Applicability of the analytical compression method for evaluating node capacity

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Braunschweig : Institut für Eisenbahnwesen und Verkehrssicherung IfEV, 2011

Veröffentlicht: 25.02.2011

http://www.digibib.tu-bs.de/?docid=00038224

Anmerkung:
Dieses Thema wurde im Februar 2011 in einer Präsentation auf dem 4. Internationalen Seminar der International Association of Railway Operations Research (IAROR) in Rom vorgestellt.

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Abstract
This paper summarizes the main contents of UIC Code 406 with its compression method. In this context, not only the problems that appear while applying the method are described, but also possibilities to solve them. One concrete example will show a typical timetable situation on a specific infrastructure featuring less node than line capacity. In this case, node capacity determines the maximum capacity of the whole infrastructure. This demonstrates the importance of evaluating the line outside station areas as well as station infrastructure itself. Furthermore, also the necessity of doing capacity evaluations for an infrastructure extract containing a constant number of trains is described. Based on this aspect the paper explains, why the occupancy rate cannot provide a significant parameter for doing node station capacity and that UIC Code 406 method cannot be applied for doing node capacity research.

Keywords
infrastructure, operation, UIC Code 406

1 Introduction

UIC Code 406 describes a concrete method for doing railway infrastructure capacity research. The intention of Code 406 is to standardize evaluations for getting comparable examination results. The explained method is quite easy to apply and should allow significant values.

One problem is that a lot of important parameters for applying the Code method are not explained clearly. That leads to a wide scope of interpretation. Apart from that, the evaluation method purely concentrates on line research. Experience has shown that in many cases, capacity bottlenecks can be found at railway nodes, but not outside the stations. Following Code 406 method, this problem is not considered, which may lead to unsignificant results. This leads to the question, if it would also be possible to apply the compression method for evaluating railway nodes or rather station areas.

2 Development and intention of UIC Code 406

The intention of creating a transnational method for evaluating railway infrastructure capacity arised from the development of rail traffic in the last decades. By reason of an increasing demand for rail traffic as well as rising quality requirements, a standardized method of capacity parameters is very important in nowadays [1]. With this background, UIC Code 406 was developed. The first issue was published in 2004 and this is the only version up to now. It is based on Code 405, which was published in the year 1996. But while Code 405 purely concentrates on giving verbal suggestions for how to improve the utilization of infrastructure [2], Code 406 explains concrete steps of evaluation, the “compression method” [1].

This method should allow the user to evaluate the capacity of “lines/nodes or corridors” [1] by using standardized definitions or rather the standardized evaluation method. The evaluation should be easy to apply and can be done fully analytically by the above mentioned compression. During the compression, the blocking time stairways of a concrete timetable on a specific infrastructure have to be shifted together as close as possible. As a result, the occupancy rate can be calculated as the difference between the evaluated time period and the time which is elapsed by the blocking times of the existing train paths. Finally, the occupancy rate has to be compared with limit values predicted in UIC Code 406.

3 Main contents of the Code

The UIC Code 406 consists of 21 pages and is devided into the four chapters *introduction*, *definitions*, *calculation of capacity consumption* and *application*.

3.1 Introduction

The introduction contains the already above mentioned intensions of the Code 406. Furthermore, three subchapters (basic parameters underpinning capacity, different views of capacity, capacity-relevant constraints) try to describe the complexity of the term “capacity”. UIC Code 406 says that capacity as such does not exist. Instead of that it is dependent on infrastructure properties, timetable and imposed punctuality level as main parameter, as well as on the interdependencies of the *number of trains*, *average speed*, *stability* of operation and *heterogeneity* of the timetable. The context of these terms is described by a capacity balance figure that allows to derive the capacity as a value. All in all, capacity can be evaluated under different points of view. From market view, a need-satisfying number of train paths is required, while running times have to be kept as short as possible, for example. From the perspective of infrastructure planning, an average “profitable utilization of the infrastructure” has to be guaranteed while considering buffer times for compensating delays. During the timetable construction, the market needs have to be connected with the infrastructure properties. In practical operation, capacity parameters permanently vary because they are based on the in that specific moment utilized train paths, attached to the availability of infrastructure as well as delays. Different constraints can negatively influence capacity. In practice they may also appear in combination. For example, priority rules can influence the flexibility of handling the sequence of train rides. Also a given timetable structure as a synchronized timetable can constrain the construction of train paths significantly. A theoretical maximum capacity can only be calculated without any kinds of conflicts. In reality this will never appear, if the above mentioned influence parameters will be considered.

