Missing tracks and switches – on the way to assess modernised stations in terms of their usefulness for railway traffic

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Abstract

Rail transport plays an important role in the vision of the development of mobility in the European Union. This is reflected in modernisation projects that include not only railway lines, but also station layouts. Unfortunately, many examples in the Czech Republic and Poland show that the 'rationalization' of the number of tracks and switches often leads to situations in which the station is no longer useful for rail traffic that would be even slightly different from the assumed standard. Currently, a simulation model is being developed to assess the modernised stations in terms of their usefulness for rail traffic. This article presents the so far solved problems related to the aspect of time, as well as track prioritisation when accepting various types of trains. It also contains the currently tested version of developed algorithm, which allows simulating the operation of stations in random traffic conditions.

KEY WORDS: *railway infrastructure; capacity; modernisation projects, simulation*

1. Introduction

The railway infrastructure in the Czech Republic and Poland has been thoroughly modernized in recent years. As part of the works, there are often changes in the track layout of railway stations, which are determined by the desire to rationalize them and adapt them to real needs. Unfortunately, financial issues often play a decisive role and 'rationalised' stations are not ready to handle traffic even with only a slight increase of it. An example of this type of station in Poland was the subject of publication at last year's edition of the Transport Means [1] conference and contributed to establishing cooperation between the Poznań University of Technology (Poland) and the University of Pardubice (Czech Republic).

Solution of this task was extended by means of simulation modelling, by elements of so-called train platforming problem and by effort to design optimization model. The set of analytical indicators presented on the last conference has been extended about tools, how to evaluate 'efficiency' of each individual station track for each individual train approaching the station with an effort to incorporate it into the final criterion of planned optimization model.

The study of the impact of missing tracks and switches will consist in observing the operation of the station during the passage of a group of trains in randomly selected relationships and in random categories (cargo trains, Express and Regio passenger trains).

The aim of the article is to present the current state of the project aimed at determining the method of characterising the station in terms of its ability to conduct rail traffic, the research is in the phase of analytic indicators, application of train platforming problem and simulation elements now. Future optimizing model is presented on the level of an intent (interim solution).

2. State-of-art level of knowledge

Publications in the field of railway transport research are usually focused on railway line technology or on railway stations. The paper [2] follows line technology and it searches for balance between train speed, travel time and energy consumption by riding between two stations. Example dealing with stations is [3], which considers using of hybrid Petri-net for simulation of railway station operation. There are also some publications to some specific themes, like improving of railway safety [4]. Our paper belongs to the third group and presents deep focus on interconnection of line and station technology together.

There are also some methods dedicated to assessment of railway infrastructure capacity. The well-known is the UIC-Code 406. This methodology is applied internationally for UIC members. Some local (national-based) methodologies are also at disposal. These methodologies create a framework for railway infrastructure capacity assessment. The remaining issue is that they are sometimes too general for individual specific purposes and several research activities are conducted to equip these principles. For instance, the paper [5] should be mentioned as an example from our research field connecting technology of railway lines and stations by searching for possibilities, how so-called compression method (based on UIC-Code 406) should be applied on the level of strategic planning. There is an effort to replace dependency of capacity assessment on one specific assessed timetable. Application of random timetable is also often issue followed by researchers, e.g. for transit network in the paper [6], for railway sector in the paper [7]. The consequence for our research is also that we cannot presuppose one specific timetable only, because it can be changed by several reasons. Stochastic operation (influence of train delay) is the first. The second one is that timetable can be changed in time (in contrast with infrastructure constructed for long time horizon) and that it can be also influenced by local short terms needs (e.g. to use a railway line as a substitutional line while reconstruction of the backbone line is lasting etc).

Next adequate research publication focused on extension of knowledge of railway station technology is [8]. It is focused on measuring of passengers' transfer times at railway stations by changing between trains. Interconnection between infrastructure and management of operation in the case of technical failure called as "infrastructure restoration and transport management" is presented by [9]. This of also evidence of need of aggregated approach to railway infrastructure, which will be followed also in our case.

Important fact for simulation and routing issues is a way, how to select applied sources and transport routes. The paper [10] is focused on selection of a depot as a source which ensure vehicle for the conveyance and how to select transport route by means of multi-criteria analysis. This approach should be inspirative for multi-objective selection of a train route selected for passing of train at solved station. The part selecting depots should be applied for selection of input and output railway line for a train in the case of application of random timetable. Mentioned vehicle routing problem can be applied for composition train routes consisted of more train or shunting movements, for example if it is necessary to use 2 different station tracks for train arrival and departure due to infrastructure limitations – missing switch points.

