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Recommendations for Enhancing UIC Code 406 Method to Evaluate Railroad Infrastructure Capacity

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RECOMMENDATIONS FOR ENHANCING UIC CODE 406 METHOD TO EVALUATE RAILROAD INFRASTRUCTURE CAPACITY

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ABSTRACT

The evaluation of the consumed railway line capacity by using UIC Code 406 is based on the route occupancy. It is analytically calculated by compressing the blocking time stairways of a timetable (*1*). In the description how to execute the UIC Code compression method many details are left open, or rather not mentioned. This means that different capacity calculations may vary in several details, not only causing different results, but also a decreasing significance.

In the following, UIC Code 406 main contents are summarized. Although UIC Code 406 was especially developed for European railroads, capacity evaluations might also play a very important role in North America, e.g. for conforming the infrastructure characteristics considering the changes of traffic in the future. The difficulties that may arise from using the current issue of Code 406 are shown by several examples. Afterwards, the disadvantages that are implicated by the compression method as a timetable-dependent examination to get significant and comparable results are discussed. It leads to the question, if these problems might be compensated by applying a method, which is independent of the original timetable. The further examination shows that this is possible, but compared with the problems caused by using the timetable-dependent method, the independent method also features a couple of other disadvantages. To achieve more significant examination results, some suggestions for UIC Code 406 further development and alternative evaluation methods are presented.

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THE INTENTION OF UIC CODE 406

On many European railroads, capacity research has a long tradition. Research in that field was dominated by the German-speaking part of Europe where most of the railroad university programs are located. The theoretical background was developed in the 1960s and 1970s based on fundamental studies from the pre-war era. Then, computer-based tools emerged both for analytical methods and for simulation. However, for many years, all these developments were focused on the operating conditions of individual national railroads. There was not much exchange of information and experiences between different countries. At the time, most academic papers were only published in their original language and never translated. Common capacity measures, guidelines for the use of tools, and even common definitions did not exist. That situation changed completely with the reformation of the European railroad system in the 1990s. Driven by the enforced introduction of open access and the creation of international corridors, common capacity measures were badly needed. Providing both such measures and a method to determine the consumed capacity is the intention of UIC Code 406 (*1*).

At the very beginning, UIC Code 406 starts with the statement that the one and only capacity does not exist. Instead, on a given infrastructure, capacity is based on the interdependencies of:

- the number of trains per time (i.e. the traffic flow)
- the average speed
- the stability of the timetable
- the heterogeneity of the traffic pattern

To get broad acceptance, even from railroads without much experience with complex capacity models, a method had to be found that was easy to apply but fast and efficient. That is, why UIC Code 406 is based on an analytical approach that does not require a specific computer tool. Like all advanced analytical models, the UIC method is based on the blocking time model which provides a very profound description of the operational use of the infrastructure by a train path. The blocking time (from the German term ‘Sperrzeit’, (*2*)) is the total elapsed time a section of track (e.g. a block section, an interlocked route) is allocated exclusively to a train movement and therefore blocked for other trains. It starts at the latest time a movement authority to enter that section (e.g. by clearing a signal) has to be issued without causing delay. It ends after the train has completely left the section and all signaling appliances have been reset to normal position so that movement authorities can be issued to another train. The blocking times form a stairway-like time channel around a train path, for conflict free operation, must not overlap with the blocking times of other trains. For a comprehensive explanation of the background of the blocking time theory see (*3*), (*4*), (*5*), and (*6*).

To calculate the consumed capacity, the blocking time method can be used in two different ways. One possibility is to calculate the average minimum line headway from the minimum line headways of the different train combinations and the relative frequencies of these train combinations. Multiplying the average minimum line headway by the number of trains delivers the consumed capacity. That principle does not need a specific timetable but only a traffic pattern (mix of trains) that allows the user to calculate the relative frequencies of all train combinations. UIC Code 406 is based on an alternative, second kind of evaluation: The consumed capacity is derived from the original timetable by virtually moving the blocking time stairways together as close as possible without any buffer times but without changing the sequence of trains (FIGURE 1). This principle is also known as the ‘compression method’.