3.2 Definitions

In this chapter, a few terms used in the further parts of Code 406 are explained. The definition of the word *capacity* plays an important role. It is defined as "the total number of possible paths in a defined time window, considering the actual path mix or known developments (…)" in station areas, on the line outside the stations or on larger extended parts of a network. An assumption is that the infrastructure operator offers paths that match the market needs of the infrastructure users.

A *line section*, in that an infrastructure has to be divided for doing evaluation, consists of "one or more coherent sections, which are limited by two neighboring stations or nodes".

3.3 Calculation of capacity consumption

The evaluation of infrastructure capacity is based on an specific timetable (or train structure). This timetable should represent the market needs and has purely to consist of paths utilized in practice regularly.

While doing further examination, the infrastructure has to be divided into neighboring parts at which the number of trains, the train mixture and signaling properties do not change. For each of these parts, the capacity consumption has to be calculated. The maximum of these values is significant.

Rules for doing compression
During the compression it is not allowed to change the regular running times as well as the sequence of trains or rather regularly used meeting points.

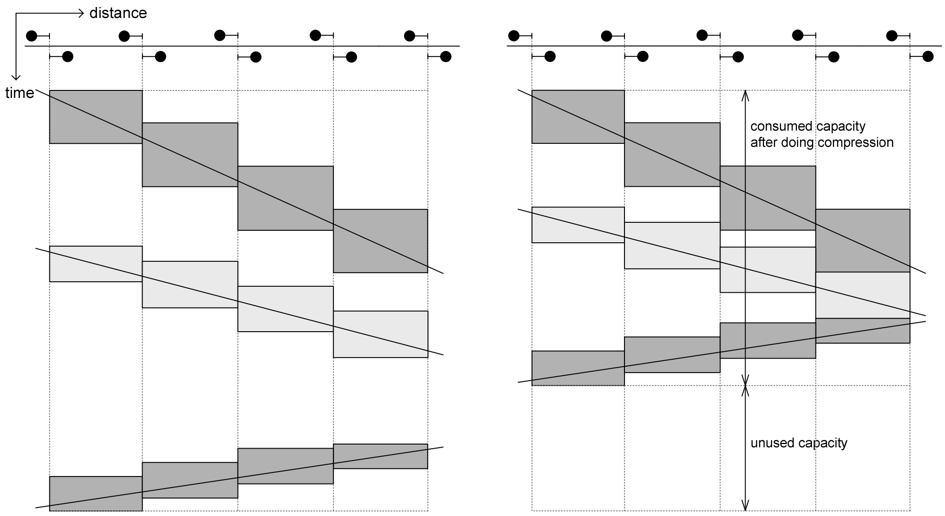


Figure 1: Time-distance-diagram of an original (left) and compressed timetable (right) [3]

On single track lines, the positions that divide the infrastructure into several compression partitions, have to be located in the meeting points.

As shown in Figure 1, the train paths have to shifted together as close as possible. After the compression, there do not remain any buffer times. This part of the evaluation can be done analytical or rather purely graphical, too.

Consideration of indirect occupancies

While doing the evaluation, also blocking time elements based on indirect occupancies have to be considered. These occupancies result from train paths (stabling of freight wagons, locomotive change etc.) or are independent from the timetable (shunting movements etc.). UIC Code 406 contains a figure which should show how to consider these aspects during the evaluation. UIC Code 406 contains a figure about the consideration of indirect occupancies which is not explained in detail, therefore the user does not get enough information how to consider these aspects.

Construction of blocking time elements

UIC Code 406 describes the time components that build the blocking time of a train movement. This is important for getting a standardized data basis for the blocking time construction. For main-/distant- and main-/main-signal system, the occupation times are explained with the characteristics of both systems. These explanations are consistent with the from specialist literature known definitions (see [4], [5]).

