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Multicriteria evaluation of variants as a decision-making support within rail-traffic simulations

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Abstract

This contribution discusses different methods of automatic decision-making support in simulated railway traffic within mesoscopic simulation tools. Concretely, this article compares the method of multicriteria evaluation of variants (utilized in the process of operative control) to other optimization methods exploited within rail-traffic simulation (e.g. reflecting rail traffic within railway stations). The used simulator and its features are described, as well as its outputs, which are used for statistical evaluation of the individual supports. Further, certain methods of automatic operative control are discussed as candidates. The method of multicriteria evaluation of variants is implemented and compared to (i) priority planning and (ii) nested/recursive simulations, in terms of minimization of train delays. At the end, the results are evaluated and discussed.

Keywords: Modelling and simulation; rail-traffic simulation; multicriteria evaluation of variants; operative control

1. Introduction

Railway transport is an important part of many people's lives. Speaking just about the European Union, eight billion people were transported by trains in 2018. With increasing traffic, there is a need for effective management, in order to operate as many trains as possible on the current infrastructure. Unless decisions are carried out quickly and securely, the traffic would collapse, as there would be extensive delays. Furthermore, it is crucial to maintain safe traffic for passengers, to avoid collisions of trains. Machine-based control is a way to improve speed, safety and reliability of railway traffic, as well as reducing costs.

There are many possible implementations of operative control. In this contribution, the main attention is paid to the method of multicriteria evaluation of variants supporting railway traffic control. In addition, some other methods are discussed, namely priority planning (e.g. applied to train routing) and nested/recursive simulation methods, which are both used for comparison of results.

As it would be unsafe and expensive to compare relevant methods of automatic control in real traffic, the experiments take place in a simulation (virtual) environment. To provide some relevant results, all methods used for comparison are required to run in the same simulator under the same conditions. For this purpose, the simulation tool MesoRail was utilized.

This contribution is divided to multiple sections. In the second section, current literature is summarized. The third section introduces the utilized software and the metric, which is later used for evaluation of outputs. The fourth section describes operative control in rail-traffic and some methods of its automatization, which are later applied. The fifth section is focused on the multicriteria evaluation of variants itself. It briefly describes the principle of defining criteria and variants, as well as their evaluation. The sixth section contains the case study, discussing the exploited scenario, criteria and variants. In the seventh section, there are results summarized, followed by the eighth section – conclusions.

2. State of the art

There are many studies about multicriteria evaluation of variants, as well as about automatic railway control supports. However, there are only few contributions about multicriteria evaluation of variants, used as an operative control support in railway traffic.

In 2007, there was presented an article (Kaakai, 2007) about optimization of station design with focus on safety of passengers, exploiting the hybrid Petri nets-based simulation model. In (Adamko and Klima, 2008), the simulation tool Villon was used to optimize the capacity of railway terminals. Another article about capacity assessment of a railway station is (Song et al., 2014), where a microscopic simulation method was used to evaluate the carrying capacity of a railway station.

(Diviš and Kavička, 2015) presents the development of the mesocopic simulator Mesorail, dedicated to investigate the capacity of railway nodes. Later, the developed simulator was exploited (Diviš and Kavička, 2016) to evaluate the nested simulation solving method of operative control of traffic in a small railway station.

A recent article (Bažant et al., 2019) documents an experiment, which is very similar to the one executed in this contribution, on a microscopic level of detail. In this experiment, the multicriteria evaluation of variants, implemented in the simulation tool Villon, exceeded the priority planning (regarding assignments of platform tracks to delayed arriving trains) in over 80 % of simulations.

This contribution addresses the application of the method of multicriteria evaluation of variants in a railway simulator, working in mesoscopic level of detail. This method is compared to other methods in the simulator, utilizing the same simulation model and scenario.

3. Materials and Methods

As stated before, the MesoRail (Diviš and Kavička, 2015) software tool is used for experiments. MesoRail represents a mesoscopic software tool specialized in rail traffic simulations (applying a mesoscopic level of details), developed at the Faculty of Electrical Engineering and Informatics of the University of Pardubice. It simulates train arrivals and movements, occupation of tracks, sojourn times, and departures. Train arrivals are managed according to the given timetable, but optionally, can be modified with random delays. Train delays result in collisions of track acquirement of respective trains, which is a task for the agent-Dispatcher to solve.

The agent-Dispatcher in the simulator uses operative control support to decide the best route for the train, which was originally handled by the priority planning method. Later, this simulator was also equipped with optional nested simulations approach (Diviš and Kavička, 2016). In our study, the method of multicriteria evaluation of variants is implemented as the third option, making it easily comparable to the other two.