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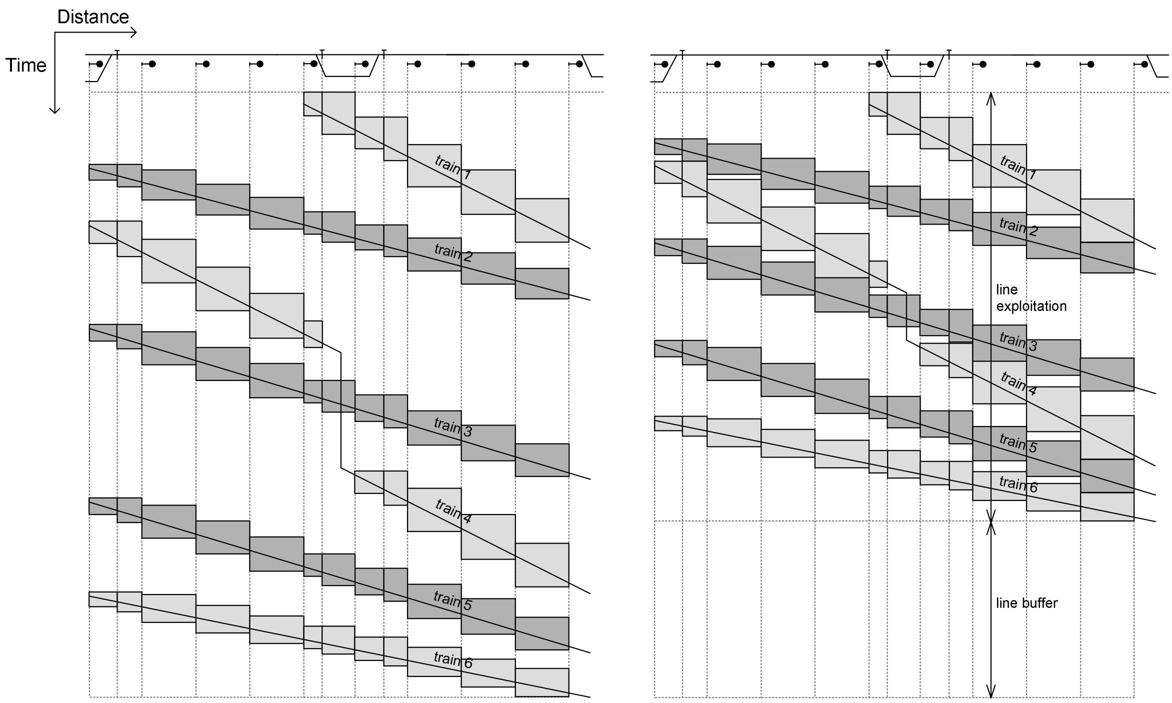

(a) original timetable (b) compressed timetable

FIGURE 1 Visualization of the consumed capacity.

In practical use, the compression is carried out by finding the critical buffer chain, e.g. the path through the diagram with the minimum sum of buffer time. UIC Code 406 concentrates exclusively on the timetable-dependent approach. The possibility of calculating the consumed capacity independently from a given timetable is not even mentioned. The reason is that the objective of the code is to evaluate capacity not for infrastructure planning but for train path management. There, the key question is whether additional train paths may be added to a given timetable without exceeding the recommended limits for an acceptable level of service. According to UIC Code 406, the consumed capacity shall not exceed the limits stated in TABLE 1. These limits are based on the practical experience with European passenger operation. If the capacity consumption is lower than these values, the attempt to insert further additional train paths of the type typical of the regarded area into the examined timetable has to be done. If it is not possible to insert such additional train paths into the timetable, the left-over capacity is lost capacity which cannot be used any more.

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TABLE 1 UIC Code 406 capacity limits

Type of line	Peak hour	Daily period	Comment
Dedicated suburban passenger traffic	85 %	70 %	The possibility to cancel some services allows for high levels of capacity utilization.
Dedicated high-speed line	75 %	60 %	-
Mixed-traffic lines	75 %	60 %	Can be higher when number of trains is low (smaller than 5 per hour) with strong heterogeneity.

At a glance, the entire procedure looks quite simple. UIC Code 406 is even a short paper of about 30 pages. However, application of that method on different kinds of infrastructure and traffic patterns brought the result that, in its current form, the code leaves a couple of important questions unanswered.

PROBLEMS CAUSED BY APPLYING THE CODE

The following paragraphs discuss selected critical points, give recommendations for practical use and develop proposals of how UIC Code 406 could be improved in further editions. Some presented examples are explicated by figures. Although the figures only describe a single-track line, they can also be applied to multi-track lines.

Compression process

Dividing the railway line into compression partitions

To execute railway line capacity by using UIC Code 406, the line has to be divided into sections with same signal and infrastructure configuration as well as the same number and mixture of trains. Further, the Code dictates that these partitions have to be *limited by two neighboring stations or nodes* (*1*). This statement gives opportunities for different choices of examination partitions.

In the following example (FIGURE 2) of a single-track line, it is shown that it is absolutely necessary to divide the line and execute the compression method between any meeting points. By considering the whole line between two nodes, it might be possible to construct further train paths even if the consumed capacity has already reached 100 %.