Calculation method

The calculation of the capacity utilization of a timetable on a specific infrastructure has to be done with the following formula:

$$k = A + B + C + D. \tag{1}$$

k = total consumption time (min)
A = infrastructure occupation (min)
B = buffer time (min)
C = supplement for single-track lines (min)
D = supplements for maintenance (min)

The infrastructure occupation A is the accumulation of the consumed time evaluated by doing the compression. Supplements for single-track lines or rather maintenance can also be considered as infrastructure occupation or as separate additional values. The percentage capacity consumption K can be calculated as the quotient of total consumption time and chosen time window.

$$K = k \cdot \frac{100}{U}. \tag{2}$$

K = capacity consumption (%)
U = chosen time window (min)

The capacity consumption represents the chained occupancy rate, as the compression does not have to be done for a partition consisting of only one specific block interval, inevitably. Instead of that, an examination partition can consist of more than one block interval.

3.4 Application

The following figure summarizes the steps of doing UIC Code 406 capacity evaluation.

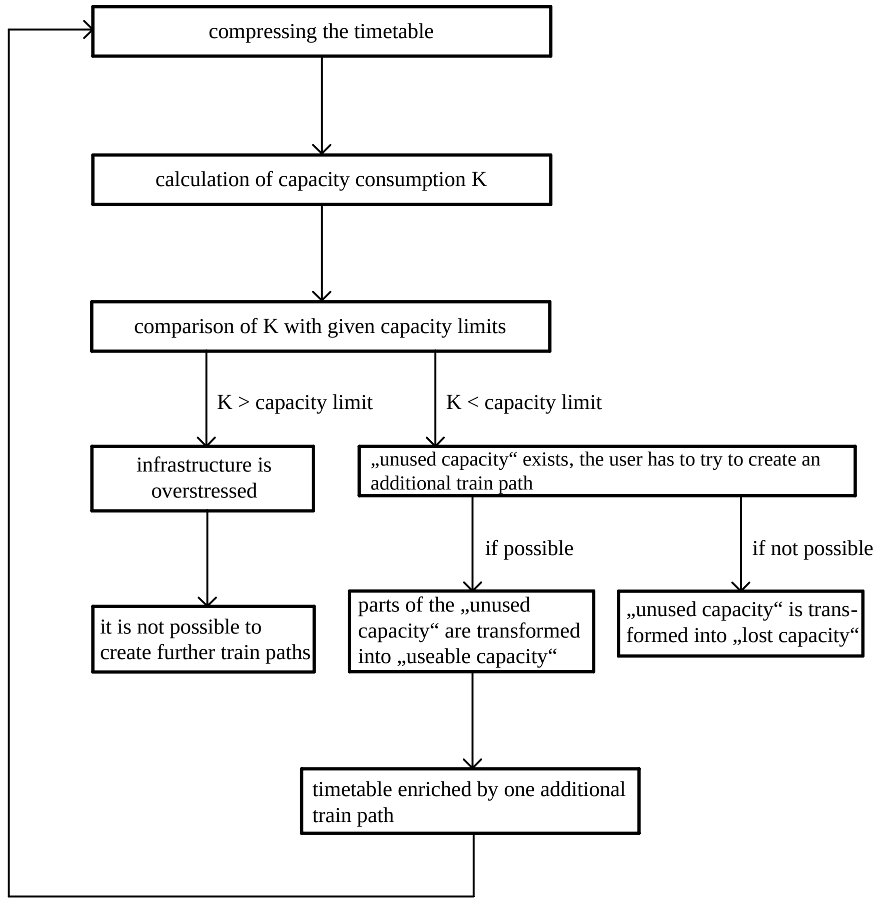


Figure 2: Several steps of the UIC Code 406 capacity evaluation [3]

As already mentioned above, the capacity consumption has to be calculated after compressing the timetable. Figure 2 also shows the further steps. At first, the capacity consumption K has to be compared with in Code 406 given limits of the occupancy rate. These values are shown in Table 1. If K is major than the predicted occupancy limit, the infrastructure is overstressed. The evaluation has to be stopped and there is not any possibility to create additional train paths without causing a significant decrease of operation quality. If the capacity limits are still not reached, *unused capacity* remains. The

Code user now has to add one additional train path which fulfills the market needs to the origin timetable. This part of the evaluation is called *enrichment process*. If a creation of this path is possible, the unused capacity will be transformed into *usable capacity*. In this case, the construction of a second additional path has to be tried. The procedure of alternating enrichment and compression has to be done until the occupancy rate limits are reached.

Table 1: UIC Code 406 capacity limits [1]

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.

