrictions, not all l machines are capable to process job j. Set M_j denotes the set of machines able to process the job j.
- precedence constraints (prec): precedence constraints may appear in a parallel machine environment, requiring that one or more jobs may have to be completed before another job is allowed to start its processing,
- starting time (S_j): S_j refers to the time when job j starts with its first processing in the system,
- completion time (C_j): C_j denotes the completion time of the operation of job j,
- tardiness (T_j): T_j is a notation of delay, that job j is completed late (after d_j).

Mixed integer programming formulation of Biskup et.al. [8] is presented here to better illustration of characteristics of parallel machine scheduling problem. The problem handled in the paper [8] can be formally defined as follows: a set $N = \{1,2,...n\}$ of n one-operation jobs will be scheduled on a set $M = \{1,2,...m\}$ of m identical machines. It is presupposed that each job $j \in N$ has a deterministic and integer processing time p_j, release date r_j equal to zero and defined due date d_j. The tardiness $T_j(S)$ of a job j in a schedule S is calculated by $T_j(S) = \max(C_j(S) - d_j, 0)$, where $C_j(S)$ denotes the completion time of the job j in the schedule S. In addition, let S_l be the sequence of jobs scheduled on machine $l \in M$. The objective of problem is to minimize total tardiness. Parallel machine scheduling problem is formulated as a mixed integer linear programming model (MILP). The notations of model are given as follows:

- C_j : completion time of job j,
- T_j : tardiness of job j,
- y_j : binary variable that takes the value one if job j is the first job on one of the m machines,
- x_{ji} : binary variable that takes the value one if job i is scheduled directly before job j on the same machine,
- $x_{i,n+1}$: binary variable that takes the value one if job i is the last job on a machine,
- R : sufficiently large number.

According to above-mentioned notations the proposed MILP model can be formulated as follows:

$$Min\ Z = \sum_{j=1}^{n} T_j \tag{1}$$

The objective (1) represents minimization of total tardiness.

$$\sum_{j=1}^{n} y_j \le m \tag{2}$$

Constraint (2) ensures that at most m jobs may be the first job on a machine.

$$y_j + \sum_{i=1, i \ne j}^{n} x_{ji} = 1 \qquad \forall j = 1, \dots, n \tag{3}$$

Constraint (3) is needed for ensuring that each of the jobs must either start on one of the machines or to be preceded by some other job.

$$\sum_{i=1, i \ne j}^{n+1} x_{ji} = 1 \qquad \forall j = 1, \dots, n \tag{4}$$

Constraint (4) ensures that each of the jobs must be succeeded by another job or that this job will be the last job on one of the machines.

$$C_j \ge p_j - R(1 - y_j) \qquad \forall j = 1, \dots, n \tag{5}$$

Constraint (5) guarantees that the completion time for the first job of each machine must be equal to or greater than its processing time.

$$C_j \geq C_i + p_j - R(1 - x_{ji}) \quad \forall i, j = 1,...,n, \quad i \neq j \tag{6}$$

For all of the remaining jobs j, the completion time C_j must be equal to or greater than its processing time p_j added to the completion time of its direct predecessor C_i. If i is not the direct predecessor of j, the subtraction of R makes constraint (6) non-restrictive.

$$T_j \geq C_j - d_j \qquad \forall j = 1,...,n \tag{7}$$

The tardiness is calculated as the difference between completion time and due date according to formula of constraint (7).

$$x_{ij} + x_{ji} \leq 1 \qquad \forall i, j = 1,...,n, \ \ i \neq j \tag{8}$$

Constraint (8) ensures that if the job i is the predecessor of job j then the job j cannot precede i.

$$\sum_{i=1}^{n} x_{in+1} \leq m \tag{9}$$

Constraint (9) states that at most m jobs can be the last.

$$y_i + \sum_{j=1, i \neq j}^{n+1} x_{ji} \leq 2 \qquad \forall i = 1,...,n \tag{10}$$

Constraint (10) ensures that the first job on a machine may have only one successor.

$$\begin{aligned} & x_{ji} \in \{0,1\} && \forall i = 1,...,n, \ j = 1,....n, i \neq j \\ & y_j \in \{0,1\} && \forall j = 1,...,n \\ & T_j, C_j \geq 0 && \forall j = 1,...,n \end{aligned} \tag{11}$$

Finally, constraints (11) define the boundary values of all variables.

The train platforming problem is directly related to scheduling problems. On this basis, the train platforming problem concerned in this research can be formulated as a parallel machine scheduling problem with resource constraints and machine eligibility restrictions. This is achieved by considering of trains as jobs and tracks as machines. The arrival time to the entry signal of a train can be expressed as release date that is the earliest time at which train can start its arriving to the platform track. Starting time of a train is equal to sum of the release date and waiting time for available platform at entry signal. Duration of arrival (ride between entry signal and platform track) is referred as starting setup time of a train. The train has to occupy a set of switches that are shared resources for (other) trains as well.

In addition, trains are only assigned particular platform tracks in order to satisfy railway connection conditions, train length and direction restrictions. These constraints are stated by eligibility restrictions. Sojourn time which is time needed for boarding (alighting) of passengers is considered as processing time. Planned departure time can be referred as a due date. The analogy between train platforming problem and parallel machine scheduling problem is shown in detail by the Table 1.