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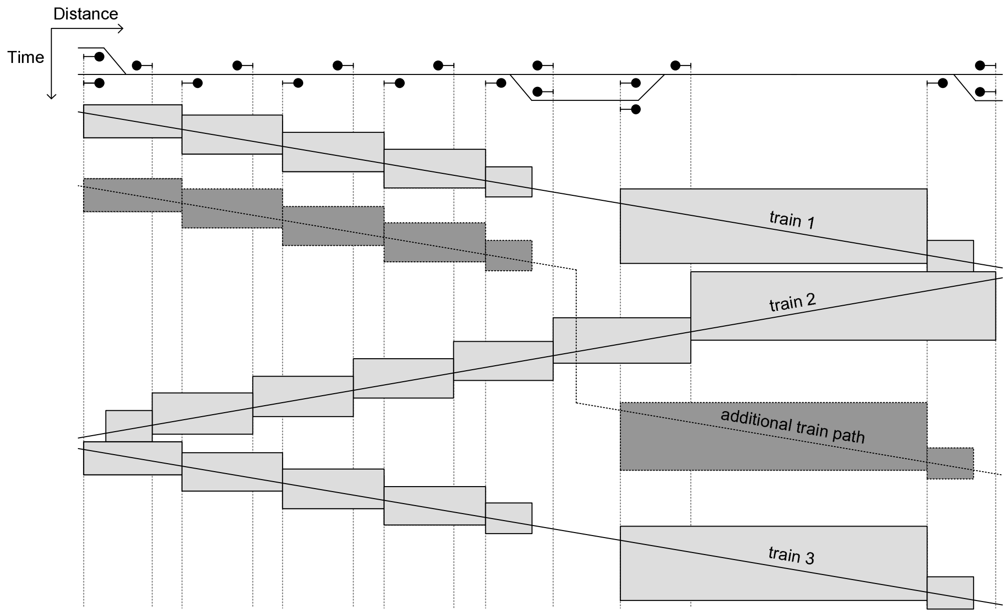

FIGURE 2 Creating additional train paths in spite of arithmetical fully utilized infrastructure in the compressed line section.

Enrichment process

Having calculated the free capacity of the original timetable, it has to be enriched by additional train paths. After creating each path, the compression must be repeated. This procedure has to be done until the dictated limit values of the route occupancy are fully utilized. In the following, some examples will show problems resulting from not clearly specified descriptions in UIC Code 406.

Dividing the line into enrichment partitions

To examine freight train paths, UIC Code 406 dictates to observe the route section between two freight nodes. Analyzing passenger train paths, the whole distance a train travels has to be inspected (*1*).

It is not mentioned how to handle a mixed traffic railway line including train paths with different destinations or lengths. Purely passenger train lines may also feature different path lengths, e.g. lines with a compacted timetable around big cities. The specification of UIC Code 406, which requires an unchanged number of trains in the analyzed section for the compression process, can not be transferred to the process of enrichment. In any case it is necessary to observe the whole train course. Parts of the train course outside the observing area may possibly raise conflicts e.g. the construction of a train meeting on the same track. Conflict-prone train paths would not be transferable to practice. Depending on infrastructure and timetable, the examination may result in overrated free capacity.

Recapitulating, every whole train course has to be checked for conflicts with already constructed additional train paths. In normal case, the examination area of the enrichment process has to be more expanded than in the process of compression.

Bundling of train paths

To keep the lost capacity resulting from the construction of additional train paths as low as possible, the additional train paths could be bundled with the already existing paths of the original timetable. But unfortunately, UIC Code 406 contains neither criteria nor methods that have to be applied while creating additional paths.

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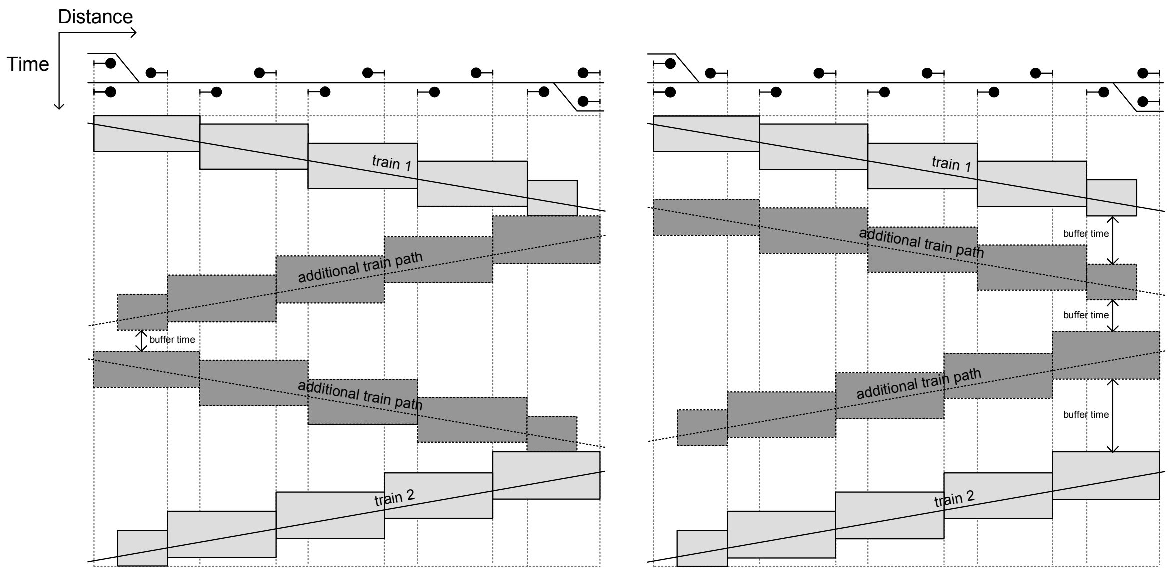

(a) without consideration of bundling (b) with direction bundled additional train paths

FIGURE 3 Buffer times after enrichment of two additional train paths.

