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EVALUATION OF TIMETABLE ROBUSTNESS CONSIDERING BUFFER TIMES' AMOUNT AND DISTRIBUTION

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Abstract *– The timetable is one of the most significant documents. Although nowadays is common to produce timetable by using some of developed sophisticated software, on many networks the timetable is created manually, based on experientially defined principles. Then, it is difficult to assess the values of timetable performance indicators. As one of the most important indicators, timetable robustness has been a subject of a large number of scientific researches in the recent past. In this paper we introduce a model for robustness evaluation based on usual scientific techniques. It considers all buffer times and their distribution over the timetable. As it is not too demanding regarding resources, model enables decision-making in the final timetable development phase.*

Keywords – Timetable, Robustness, Simulation, DEA

1. INTRODUCTION

Recently, many models have been developed for a timetable designing process, as well as software tools. However, in many cases, the timetable is made on the basis of experiential principles, without any optimization. On the other hand, railway infrastructure, even in developed European countries, has become a bottleneck with increasing demand for transportation. Therefore, in recent years, great attention has been paid to assessing the quality of infrastructure utilization, primarily through the assessment of timetable parameters, as one of the most important documents of the railway system.

After the restructuring of the railway system, the timetable process went through changes. Train paths are entered in the timetable on the basis of received paths requests, or on the basis of the assumption of which services will be requested during the timetable period of validity. For services that are not regularly planned, requests are submitted and, accordingly, the so-called *ad hoc* paths are designed, if all conditions are met.

On the other hand, the Infrastructure Manager (IM) and the Railway Undertaking (RU) are bound by a contract, which obliges them to pay penalties in case of non-compliance with the timetable or deviation from it. On the other hand, it is necessary to design such a timetable that will enable the smooth functioning of traffic, while minimizing disturbances in it.

This paper describes a theoretical approach to assess the quality of the developed timetable, in order to enable the identification of its weaknesses and their elimination, but also for the comparison of two or more timetables, from the aspect of robustness.

2. MOTIVATION

The timetable must be designed in a such way that it can withstand the delays and perturbations that may occur, without losing its functionality. In [1], a list of indicators for quality assessment is proposed. It contains the following:

- Infrastructure occupation,
- Timetable feasibility,
- Timetable stability,
- Timetable robustness and
- Timetable recilience.

Robustness is the ability of a timetable to withstand the small delays that occur during its execution. In other words, a more robust timetable can withstand more minor primary delays, in the sense that the transfer of those delays will be minimal or even completely neutralized. In order to enable the robustness of the timetable, it is necessary to implement time reserves within the headways, in order to prevent the transfer of delays from one train

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path to another.

The amount of time reserves that can be implemented in the timetable are not infinite. If we observe a timetable and if we would perform train compression in it, in the manner described in UIC Leaflet 406 [2], the total amount, ie. the sum of available time reserves represents the time from the moment of completion of the last train run in the observed period, to the moment of the beginning of the execution of the next cycle of the observed timetable, reduced by headway time. For a hypothetical one-hour timetable this is shown in Figure 1.

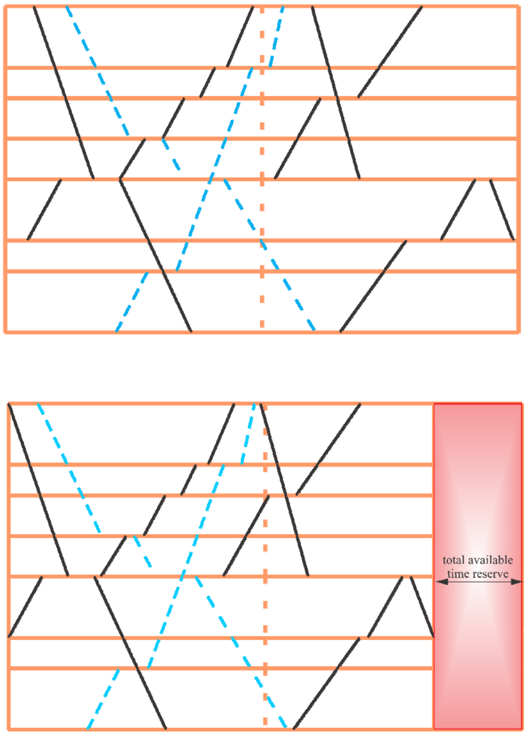

Fig.1. Uncompressed and compressed timetable, with maximum buffer-times amount

From the point of view of robustness, the compressed timetable is not robust at all. Any generated delay would be transferred from one train path to another, due to the absence of time reserves between paths. In practice, this amount of time reserves should be divided into individual buffer times and inserted into headway times.

From the above it follows that the timetable is more robust if the time reserves are more evenly distributed, both in time and space, ie. the maximum robustness would be achieved if the time reserves were completely evenly distributed in each of the stations, as well as throughout the observed time period. A large number of minimum headway times, which are relatively close to each other, will most likely affect one train path multiple times (or even have multiple effects on several train paths), which means a higher probability of transferring delays from a delayed train to another.

Such an ideal distribution of time reserves is not possible in practice, given the required timetable feasibility.