Our simulation will be based on multi-scenario approach. This is common for example in the field of urban planning [11]. In our case, creating of different operational scenarios will be a tool, how to anticipate different operational modes of solved railway station in the case of uncertain timetable, especially in future time horizons.

Solution of so-called train platforming problem as a mixed-integer liner problem is presented in [12]. Rescheduling of plan how to allocate station tracks to trains for reduction of negative impacts caused by train delay in the way of train platforming problem and the ways how to simplify this computation are discussed by [13]. Aspects of real-time solution are mentioned in [14]. We will apply this principle in its basic form as an static assignment problem, but we would like to introduce it in different context - as a part of assessment of railway station infrastructure capacity.

3. Case study description

The problem of missing tracks and switches is not unique to any particular type or size of stations. Although we want the target solution to be as generalised as possible, its testing for many different station layouts would be unjustified due to time reasons. Therefore, while working on the concept, we focused on a fragment of a fictional railway network (Fig. 1). Operational concept is characterized in extended way for illustration of motivation for design of station-layout with such infrastructure limitations.

Its central point is the Skalice station, situated on a double-track main line between the Anastazewo and Borek stations. Freight as well as passenger trains run on this line. There are 2 categories of passenger trains marked as Express and Regio. The Skalice station is also connected by a local line with the town of Cieplice, and this line is used almost exclusively for Regio passenger trains operated by bidirectional diesel motor units (DMU).

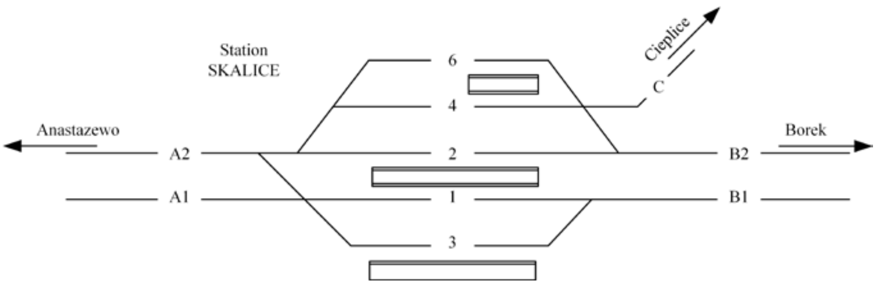

Fig. 1 Scheme of a fragment of a fictitious railway network used in the research

The fictional Skalice station, built at the beginning of the 20^{th} century as passenger and freight station, has recently been modernised. Due to the low interest in sending cargo shipments, side tracks were completely removed, the warehouse buildings were demolished, and the cargo yard was rebuilt into a parking lot with electric car charging stations. The remaining infrastructure was also adapted to the current traffic situation:

- Due to the using of short DMUs on the line towards Cieplice, the platform between tracks 4 and 6 is only 50 meters long, which is insufficient for passenger trains running between Anastazewo and Borek
- The single-edge platform at track No. 3 is used by trains launched in the shortened relation from Skalice in the direction of Anastazewo (the first and last train of the day, time-dependent on the train from/to Cieplice)
- All trains from the Cieplice terminate (end) in Skalice, therefore there are no turnouts enabling the passage from track 1 to 2 from the Anastazewo side and between tracks 1 and 2 from Borek side of the station.

It should be noted that the limitations mentioned above are not absolute. Formally, it is possible to accept a passenger

train on tracks No. 4 or 6 with short platform, although it requires blocking some doors by the train staff and passing passengers to carriages that fit at the platform. Similarly, trains running on the main line (in relations unforeseen by the designers of the modernised station) can be launched – although it will involve the necessity to travel along the left track or to carry out additional shunting movements at the Skalice station.
Practical examples of stations with similar layout can be found. Similar is the station Zadní Třebaň located 30 km southwest of Prague (line Prague - Plzeň). Limited operation is possible at the station Sława Wielkopolska 35 km northeast of Poznań (line Poznań - Wągrowiec). Some connections between main line tracks miss at some stations on the double-track line between Chomutov and Karlovy Vary in northwest Bohemia. It is presupposed that train can come to station using irregular line track (from neighbour station), what is supported by remote dispatching of these stations. Layout of the station Skalice is fictive (modified) due to research purposes.