4 Problems caused by applying the Code

The following paragraphs discuss selected problems which appear during the application of the UIC Code 406 evaluation method. For further information about compression, enrichment and market suitability problems also see [3, 6].

4.1 Compression process

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 partition limits.

Examinations have shown that it is absolutely necessary to 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 % [3, 6].

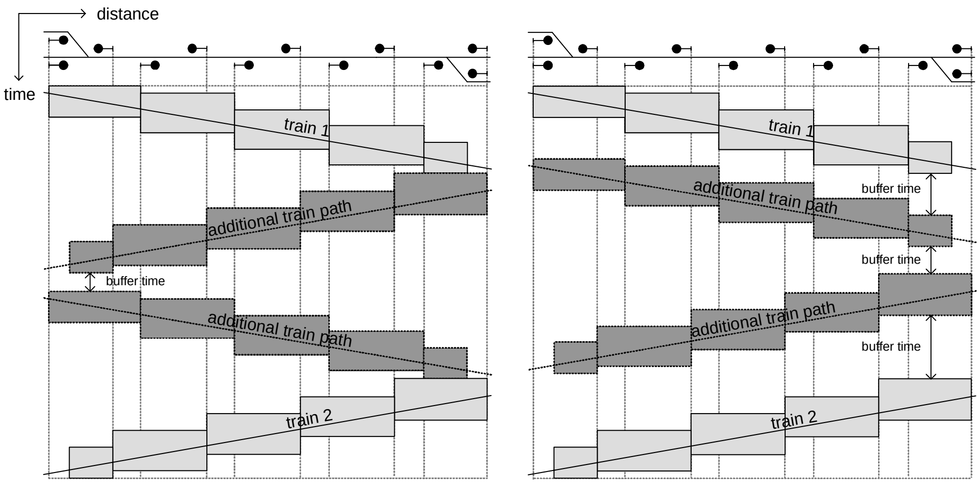
4.2 Enrichment process

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 cannot 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.

4.3 Capacity influenced by market suitability

The compression method is based on a specific timetable. Therefore the evaluation results are not purely dependent on infrastructure properties. Instead of that, market suitability plays a very important role, concerning the capacity loss appearing during the enrichment process. In the following, some different examples of market suitability influence are presented.

Consideration of train path bundling
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.



(a) without consideration of bundling (b) with direction bundling

Figure 3: Buffer times after enrichment of two additional train paths [6]

In the presented example (Fig. 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.

Creating further additional train paths in an already large enriched timetable

In the following example of a timetable (Fig. 4), 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 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.