The output metric is the weighted total delay increment, which is the sum of delay increments of all trains, each multiplied by its weight. The weights are chosen according to directive SM124 of the state company Správa železnic, s.o. (Railway Infrastructure Administration, state organization – the Czech Republic).

4. Operative control of railway traffic

The control of railway traffic mainly consists of medium-term plans (timetables), which are developed based on experience. These timetables define train arrivals, departures and waiting times. In an ideal case, each train should arrive and depart as defined, without causing delays to other trains. But in reality, there are many impacts which can affect the timetable. These especially include weather conditions, railway defects, train accidents and breakdowns. Whatever the reason is, a delayed train, as it cannot follow the timetable precisely, easily causes further delays to other trains, as it blocks tracks and platforms.

The convenient way to deal with such collisions is to let an expert employee decide, which track (and optionally a platform) suits the delayed train best. An expert usually takes the original timetable into account, trying to solve the problem without causing extensive delays to the train, as well as the rest of the traffic. Such an expert makes a decision according to his knowledge of the railway, his experience, and some look-ahead of the traffic. All of these resources are limited and subjective to each such expert. Human control also suffers from human errors and its quality always depends on the respective person's condition and mood.

The machine-based control, on the other hand, does not suffer from disadvantages like these. It can make automatic decisions safely, reliably and effectively without any time constraints. Computers are also capable of way faster, long-range communication and cooperation.

There are many approaches to develop a machine control. These approaches are usually also using medium-term or long-term plans, adding some software operative support. An operative support can be an expert system, simulating an expert's decisions. It can also take the current state of the railway into account, as well as some look-ahead of it.

4.1. Priority planning

The basic support, which is constructed in one-shot using only experience, is the priority planning related to routing trains (to different platform tracks). In this case, the supportive software reacts when a train cannot proceed to its designated track and assigns another track to it. The decision consists of searching a list of appropriate tracks for the train, which are equipped with priority. The highest priority track is the one defined in the timetable. Once it is not available, the second highest priority is chosen and so on.

The priority list is created using experience and knowledge of technical possibilities of the railway. The method is very fast, as it only needs to follow the list, and check whether a track is occupied. It does consider the current state, but only in terms of free or occupied tracks. It does not take the future traffic into account at all. This may result in blocking of tracks, which will be needed shortly by other trains, causing them to reroute as well.

4.2. Nested simulations

Thinking about the preceding approach as of an easy and fast one, the nested simulations method can be considered its opposite. When there is a track collision, the supportive software starts a simulation for each other acceptable track. This repeats for any further collision in every simulation, potentially nesting numerous times, until a pre-defined boundary is reached. The bound has to be chosen carefully, as the more recursions are performed, the better is the solution, but the longer it takes. It can easily end up so slow, that the decision is useless at the time it is delivered. This can be solved by an additional time-point boundary, representing the portion of time resource available for a nested epoch.

If the recursion boundary is reached, there should be another, faster method available to solve the deepest simulation epoch. It is pretty common to use priority planning, which is described above, and which provides a solution almost immediately. Once all the nested simulations in an epoch are finished, each of them is evaluated and the best fit is chosen. This is repeated through each epoch, resulting in just one track, which is assigned to the train.

Computational demands of this method are really high, but on the other hand, it can provide high-quality results. It does not need much of the original decision-making process implemented, as it only needs to know which tracks are permitted for each train to use. In contrast, it is important to provide detailed information of the infrastructure, so the simulation model reflects the simulated model. (Which is easy in a simulation, but can become challenging in reality.) But the main advantage of this approach is the look-head, as the future traffic is predicted by the simulator and it takes it into account. Of course, the more detailed the input information, and the more computational resources are used, the better are decisions.

5. Multicriteria evaluations of variants

So far, two methods of automatic operative control were described. Both methods are already implemented in the MesoRail simulator and are used as a reference for comparison of results. The multicriteria evaluation of variants is yet another available approach. It allows a solver to evaluate alternatives by defined weighted criteria. The best-fit alternative is then used.

5.1. Criteria

A criterion reflects a need. If the need is essential, it becomes a requirement. A requirement is not evaluated, it has to be met. For the purpose of this contribution, a requirement could be, for example, avoidance of train collisions. That simply shouldn't happen, even though a train would reach the platform faster. A criterion, on the other hand, is generally necessary, but can be omitted due to other needs.

Such criteria should cover all the needs connected with the control, which often requires a real-life expert to define them.