4. Known issues

Distribution of train runs in time and space are crucial aspects by capacity assessment of railway stations. Next simplified example illustrates it.

When trains come stepwise and each occupies the station track for 10 minutes, only one track will be suitable for 6 trains per hour (and the station like Skalice will seem as oversized). When these trains must be at the station together (e.g. for possibility of mutual interchanges), 6 tracks are needed (and the station Skalice will become insufficient).

Next limitation is accessibility (connectivity) between line and station tracks. Theoretically, when these 6 trains will run from Anastazewo (track A1) to Borek (B1), 4 tracks more at the station Skalice will be needed due to missing switches and turnovers (see Fig. 1) to allow mutual interchanges despite that 3 tracks No. 2, 4, 6 will remain free.

The issue is to connect time and spatial aspects with the probability of occurrence of such operational situation. For example, when all trains from Anastazewo to Borek will run individually, the need of station track No. 3 should be characterized as “reserve” for the case of overtaking of delayed tracks only and this station layout will be suitable. When it will be an interchange node of more than 2 trains in direction Borek, the station should have capacity problem. What is the probability that such situation will occur may be in next 50 years. Railway infrastructure is usually designed for such long time.

4.1. Priorities of tracks

As it follows form above mentioned example, not all station tracks are suitable for all trains. There can be found 2 main reasons, why a station track could be totally insufficient. The first one is the fact that there is no connection between required station and line tracks. Absence of electric contact line is the second one for electric trains.

Station tracks should be also partially insufficient. For example, this occurs in mentioned case of long train and short platform. On the other hand, there can be some other reasons for partial insufficiency - e.g. when train must use irregular line track by running from/to neighbour station; when additional shunting movement is necessary (e.g. by train set reversing on dead-end tracks); when train crosses other tracks - what has 2 negative effects (train must run slow by entering or leaving station track and it can possibly cause need to stop other trains in collision directions).

This leads to scoring of assignment of trains to tracks by points. Trains are sorted according to types (categories) in this case. Full value of 100 points belongs to situation when the most suitable station track is assigned to a train. Typically for Express passing trains this is a straight track where no reduction of speed (related to drive to diverging track) is necessary (e.g. line 1 for trains from Anastazewo to Borek in Skalice). On the other hand, using of diverting track should be sometimes evaluated by 100 points as well. It can be an example of Regional train when it should be overtaken by Express train (track 3 is the most suitable for this in relation Anastazewo - Borek). It is suggested that slower speed and risk of collision drives should be penalized by reduction of 25 points per crossing of each neighbouring station track. This protects the task to assign such station tracks with low probability of utilization. In simple, there is a general effort to use as straight routes as possible with exception of planned cases (e.g. by overtaking).

This value should be modified in individual cases according to individual needs. Potential usage of totally insufficient station track will be incorporated in the way of constraint expressing this impossibility.

4.2. Time slots

Assessments based on railway simulation models are usually performed for selected period with given timetable. The crucial role of simulation is to model impact of possible operational delays in such cases. State-of-art feature (especially) in passenger traffic is application of periodic timetables with predefined operational situations which are repeated (e.g. that trains from all lines meet at given time and then the station is free for the rest of period). This leads to idea to assess railway capacity not in the point of view of time period, but as a spot process assessing the moments when the trains meet.

Mathematically this can be formulated as an assignment linear programming problem known as train platforming problem. The solution will be realized in static way. In other words, we would like to check if it is possible to assign defined set of trains on station tracks. When acceptable solution exists, the value of target function (total volume of assigned points) will evaluate appropriateness of the infrastructure (station layout).

On the other hand, the fact that the solution potentially does not exist is not a solution in practical point of view. So, the problem has been extended to three static time periods - the planned one (basic) and one before and one after.

Trains with no chance to be assigned into basic time period (because of no suitable track at disposal) should be assigned to one of the additional periods (one before or one after). This assignment is evaluated by decreased volume of points. The value of this penalty should be set individually according to each individual case. The facts like if it is better to come with that train before or after (in the point of view of interchanges) or if it is better to use partially insufficient track (e.g. track with short platform for long train) or to serve the train in advance or after could be decided this way. Individual penalties for time frame or for insufficient track are assumed together.