Delays that the implemented time reserves can withstand cannot be determined in advance, given that train delays are random events. Several papers deal in great detail with determining the probability of train delays. Also, in [3], the influence of time reserve distribution on train delays was analyzed, by simulating delays with predefined probability distributions and depending on the adopted mean value of the buffer time.

3. TIMETABLE ROBUSTNESS EVALUATION PROCESS

Since delays depend on many parameters, the timetable realization, determining the distribution of probabilities of delays will not always lead to quality results.

The model assumes that each timetable can be cosidered as a technical system. Then, by simulation, it is possible to determine the values of individual parameters on the basis of which it would be possible to compare timetables, according to efficiency. The block diagram of the model is shown in Figure 2.

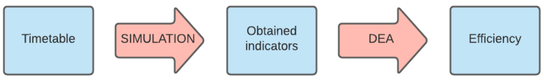

Fig.2. Model Block-diagram

Today's digital computer technology provides the possibility of a relatively easy process of computer simulation of timetable realizations.

If we considered each delay, of each individual event in the timetable, as a random variable, with an identical probability distribution, and if we assume that their expected values and variance are finite, then the central limit theorem would apply to the case of a large number of repetitions. The algorithm of the simulation process is shown in Figure 3.

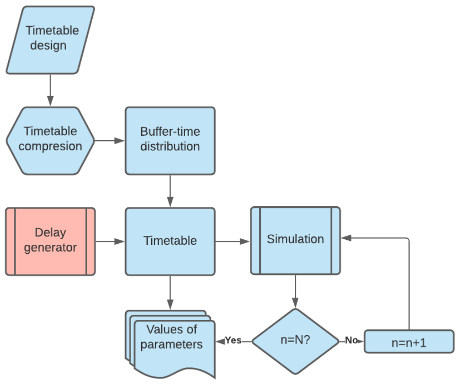

Fig.3. Proposed timetable simulation algorithm

The number of repetitions is not strictly defined; although it is easy with today's computers to repeat the experiment tens of thousands of times, in [3] and [4] the results with acceptable accuracy were obtained with a 500 repetitions.

Statistical indicators, such as the average value of the buffer time, etc., could be determined directly from the timetable, while the expected value of the secondary delays are obtained as the mean values of all repetitions.

The Data Environment Analysis (DEA) method is one of the most commonly used methods for determining the relative efficiency of a set of mutually independent decision units (DMU). In this model, each timetable, with a unique path pattern layout and a unique distribution of time reserves in the headway times between them, as well as the values of each individual buffer time, represents one DMU.

The application of the DEA model for the evaluation of efficiency in the field of railway transport is not new, but it has not been used for the evaluation of the timetable efficiency nor timetable comparation by robustness.

The DEA method involves determining two sets of factors: input and output factors, which represent the basic ratio for determining efficiency.

The set of input factors should be formed on the basis of statistical indicators that can be defined over the timetable in question. These should be such indicators that can be expected to have a significant impact on delays, and thus on the robustness of the timetable. With this in mind, we propose the following indicators for a set of input factors:

- Total number of paths,
- Total number of implemented buffer times,
- Total amount of implemented time reserves,
- Average number of implemented buffer times, per train path,
- Average value of buffer time, per path,
- Average value of one time reserve, etc.

Some of the above indicators are "interdependent", i.e. grouping all indicators into a set of input factors can be redundant. If this happens, it is possible to relax the set of input factors by removing a number of indicators from the set, as described in [5].

With a set of output factors, things are slightly more complex, although the number of indicators - candidates for the output factor, is much smaller. Namely, in order to make a comparison according to robustness between several timetables, it is necessary to observe the sum of all secondary delays. However, the DEA method, in its most general form, is a model for maximizing the ratio of output and input factors, so if the sum of secondary delays is taken directly, those DMUs (timetables) whose secondary delays are higher would be considered as more efficient.

To prevent this, we chose the reciprocal of the sum of the secondary delays as the output factor. It is now possible to use DEA method to compare timetables according to robustness, by defining the relative efficiency of the technical system. The block diagram of the DEA model is shown in Figure 4.

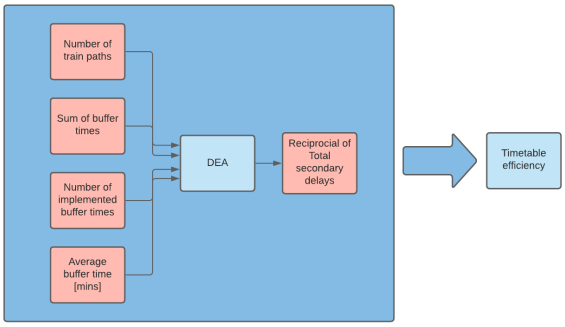

Fig.4. DEA method decision process

The DMU, whose efficiency is equal to one, will be considered the most robust - efficient, while all the others will be considered inefficient. In case of the need to rank all timetables, the so-called super-efficiency DEA method has been used.

4. CONCLUSION

The described two-stage model should allow a simple and easy comparison of timetables based on robustness. The model uses common techniques, simulation and DEA analysis. The model is set up to allow comparison of different timetables, even comparison of timetables for different railway lines, which allows the assessment of the quality of work of timetable constructors or software.

With minimal modifications, practically only with the change of output indicators from the DEA model, the model can also be used to evaluate other timetable performance indicators.

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