5.2. Criteria weights

Not all criteria are of the same importance. Thus, once they are defined, it is necessary to evaluate them. In multicriteria evaluation of variants, the criteria are equipped with weights. There are multiple ways of assessing the weight of criteria, and in this contribution, the Saaty's 1-9 scale method (Saaty, 1990) is used. The Saaty's method compares the criteria in pairs to each other. Each pair comparison provides a number, which describes how many times more important is the criterion, than the other one. This results in a matrix, which is called Saaty's matrix. The matrix must be normalized using geometric averages. The sum of rows (or columns) divided by the sum of the whole matrix then provides the weight of the respective criterion.

It is often necessary to consult experts of the target domain about the comparison, since it is subjective and not always accurate.

5.3. Variants

Variants reflect alternatives, which can be used to solve the problem. Each variant should provide an acceptable result. (In means of technical possibilities.)

5.4. Evaluation of variants

With both weighted criteria and variants defined, the last step of decision-making is evaluation of variants. For each variant, the value of each criterion is multiplied by the weight of the criterion, and such ratings are then summed together. The resulting value represents the variant's fitness. Of course, the variant with the highest value is chosen to solve the problem.

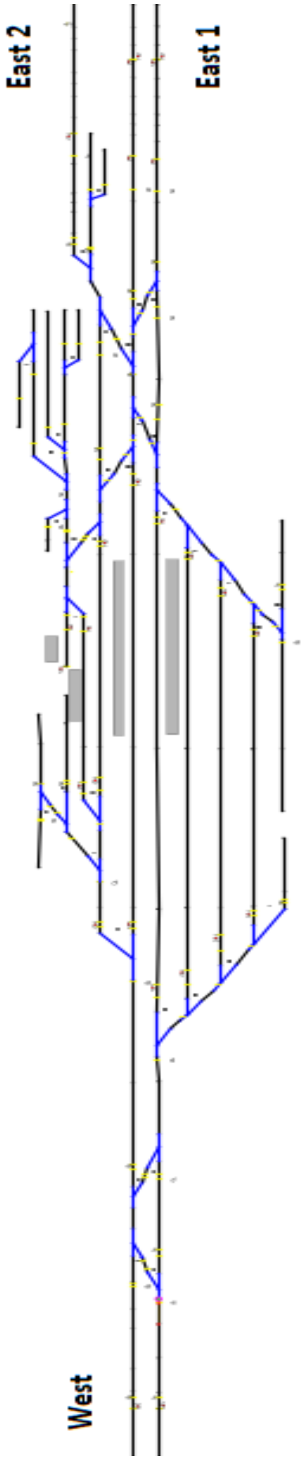

Figure 1. The Zdice railway station rail layout (from MesoRail)

6. Case study

This case study focuses on traffic in a small railway station called Zdice in the Czech Republic. The schema of the station's rail layout is illustrated in Figure 1. There is a total of four platforms with some adjacent tracks, as well as other tracks for transit trains.

In the MesoRail simulation tool, trains are generated on the input track at the border of the simulation environment, at the scheduled time. The generation time is optionally modified by a delay.

A train which does not stop at the station only needs a free track to pass through. On the other hand, a stopping train is limited to tracks which are adjacent to platforms. Such tracks may sometimes be occupied by other dwelling trains, making it a bottle-neck. Another bottle-neck are exit tracks, which are frequently occupied by arriving and departing trains.

As long as all the trains are following the timetable precisely, the traffic flows flawlessly. But if a train is delayed, it may dwell at a platform so long that another train, arriving to the same platform later, has to wait until it departs. Furthermore, the train could be so delayed, that it has to wait, because the platform is occupied by another train.

So the main task of the operative control support is the assignment of a track to a potentially delayed train. The track should be chosen accordingly to minimize the delay of trains. As for the exit tracks, these are occupied according to the source and the destination of the train. Therefore, it cannot be operatively changed to speed things up. However, the assignment of platform tracks can be optimized to reflect the needs.

To confront the chosen method, the same simulation scenarios, with the same pseudorandom number generator seeds (affecting the delays), were executed with the present methods of (i) priority planning and (ii) nested simulation solving. As already mentioned, the method of multicriteria evaluation of variants has been chosen for this case study. For implementation, the criteria and variants need to be defined.

6.1. Variants of re-routing

Similarly to other discussed approaches, an arriving train follows its timetable. In the timetable, the train is assigned a track and the time of expected arrival and departure. If the train is arriving to the station and the assigned track is occupied, then the re-routing is triggered. A variant basically represents any admissible platform track, which is at its disposal, including the one that was originally assigned to the train.

6.2. Criteria for re-routing

The criteria should reflect the need for minimization of train delays. The following criteria were defined:

- Criterion A: Platform availability,
- Criterion B: Platform sufficiency,
- Criterion C: Platform distance.