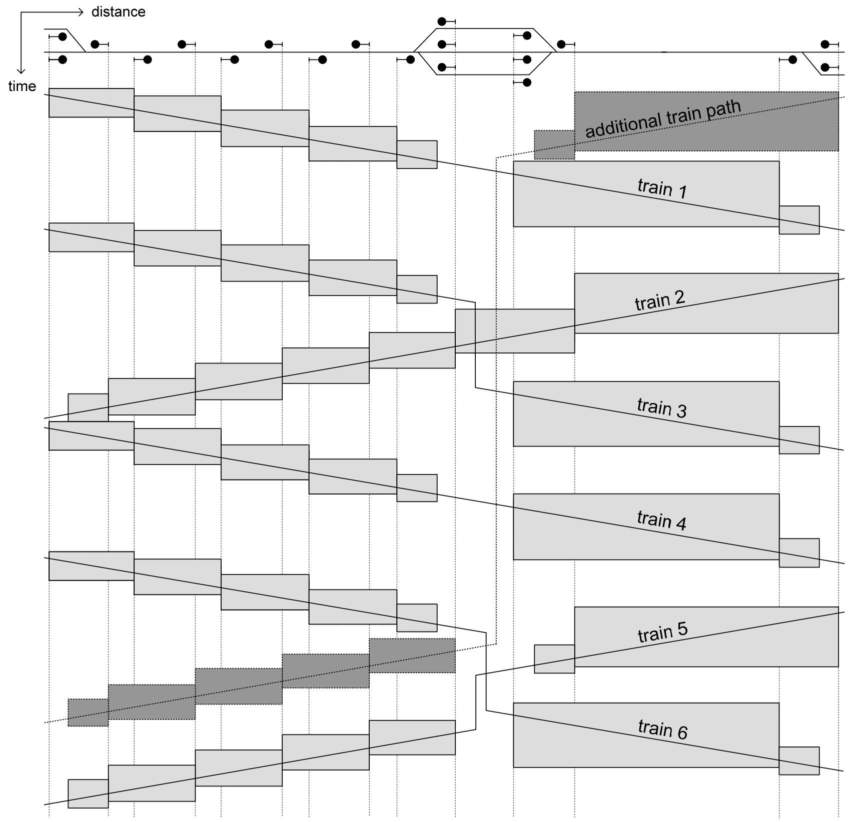


Figure 4: Additional train path with long meeting time [6]

The example shows that it is necessary to make a decision between minimizing the capacity loss and a decreasing market suitability during the execution of the enrichment process.

4.4 Applying the UIC Code 406 compression method in station areas

Although UIC Code 406 describes within its summary, i.e. on one of the first pages that the main purpose of the Code is to offer a method for evaluating “lines/nodes or corridors” [1], the descriptions do not content anything about node evaluations. Instead of that, the Code purely concentrate on line evaluations, i.e. on the infrastructure outside the station areas. That leads to the question, if it is even necessary to do station evaluations or if it is expedient to evaluate only line capacity.

The importance of considering station areas for doing capacity research
Experience has shown that station evaluations cannot be disregarded. In many cases, occupancy problems rather appear in station areas instead of the infrastructure outside the stations. One example is shown in Figure 5. Outside the station b, the UIC Code capacity limits (see Table 1) are still not reached. Without any problems it is possible to create one

additional train path. In practice, it would not be possible to use this path. The station b represents the end of a railway line which contains only two tracks, therefore a maximum of two trains may occupy the station synchronized. In the example, it would have to be used by three train paths at the same time.

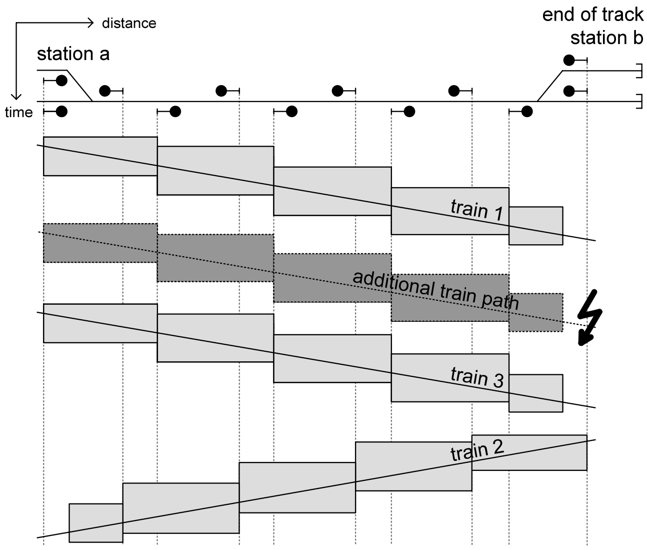


Figure 5: Additional train path results in over-occupancy at the terminus [6]

The construction of a third train path would result in non-practicable over-occupancy. By only following the UIC Code 406 compression method, such 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.

In the following, it will be discussed if the compression method can also be applied in station areas. The first step will be to check if the prediction of the Code that the number of trains within a specific compression partition must not change, makes sense.

Change in the number of trains between two neighboring meeting points

If a branch is located between two neighboring stations, a change in the number of trains between two meeting points will be possible. One example is shown in Figure 6. Applying the Code prediction to compress the line between the two meeting points, the maximum capacity consumption is calculated between the branch and station b. At this part of the infrastructure, the occupancy rate is about 85 % - the occupancy limits given in UIC Code 406 are exceeded. It would not be possible to create additional paths, the evaluation is finished. In practice, on the left part of the infrastructure extract, between station a and branch, there is still free capacity. The occupancy rate is only about 53%. A creation of one additional path will cause an increase of the consumption to 62%. The non-consideration of this aspect by concentrating on the infrastructure partition on the right side of the branch will cause insignificant results. Furthermore, the example shows that the part of infrastructure utilized by the highest number of trains does not have to feature the most extended consumption of capacity. Instead of that, it is dependent on the average speed of trains as well as the length of the several block sections.