4.3. Time dependencies between trains

The first problem we encountered after generating a test set of trains running through the station (Skalice) was the issue of time dependencies. As mentioned in Introduction, our goal was not to run the simulation in real time, so we initially assumed that all trains would enter the station simultaneously. Of course, in some situations such an assumption is entirely legitimate, but on closer analysis it turned out that it leads to situations that are inconsistent with the rules of rail traffic management. Two scenarios deserve special attention:

- One train goes across the route prepared for another train. For example, a train leaving track 3 in the direction of Anastazewo (on the right track) blocks the train from entering Anastazewo on track A1. Situations of this type occur even more often at stations located on single-track lines, where the entry of the train may block all switches at the station (due to safety reasons).
- Entry of two trains from the same direction (on the same track). Due to the fact that successive trains are always separated from each other, the time between them amounts to at least a few minutes and cannot be ignored – as it is comparable to the time of a train stopping at a station. Most often, the next train will be able to enter the same track, as the previous train will leave the station in the meantime.

The initial solution to the problem outlined here was to analyse the operation of the station in three time slots: the main one, as well as slightly before and after it. This approach allows for achieving a satisfactory compliance of the model with reality for a larger group of scenarios than in the case of limiting the analysis to one time slot, but it still has significant limitations with more extensive case studies. This was an impulse to change the model type – from a simple linear model to a network model, which was briefly characterised in this chapter 4.

5. Interim solution

5.1. Solution based on linear programming model

Let the set of trains is marked as **S** (services), the set of station tracks as **P** (platforms) and set of three time periods as **T** (time). The binary variables of x_{ijr} express if a train $i \in \mathbf{S}$ will be assigned to the track of $j \in \mathbf{P}$ in time period of $r \in \mathbf{T}$ or not. The constants of e_{ijr} represents how many points brings assignment of a train $i \in \mathbf{S}$ to the track of $j \in \mathbf{P}$ in time period of $r \in \mathbf{T}$. Binary constants of a_{ijr} express if it is possible to assign a train $i \in \mathbf{S}$ to the track of $j \in \mathbf{P}$ in time period of $r \in \mathbf{T}$ or not.

To maximize $$y = \sum_{r \in \mathbf{T}} \sum_{j \in \mathbf{P}} \sum_{i \in \mathbf{S}} e_{ijr} \cdot x_{ijr} \tag{1}$$

Subject to: $$\sum_{r \in \mathbf{T}} \sum_{j \in \mathbf{P}} x_{ijr} = 1 \qquad \forall\, i \in \mathbf{S} \tag{2}$$

$$\sum_{i \in \mathbf{S}} x_{ijr} \leq 1 \qquad \forall\, j \in \mathbf{P},\ \forall\, r \in \mathbf{T} \tag{3}$$

$$x_{ijr} \leq a_{ijr} \qquad \forall\, j \in \mathbf{P},\ \forall\, r \in \mathbf{T} \tag{4}$$

$$x_{ijr} \in \{0; 1\} \qquad \forall\, i \in \mathbf{S},\ \forall\, j \in \mathbf{P},\ \forall\, r \in \mathbf{T} \tag{5}$$

More variants of station infrastructure can be assessed in the way that this linear programming task (1)-(5) is solved repeatedly for each of them (with the same extent of operation - timetable) and the one with maximal number of reached points should be selected. When there are more meetings of trains (e.g. Expresses at X:00 and Regio at X:30), they are solved individually and the points are put together. Problem should be that computational demands are rising by rising the numbers of trains and tracks. For example, by application of Microsoft Excel Slover on the example of Skalice it should be computed for about 10 trains only (10 trains to 3 periods to 5 station tracks means 150 variables).

5.2. Solution based on graph theory

As mentioned in sections 4 and 5.1, the initial attempts to model the situation considered in this paper were based on linear programming. Due to computational demands, need to solve more complex stations and due to the need to better reflect the issue of time, it was decided to change the model and base it on the theory of graphs. Obviously, graphs are very often used for modelling transport systems [15], because they allow for intuitive recording of information about the road network and its characteristics (e.g. capacity or direction of traffic). However, this standard approach does not fully reflect the way the stations work. For example, the case-study station layout allows trains to pass between track A2 and track 1 in both directions, but the direction A2→1 is only available for incoming trains, and 1→A2 for trains leaving Skalice station. A way to record the combined information about the available connections between the tracks for incoming and outgoing trains is to use a graph in which the source and sink are distinguished (Fig. 2).