The first criteria, speaking of platform occupancy, is clearly the availability of the platform. If there are enough free, usable platforms, then there is no reason for the train to wait for an already occupied one. On the other hand, an occupied platform would be released shortly, even before the train actually reaches the platform, which makes it a suitable alternative. Also, if no platform is available, the train should be able to continue approaching the station instead of waiting, potentially blocking other trains.

For this reason, a look-ahead is used. The platform availability in time can be inferred from the blocking train's estimated departure. Similarly, the solved train's future demands can be inferred from its estimated arrival. Of course, the quality of these estimations may greatly affect the results. The value of *Criterion A* (*Platform availability*) for the given track *k* is defined as follows:

$$val(A,k) = \min\left(\frac{t_a - t_0}{t_b - t_0}, 1\right)$$

where t_a stands for the solved train's estimated arrival, t_b expresses the blocking train's estimated departure and t_o is the current time.

With the first criterion, the train should always be assigned to an empty platform, or to the first platform available. Even though it uses look-ahead, it is not aware of other arriving trains. Therefore, the second criterion focuses on other train arrivals. The solved train effectively blocks the assigned platform until its departure, while other arriving trains need the platform at the time of their arrival. Again, results are highly dependent on the quality of estimations. The value of the *Criterion B* (*Platform sufficiency*) for the given track *k* is defined as follows:

$$val(B,k) = \min\left(\frac{t_f - t_0}{t_d - t_0}, 1\right)$$

where t_d means the solved train's estimated departure, t_f stands for the first estimated arrival of any other train to the same platform and t_o is the current time.

As such, platforms are chosen logically. The third criterion is of a practical nature. In accordance with the two criteria above, if there are free platforms without other trains arriving soon, this method chooses the track randomly. So the last criterion adds a tendency to minimize the distance. The value of the Criterion C (Platform distance) for the given track *k* is defined as follows:

$$val(C,k) = \frac{1}{a+1}$$

where *a* expresses alternation. The alternation is defined as the distance between the prospective platform and the originally planned one. The distance is zero for the originally planned platform and increases by 1 for each successive adjacent platform.

6.3. Evaluation

As explained in (5.2), criteria are equipped with weights, which are calculated utilizing the Saaty's method. In this contribution, there are three criteria (*A*, *B* and *C*) defined, equipped with weights w_A, w_B and w_C.

The criterion values, which are computed according to equations above, result in the following matrix:

$$\begin{array}{c|cccc} & k_1 & k_2 & \cdots & k_m \\ \hline A & y_{11} & y_{12} & \cdots & y_{1m} \\ B & y_{21} & y_{22} & \cdots & y_{2m} \\ C & y_{31} & y_{32} & \cdots & y_{3m} \end{array}$$

Where y_{ij} represents the value of criterion *i* for the variant (track) *k*. The fitness O_j of each track k_j is computed as the sum of ratings of all criteria:

$$O_j = \sum_{i=A}^{C} y_{i,j} * w_i$$

As a result, the best-fit variant is chosen, and the corresponding track is assigned to the train.

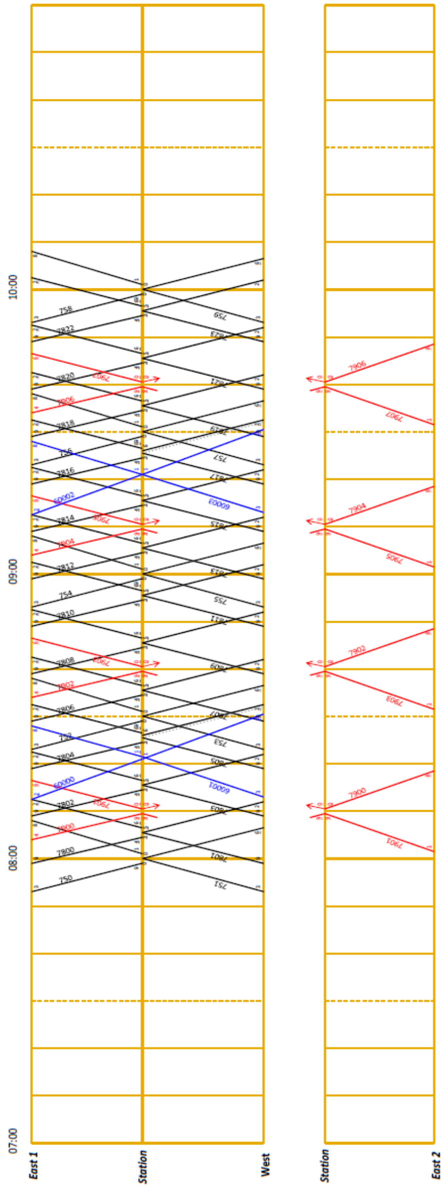

Figure 2. The graphic timetable related to the scenario

6.4. Simulation scenario

The preceding calculations exploit the Track occupation plan of the station. As real arrivals may differ according to train delays, all relevant estimations are recalculated at the moment of triggering the control support.