In the presented example (FIGURE 3), the original timetable is enriched by two additional train paths with opposed directions. Depending on infrastructure, the capacity loss considering direction bundling may be lower than in randomized additional train paths. This may lead to an enlarging number of possible trains until the whole capacity is utilized. However, by enriching passenger train paths, direction bundling is contrary to the ambition of creating synchronized timetables. According to opposing train paths, a bundling does not allow to keep synchronized time spaces between train paths of the same direction. Under certain conditions, it is not possible to fulfill the *market needs*, which are not described in UIC Code 406 in this context.

In any case, passenger train paths have to be checked as well as freight train paths, if the opportunity of transferring direction bundled paths to reality is given. On the one hand, this means to consider customer needs in terms of synchronization and connection between several trains or routes. On the other hand, operational needs, e.g. in terms of the availableness of train sets, have to be checked. These aspects do not only apply to direction bundling but also to speed bundling.

While executing the enrichment process, it is necessary to make a decision between minimizing the capacity loss and a decreasing market suitability.

Consideration of circulation plans influencing market suitability

As an aspect of market suitability, it makes sense to consider the attribution of additional train paths to circulation plans. UIC Code 406 contains no information about this. While having notice of existing circulations, additional train paths could be allocated to them. This might result in a major number of possible train paths without needing more train sets.

If this is not practicable one can alternatively try to consider additional paths in own circulation plans by keeping the number of further circulations as low as possible, or to change existing circulation plans.
In general there is no dependency between the allocation of additional train paths to given circulation plans and the capacity loss inevitably. However, to optimize the operating procedure, it might be appropriate to check the transferability of an enriched timetable to reality in any case.

Creating further additional train paths in an already large enriched timetable

As mentioned before, UIC Code 406 dictates to repeat the compression and examine the route occupancy after creating each train path (*1*).

In the following example (FIGURE 4) of a timetable, the peak hour occupancy limit given in UIC Code 406 is not fully utilized. Although it is possible to create an additional train path, it contains a very long

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meeting time linked with an enlargement of the total running time. Also in this case, market suitability plays an important role, particularly concerning an already large enriched or highly utilized timetable. Depending on customer needs, it is necessary to decide up to which total or rather average running time an additional train path might be transferred into practice, in any case.

To evaluate realistic results, it is not adequate to concentrate on an exclusively analytical examination by looking at the limits given in UIC Code 406.

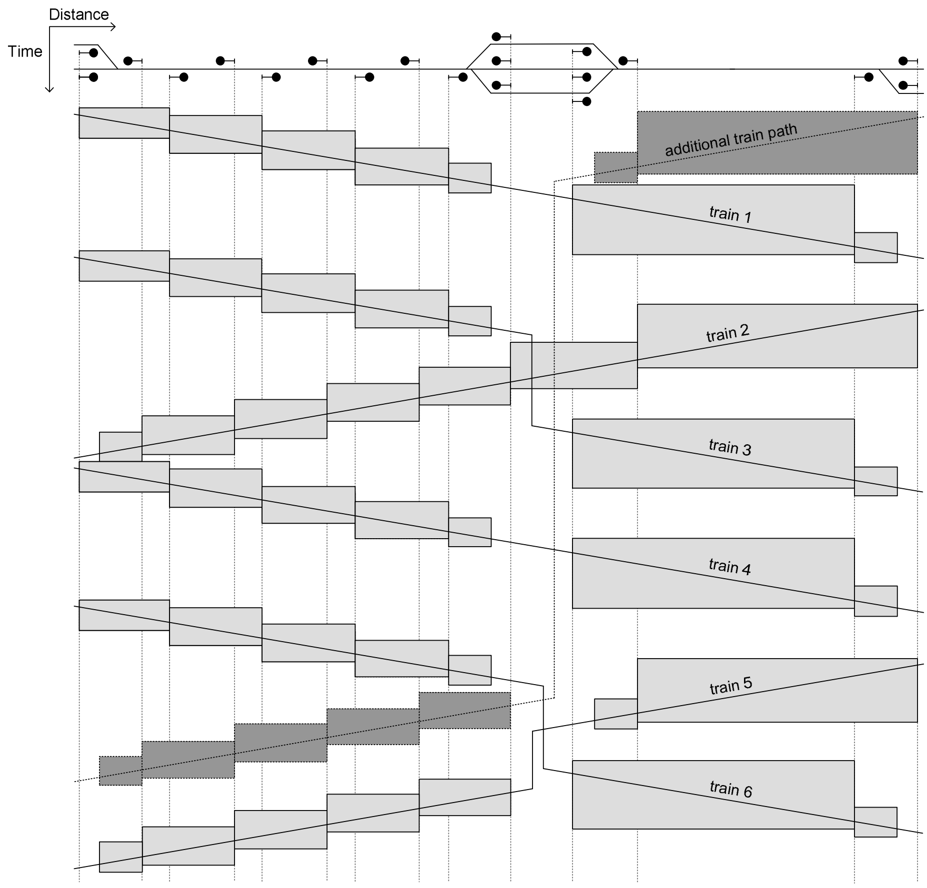

FIGURE 4 Additional train path with long meeting time.