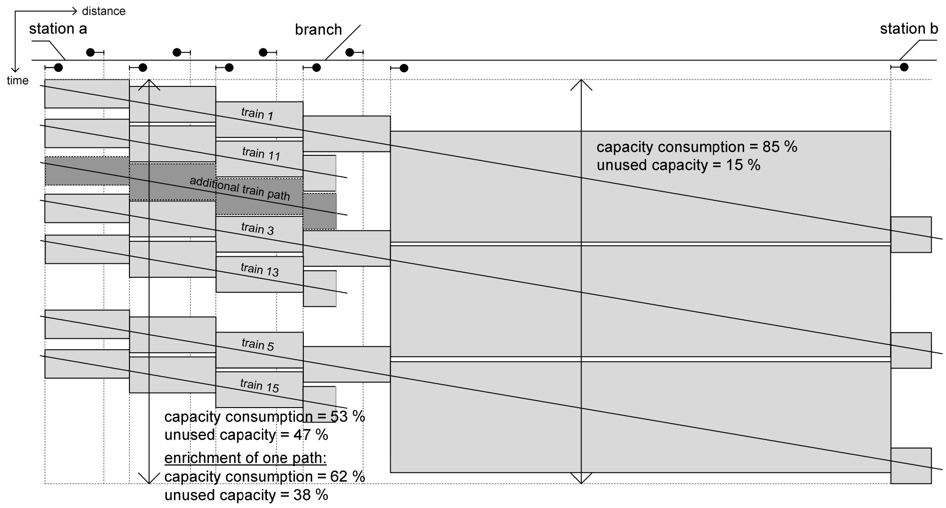


Figure 6: Applying the compression method on an infrastructure part containing a branch

In summary, the division of infrastructure for doing compression does not purely have to be done in meeting points, but also at branches outside the stations. Therefore a branch between two stations leads to an increase of evaluation partitions from one to two. This aspect has also to be considered in the following chapters about the trial of applying UIC Code 406 compression method for doing station capacity research.

Dividing a station area into compression partitions

As mentioned above, a division of infrastructure has to be located at each point of changing number of trains. Thus, three different compression partitions adjoin at a switch. Especially in station areas, this will lead to a large number of very short compression partitions. In opposite to the infrastructure outside the stations, during the blocking time construction it has to be considered that a partition is not limited by signals, inevitably. Figure 7 presents an extract of a station area. The demonstration contains several compression partitions (1 and 3). Apart from train 1 and 9, every train path of the origin timetable uses the diverging track of the switch. The result is shown in Figure 8. Partition 1 is fully utilized, the consumption is 100 %. Furthermore one can see that the occupancy of partition 3 is only 59 %. Following UIC Code 406, the partition has to get enriched by further train paths until the occupancy limits are reached.

Partition 3 is the main track of a switch. Therefore, each train using this partition also has to use the neighboring parts of infrastructure. In this case, these are the partitions 1 and 6. The evaluation has shown that partition 1 cannot be enriched by further trains. Therefore, part 3 also cannot be utilized by more trains, although the very low consumption.