Tab. 1 - Terms of analogy between train platforming and parallel machine scheduling

Train Platforming Problem		**Parallel Machine Scheduling Problem**
Train		Job
Platform track		Identical parallel machine
Arrival time to the entry signals of a train		Release date
Departure time from entry signals towards platform		Starting time
Arrival duration between entry signals and platform		Starting setup time
Arrival time to the exit signals of a train		Completion time
Planned departure time		Due Date
Delay		Tardiness
Switch		Resource
Eligibility restrictions		Machine eligibility restrictions

Source: Authors

A multi-objective MILP are developed for solving the train platforming problem. The possible objectives of the model are to minimize deviations from planned departure time and to maximize number of assigned trains and to maximize number of connecting trains assigned to the same platform. The proposed MILP model will be based on the following assumptions:

- a train can be assigned one platform track at a time at most,
- only passenger trains are taken into account since cargo trains do not affect the plan,
- platform tracks are available for the scheduling horizon,
- all parameters are deterministic (for study purposes),
- release dates of trains are based on timetable,
- it is possible to arrive at a particular platform track using different combination of switches,
- each train needs a train route to arrive to the platform track. The same switches can be used for arriving two different platforms however; a switch can be used by one train (train route) at a time at most.

There are a set J of trains that arrive and depart to/from the station, a collection L of platform tracks connecting to the entry/exit lines and a set D of directions. Moreover, for each ordered pair $(d_1, d_2) \in D \times D$ corresponding to arrival direction d_1 and departure direction d_2. The last one is a collection S of switches that are used for crossing one track to another. The indices of concerned problem are given as follows:

- i, j and $q \in J$ are indices used to show a particular trains,
- $l, m \in L$ are indices used to show a particular platform tracks,
- $r \in R$ is the index used to show a particular switch.

The parameters of mathematical model are given in below:

(a) railway station topology,

(b) planning period,

(c) list of all trains based on classification,

(d) list of trains required to use the same platform (due to ensuring of comfort and quick interchange known as “edge-edge interchange”) and a list of groups of platform tracks located at one platform together (allowing this type of interchange),

(e) list of incoming trains and their following parameters (incoming train j),

- arrival time of the train j to the entry signal,

- arrival duration of train j from entry signal to the platform track,
- combination of switches that are used by train j for reaching of platform track l from d_1,
- sojourn time of train j,
- eligibility of train j to the platform track l,

(f) list of outgoing trains and their following parameters (outgoing train j):

- departure time of the train j,
- departure duration of the train j from the platform track l,
- combination of swithces that are used by the train j going from platform track l to d_2,

(g) distance matrix between platform tracks: the matrix elements can be defined as time necessary for walking of passengers between two platform track in minutes.

Decision variables of model are given as follows:

- occupation time of the train j (arrival time of the train j),
- variable that defines whether the train j is assigned to the platform track l,
- waiting time of train j at entry signal,
- waiting time of the train j on platform track,
- real departure time of the train j from entry signals to platform track,
- real arrival time of the train j to platform track,
- real departure time of the train j from platform track (occupation of switch area),

Constraints of model are given as follows:

(a) it is not allowed that train leaves before departure time (according to time schedule and with regard on alighting and boarding passengers),

(b) there should be some constraints which are related to calculation of decision variables of real departure time of each train j from entry signals to the platform track, real arrival time of each train j to the platform track and real departure time of each train from platform track,

(c) each train must be assigned to any platform track,

(d) each train can be assigned to the particular platform tracks with respect to eligibility restrictions,

(e) constraints for waiting time of each train at entry signal and on platform track must be controlled,

(f) prevention of constraints overlapping must be formulated due to reason that only one train can occupy the particular switch (train route) at a time. There are three overlapping constraints for two trains:

- overlapping constraint for the trains that are entering the station from the same direction,
- overlapping constraint for the case that train is entering and the other one is exiting,
- overlapping constraint for the trains that both are exiting from the station in the same direction.

(g) There can be alternative routes to arrive to some platform tracks (by different sets of switches) and it must be declared.

(h) Connecting trains must wait for passengers who are interchanging from another train.

(i) To prevent accident of trains, safety constraints must be considered as well.

CONCLUSION

This paper addresses train platforming problem, which is the problem of assignment of trains to platform tracks, but train routes for incoming and outgoing trains in a (large) railway station must be assigned as well. Inputs of the problem are the daily timetable and the structural constraints of the railway station. Daily timetable shows arrival and departure times of trains to/from the railway station. Structural constraints are directly related to railway station topology that includes several special constraints about platform tracks, switch areas and directions (railway lines). There are three significant considerations: (i) railway connections between platform tracks and entry/exit lines, (ii) eligibility based on train length and platform length, (iii) existence of dead-end platform tracks. There are also several additional operation constraints based on railway station topology and operation technology.

Milestone of this study is to model this problem as parallel machine scheduling problem. To the best of our knowledge, no relevant studies focused on consideration of train platforming problem as a parallel machine scheduling problem have been at disposal.

The train platforming problem concerned in this study is formulated as an identical parallel machine scheduling problem with resource constraints and machine eligibility restrictions. Trains and platform tracks are synonymous for jobs and machines. Processing time is equivalent concept for sojourn time. Because all platform tracks are used for alighting and boarding of passengers and sojourn time is the same by all platform tracks for a particular train, platform tracks can be named as identical parallel machines. Shared resources of parallel machines are switches which guide a train from one track to another. There are three important eligibility constraints based on train routing in railway station as it is pointed out before. In machine scheduling, these constraints are called as "machine eligibility restrictions".

Train platforming problem is relatively easy to solve for small railway stations with relative small numbers of trains and platform tracks. However, it becomes a difficult optimization problem when it is applied to complex railway station topologies, such as those associated with the main European stations, having hundreds of trains (operated per day) and tens of platform tracks. The mathematical model may not be adequate for solving real life platform track assignment problem (in the case of such complex station topologies). For future research, several meta-heuristic approaches can be applied to increase the quality of solution for large size problems. These methods can be genetic algorithm, tabu search or simulated annealing. On the other hand, model presented in this paper as a concept of solution, is representing a base for this future research.

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