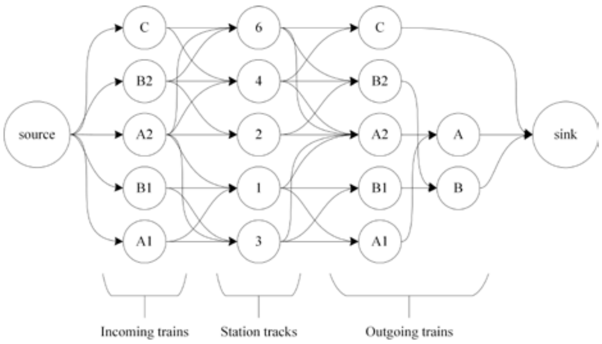

Fig. 2 Graph used for modelling the case-study station

When compiling the graph, it was assumed that trains can arrive on any track (left or right) and this does not depend on the decision made in Skalice. However, a station can send trains in the direction of Anastazewo or Borek on one of the two tracks, although the use of the right-hand track should be the preferred option (which is reflected in the scoring system described in section 4.1). By modelling the operation of the station in the form of a graph, carrying out the simulation comes down to two simple steps:

- Generating a random set of trains to pass the station, according to some probability functions. Each train consist information about its origin in terms of track on which it comes, its destination and type (Express, Regional or cargo). It is important that there should be at least one possible route for each train in the set
- For successive trains from the set a best route leading between source and sink (in terms of score described in section 4.1) is determined and the cumulative score is saved. At the beginning, each arc has a capacity of 1 and when there is no possibility to find a route, the whole graph is reset (the capacities are restored). This corresponds to changing to the next time frame.

Step 2 is repeated for each possible order of trains in the test set, allowing the best order (with the best score) to be determined. The algorithm in pseudo-code has been presented in Fig. 3.

```
MaxScore as integer = 0
BestOrder as List of Trains
CurrentScore as integer = 0
For each possible order of trains in the set
        Reset network
        CurrentScore = 0
        For each train in the set
                If it is not possible to find a route for a given train then
                        reset network
                        CurrentScore -= penalty for next time frame
                Find the best route
                Increase the flow in the used arcs (or track nodes)
                CurrentScore += RouteScore
        If CurrentScore > MaxScore then
                MaxScore = CurrentScore
                BestOrder = this order
```

Fig. 3 Algorithm in pseudo-code

6. Conclusions

The development of a simulation model to evaluate the modernised stations in terms of their suitability for rail traffic is a complex decision-making problem. Such a model must take into account the attributes resulting from the extensive operational context and conditions of station operation that generate specific problems in obtaining model results. The attributes should reflect the reality in relation to to priorities of tracks, time slots, time dependencies between trains, but one should also remember about the parameters of the model, the values of which are assumed under conditions of uncertainty (e.g. time values characterising timetables in long time horizons).

As a result, we presented two interim solutions (at the testing stage). The former is based on the class of linear programming models and the latter is based on graph theory. In search of solutions, we use the so-called multi-scenario approach, that is using an appropriate number of different operating scenarios to predict different modes of station operation. This is also a fact, why simulation is applied in different way in our approach – to simulate overall situation in traffic. Standardly it is focused especially on assessment of train delay. This has the advantage that each scenario is a specific element of the decision space. One could even, after specifying its structure in the form of a set of parameters, generate such a scenario in a systematic or random manner. Unfortunately, even for small choice sets, the computational requirements increase significantly, especially as the values of other parameters (number of trains and tracks) increase. To obtain such a solution, it is also possible to use static time periods, which, although allow for satisfactory compliance of the model with reality for a larger group of scenarios, still cause significant limitations in more extensive case studies. The linear programming approach in this case becomes ineffective, and may not even give an efficient solution. The indicated limitations gave us reasons to change the model type from a simple linear model to a network model (graph).

In order to determine the value of the objective function in both classes of models, it is convenient to use integer scoring. We use it in assigning trains to tracks and as a component of the penalty function. It should be pointed out that this scoring is a critical component of the model and in the perspective of working on it, it should be subject to separate tests, e.g. with the use of training sets.

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