Consideration of useable lengths in stations

Not only at the process of constructing train paths, but also while doing the enrichment process, the consideration of station track's usable lengths plays an important role. In practice it may occur that the length of a train set exceeds the usable lengths of a station track. In this case, the train may pass through the station, but it is not possible to stop the train to let another one pass.

To avoid conflicts while constructing additional train paths, one has to consider that trains may only meet at tracks offering an adequate useable length. If this is not possible, meetings of an additional train with trains of the original timetable have to be switched into alternative stations. That results in a decrease of flexibility at the process of scheduling. This may also mean that free infrastructure capacities could not be utilized as requested. Assumed an availability of all meeting tracks in every station, a full utilization of infrastructure capacity is not possible. This results in a higher possibility of non-utilizable free capacities, combined with a decreasing significance of occupancy rate results. UIC Code 406 does not discuss this topic. In practice, the following procedure might be applied, if only one train of a two-train-meeting possesses an overlength: It is necessary to look if the track of the non-overlength train is sufficient for being used by the overlength train. In this

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case, track allocations have to be switched. On the one hand, this may result in a better utilization of free capacities, on the other hand, UIC Code 406 does not allow to change track allocations of the original timetable. Alternatively it might be thinkable to construct additional train paths for shorter train sets. However, this might be contrary to the instructions of keeping *typical characteristics of the paths* during the enrichment process given in the UIC Code. Unfortunately, it is not defined in detail what is meant by typical characteristics.

Occupancy conflicts in stations
Inside the stations, it is not allowed to induce conflicts in the allocations of several trains. This should not only be considered while constructing a timetable but also during the enrichment process. In practice it means that the number of trains may not exceed the number of station tracks at the same time. UIC Code 406 examination method only observes the railway line outside the stations and contains nothing about occupancy problems. Therefore, the possibility of creating paths resulting in over-occupied stations is not precluded.

In FIGURE 5 an exemplary occupancy conflict is shown. The station on the right hand of the figure represents the end of a railway line. It contains two tracks, therefore a maximum of two trains may occupy the station synchronized. The construction of a third train path would result in non-practicable over-occupancy. By only following the UIC Code 406 compression method, an occupancy problem may occur without being recognized. As shown in the figure, station occupancy could significantly influence the practicability of enriched timetables and has to be considered in any case.

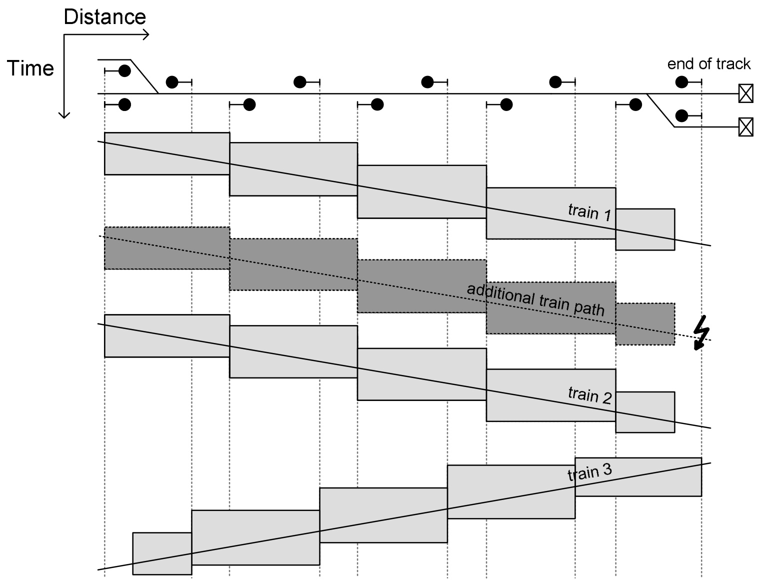

FIGURE 5 Additional train path results in over-occupancy at the terminus.

GENERAL DISADVANTAGES OF USING THE COMPRESSION METHOD

By presenting some examples, a few problems of applying UIC Code 406 were already described. For other kinds of problems e.g. see (*7*) and (*8*). In the following, several general disadvantages resulting from using the compression method are shown.

Occurrence of network effects based on the context between lengths of trains and meeting tracks

As already mentioned, the utilizable length of meeting tracks has to be considered not only during timetable construction but also while doing the enrichment process. The lengths of trains passing a station without stopping and meeting by another train are not observed. In practice, the opportunity to change meeting processes in other stations plays an important role: Meetings of a delayed train might be shifted into alternative stations causing a decrease of delay transmission. While concentrating on the compression method, a non-consideration of passing train lengths may produce unrealistic results. The problem is explained by FIGURE 6.