In the experiment, the scenario of the railway station Zdice consists of 46 trains (4 Cargo trains, 32 Regio trains and 10 Express trains) in a 2-hour time window. The scenario is further discussed in (Kavička et al., 2020) and the Figure 2 contains the related graphic timetable.

7. Results and discussion

For experiments, the first method tested was priority planning. Its outputs are reference results for the method of multicriteria evaluation of variants. Another used method is nested simulations, already developed and verified in (Diviš and Kavička, 2016), which provides certain improvement.

Consequently, the method of multicriteria evaluation of variants itself was applied in several setups of criteria weights. For each setup, there were 100 replications executed. Results are brought together in Table 1. For each experiment, there is the mean sum of weighted delay increment, and half of the confidence interval stated.

Table 1. Results

Method	Weights (A, B, C)	meanSWDI ± halfwidth
Priority planning	-	30.47 ± 3.06 min.
Nested simulations	-	26.46 ± 2.74 min.
MCEV	(0.3, 0.3, 0,4)	28.56 ± 2.80 min.
MCEV	(0.3, 0.4, 0.3)	28.56 ± 2.80 min.
MCEV	(0.4, 0.3, 0.3)	28.56 ± 2.80 min.
MCEV	(0.4, 0.4, 0.2)	28.38 ± 2.77 min.
MCEV	(0.4, 0.5, 0.1)	28.61 ± 2.83 min.
MCEV	(0.5, 0.4, 0.1)	28.67 ± 2.83 min.
MCEV	(0.5, 0.5, 0)	28.71 ± 2.83 min.

Apparently, each weights setup caused slight decrement of the cumulative delay, in comparison to the priority planning method. On the other hand, different setups of weights of the multicriteria evaluation of variants method produce just small differences, while the best result has been achieved with weights of 0.4 for Criterion A, 0.4 for Criterion B and 0.2 for Criterion C.

The method of nested simulations granted strong improvement, compared to the priority planning method, with only one nesting. It also exceeded the method of multicriteria evaluation of variants. However, it is necessary to point out that computational demands of the method are extensive. Considering the time of computation, it could be used for creation of tactical or strategical plans, while the method of multicriteria evaluation of variants may potentially be used for operative decision-making.

8. Conclusions

In this contribution, the method of multicriteria evaluation of variants as a tool of decision-making support in a railway simulator was presented. Similar studies were explored, as well as other methods, which can be utilized for the same purpose. The chosen method was implemented in the simulation tool MesoRail and compared to the methods of priority planning and nested simulations, which were already at disposal in the simulator.

Experiments were carried out in simulation of the small railway station called Zdice, exploiting a timetable, provided by the Railway Infrastructure Administration corporation. Also, the sum of weighted increment of delay was calculated according to a valid standard.

Results do not vary much with different weight setups, but in every experiment, the method of multicriteria evaluation of variants surpassed priority planning. In contrast to nested simulations, it does not demand many computational resources, even though it needs additional computations when compared to priority planning, in order to estimate the future state of the system.

Above all, this means the method of multicriteria evaluation of variants needs predictions of arrivals and departures of trains, while the method of priority planning does not. Since the growth of demands is not dramatic, a similar support could possibly make decisions (or recommendations) in real time, or in real traffic.

It is necessary to mention, that quality of decisions of this support is very dependent on the accuracy of these predictions. If the support has wrong information about the system, even if the estimations are wrong, it may fail to precisely evaluate variants and its ability to make decisions degrades. So, with a better estimator of arrivals and departures, the support could possibly achieve even better results.

The best results of multicriteria evaluation of variants were gained with the setup of weights 0.4, 0.4 and 0.2. Obviously, dominant criteria were Criterion A and Criterion B, meaning it is important to allocate a free (or the next available) platform, as well as a platform where the train will not cause additional delays to other arriving trains. On the other hand, the Criterion C had lower weight. This setup may not be optimal in terms of costs, since it may result in increase of distances to travel and more frequent adjustments of switches. However, in terms of sum of weighted cumulative increment of delay, it apparently does not provide a strong enhancement.

At present, additional research options are considered, for example to concretize optimal weights to more ranks. It could be achieved for example using evolutionary algorithm, but such experiment would claim many computational resources and is out of the scope of this contribution.

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