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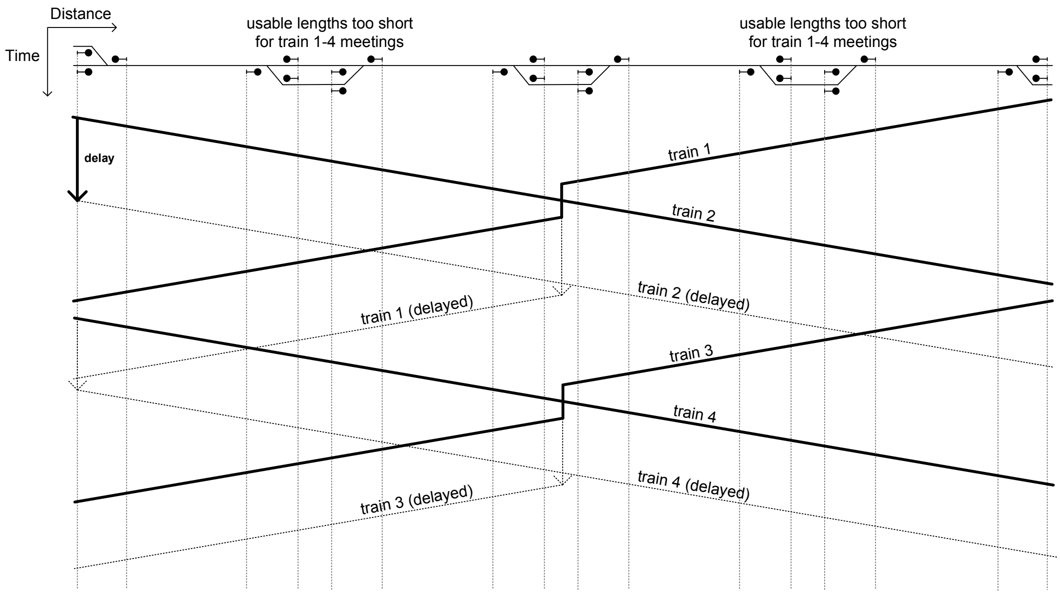
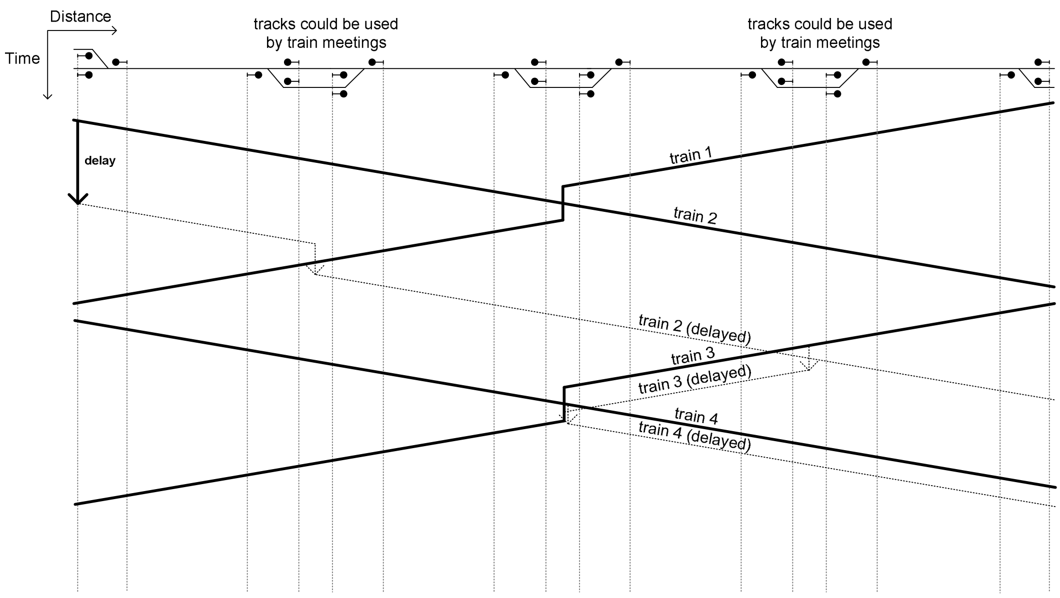


a) without possibility to switch meeting points of trains 1-4



b) all station tracks can be used by train 1-4 meetings

FIGURE 6 Change meeting points for decreasing delays.

In FIGURE 6, two infrastructure examples are shown. Both have the same number of meeting points same positioned. Therefore, the capacity research by applying UIC Code 406 compression method produces identical results on both infrastructures. The shown timetable contains quick train meetings. Contrary to the second part of the figure, in the first example, the useable lengths of some meeting point tracks are too short to be used for meetings of the trains 1-4. Train 2 leaves the first station delayed. Because of the non-possibility of switching train meetings to other stations, almost the full delay is transferred to the other trains of the timetable as *network-effects*. Finally, all trains are affected by the delay based on train 2. Also, a decrease of the delays is not possible. In the second variant containing long enough station tracks, the meeting of train 1 and train 2 is

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switched into another meeting point as well as the meeting of train 2 and train 3. Compared to the first scenario, the delay of train 2 increases at the first meeting point. However, train 1 can be kept without any delay on the whole course. By changing the meetings of train 2 and 3, a further delay transfer is also reduced as the length of the delay-affected course sections of each train. The example shows that the practicable capacity considering the handling of delays can be influenced by infrastructure characteristics significantly. In this case, the problem is based on the different lengths of trains. Some trains are short enough and may regularly use the critical stations for meeting, while other trains, as shown in the figure, are too long. Only a few trains (number 1-4) exceed the useable lengths in our case. If *all* trains of a timetable exceeded the useable length of a station, which does not apply in the presented example, the presented problem could be compensated by skipping the meeting point and regarding the previous and next station as limits while doing the compression.

However, to evaluate realistic values belonging to the timetable example of FIGURE 6, the probability of several train path delays should be also considered as the ability of decreasing delays by switching meetings, based on the length of train sets and station tracks. UIC Code 406 does not contain anything about delay sensitivity, network effects, and how to handle it. In practice, delays and other interferences may result in less enrichment ability. Based on a practical used timetable, critical parameters might be derived from real operation.

In summary, a consideration of the timetable ability to decrease delays would provide more realistic results. While concentrating on the graphical compression method, one can simply allocate blanket buffer times around each blocking time stairway possessing a high delay probability. These time spaces can be used to compensate delays. While considering the spaces as normal buffer times from an original timetable, it will keep these elements free of additional train paths, but will result in less free capacity. To improve punctuality, the Austrian Railways (ÖBB) followed a similar conception while considering so-called ‘quality factors’ during capacity evaluations (*9*). A surely more realistic option would be to consider interferences by distribution functions. However, this is not possible while using a pure analytical method.

Connection between the construction of the original timetable and the evaluated capacity

In one of the previous chapters it is already described that it is possible to increase the infrastructure capacity reserve by using direction or speed bundling. This also applies for the original timetable. A change in the train combinations could also reduce the loss of capacity.

Recapitulating, the infrastructure capacity examined by the UIC Code 406 compression method is significantly based on the train combinations of the original timetable. Changes in the train combinations may lead to different capacity results without varying the number of trains. Capacity values exclusively depending on the characteristics of infrastructure cannot be quantified. Unfavorable train combinations in the original timetable may produce an unrealistic loss of capacity compared with considering the real characteristics of the infrastructure.

METHODS TO EVALUATE RAILROAD LINE CAPACITY WITHOUT A GIVEN TIMETABLE

After having presented some disadvantages of the UIC Code 406 method, the question arises, if it might be more expedient to evaluate capacity by examining a virtual traffic diagram instead of an original timetable.

Compression of a virtual timetable

As an alternative to a specific timetable, the practical running times of an original timetable could be considered by defining model trains (e.g. differ between the three models long-distance, regional and freight trains). To each model train, the probability of occurrence in the timetable has to be defined as well as the whole number of daily trains. Based on model trains and time variation curve, a virtual timetable can be constructed. It can be compressed or rather evaluated in the same way as doing UIC Code 406 original timetable-dependent evaluation. The main difference to the UIC method is shown in the results: While dropping out original timetable constraints during the compression of this virtual timetable, it is possible to get results that are predominantly based on infrastructure characteristics. Without varying input parameters between different lines, one get comparable, well-defined results.

A similar conception is used by the asynchronous simulation of the German software package SLS, which has been developing since the 1970s by the *Institute of Transport Science* from *RWTH Aachen* (*10*), (*11*).

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Comparison of evaluation based on virtual traffic diagram and UIC Code 406 method results
In TABLE 2 it is shown that, in dependence on the input data, a virtual traffic diagram based evaluation provides output parameters that may differ from the parameters derived from a timetable-dependent approach.

TABLE 2 Evaluation methods depending on input and output parameters

output parameters / input parameters	capacity utilisable by additional train paths	timetable of additional train paths	infrastructure potential	potential of enriching a given timetable
specific timetable	X	X	-	X
virtual traffic diagram	X	-	X	-

As already mentioned, it is not adequate to evaluate the real capacity of infrastructure based on an exclusive capacity value examined by the analytical, timetable-dependent UIC Code 406 method. While the virtual traffic diagram based evaluation affords general results for infrastructure capacity, it does not allow to consider aspects of a specific timetable. According to this, both types of examination possess several disadvantages. To reach as significant as possible results, the timetable-dependent evaluation based on the UIC Code 406 method can be complemented by a virtual traffic diagram evaluation. In this way, the disadvantages of each method might be compensated, another advantage is shown in the following chapter.

Compensation of capacity misinterpretations based on the UIC Code 406 method
The influence of the train combinations on the UIC Code 406 method results was already mentioned in previous. A specific timetable with different train combinations may cause less capacity than the evaluation of a variable timetable with the same number of trains on the same infrastructure. Contrary to this problem, the usage of a virtual traffic diagram evaluation results in more realistic capacity values. It is based on the principles of establishing a timetable with a maximum number of trains for a given frequency of train combinations. It ignores customer needs, timetable synchronizations, and operational constraints. By developing an evaluation method combining timetable-dependent and virtual traffic diagram examination, the capacity loss based on original timetable constraints can be calculated by comparing the maximum number of trains in both types of evaluation.

In FIGURE 7, the essential differences in the results of both methods are summarized. The dark shaded elements of utilizable capacity illustrate the mentioned difference between the results of both methods.

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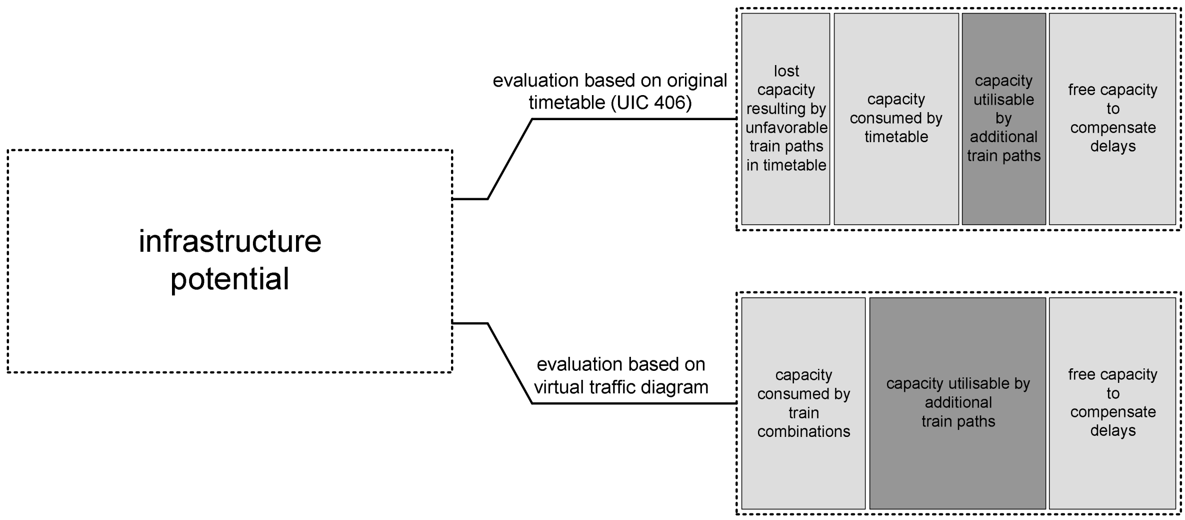

FIGURE 7 Quantitative results of UIC Code 406 evaluation in comparison with evaluation based on a virtual traffic diagram.

ADOPTING UIC CAPACITY EVALUATIONS TO NORTH AMERICAN RAILROADS

UIC Code 406 was developed for the operating conditions of European railroads. Operating characteristics between European and North American railroads differ significantly in several ways. North American freight lines are operated on an on-demand basic without using scheduling in the way European railroads do. There might be some kind of transportation scheduling but not in the sense of precisely planned train paths that form a conflict-free timetable. A timetable-based method would not really fit to that kind of operation. However, in conjunction with computer-based simulation systems, the compression method might make some sense. If a computer generated a number of typical timetable patterns for a given line, the consumed capacity could be evaluated by the compression method. With an advanced computer program, maybe as part of a simulation software package, the compression could even be done automatically. Evaluating the consumed capacity for different traffic patterns in dependence on the traffic flow would provide a very detailed picture of the operational capabilities of a line. The development of a best practice procedure of how to apply the compression method under North American operating conditions might be an interesting subject of research. On North American lines with mixed operation of freight and passenger trains, the situation is slightly different. Here, the passenger timetable already provides a basic traffic pattern, the freight train paths could be built around. This limits the number of possible traffic patterns to be generated but does change the basic principle.

CONCLUSION

In summary, two different problems result from applying UIC Code 406. On the one hand, concerning the problems described earlier in this paper, there are still open questions of how the compression method could be applied, e.g. especially on long stretches of single track with many sidings as typical for North American freight railroads. To constrict different interpretations, the Code should be concretized by some mentioned aspects, connected with producing more realistic results. On the other hand, a pure concentration on evaluating the original timetable features some general disadvantages. The train combinations affect the examination results. Users of UIC Code 406 only get information about the possibility of enriching the original timetable. Applying a virtual traffic diagram method leads to more realistic results of infrastructure capacity. This kind of evaluation may also be based on compression. While connecting both kinds of methods, the disadvantages of one method can be compensated by the other method's advantages. It results in different capacity parameters as shown in TABLE 2. As a whole, these values are able to describe the infrastructure characteristics in consideration of a concrete timetable more significantly as by applying only one of the two procedures.

In the first meeting of the TRB Rail Capacity Joint Subcommittee in January 2009, the need for a railroad capacity manual was expressed. After having done some research concerning the best-practice procedure to

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adopt the compression method to North American operating conditions, this advisements could become part of the selection of suggested methods in that manual.

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