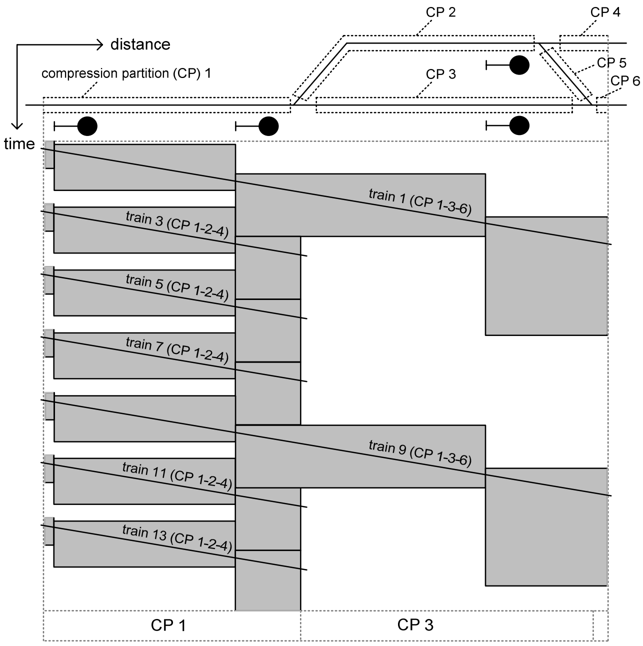


Figure 7: Example for a time-distance-diagram in a station area

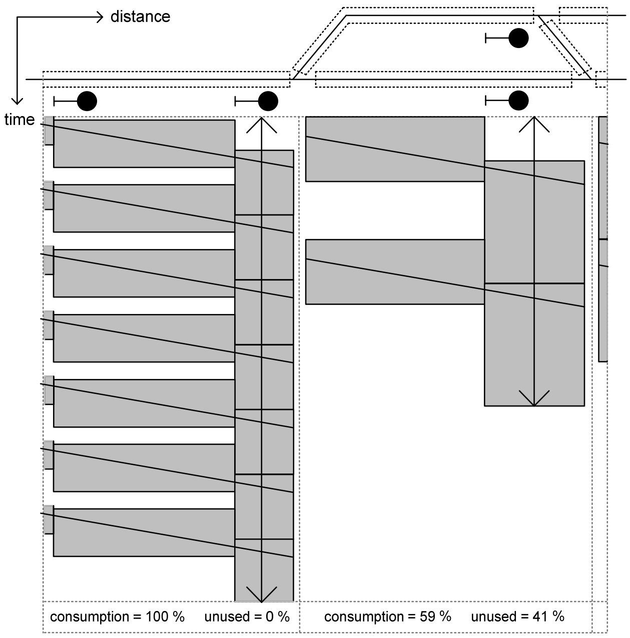


Figure 8: Compression results of Fig. 7 timetable

Summarized, in opposite to the infrastructure outside the stations, the maximum capacity can be reached at a calculated consumption of much less then given in the Code limits. For getting significant results, all compression partitions of routes that lock each other have to be evaluated synchronized. The maximum consumption value (here: partition 1 with 100 %) is significant for all of the concerned routes. In normal case, still in stations containing only two tracks, it is possible to use more than one route synchronized. This problem is specified in the following chapter.

4.5 Impacts of route dependencies in station areas

Figure 9 represents a station infrastructure, on which several routes can be used synchronized. Both parts of the figure show a specific point of time with the at this time utilized routes. At the first point of time (the upper part of the figure), four different routes (1 - 4) are used synchronized. The second situation only contains one route (5). The lower situation does not allow a second route, each other route is locked by the utilized route 5.

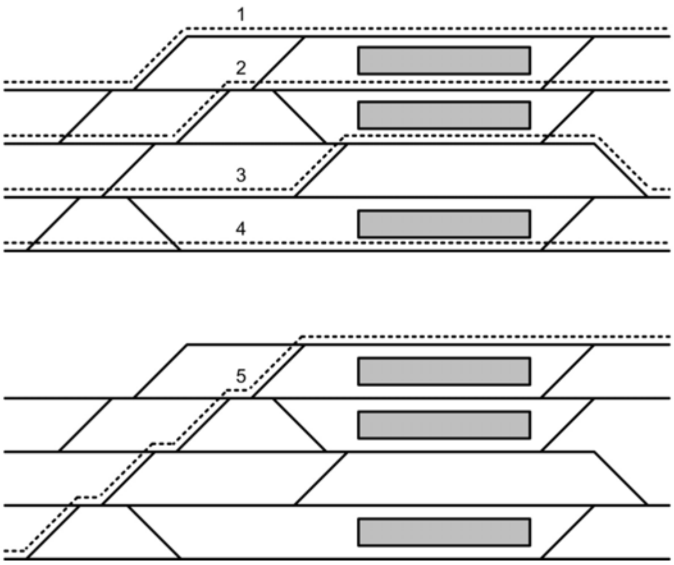


Figure 9: different routes in a station infrastructure

During the enrichment process it is possible that a timetable will be enriched by a large number of paths utilizing route 5. In this case, the maximum capacity is reached at a much lower number of trains compared with the construction of paths on the route 1 - 4. The maximum station capacity is less dependent on infrastructure properties, but significantly based on the combination of synchronized used routes. Thus, capacity evaluations cannot be done by applying the stepwise enforcement of enrichment and compression.

Instead of that, all routes would have to be considered synchronized. The construction of additional train paths has to guarantee a train structure providing a maximum number of trains. This structure would hardly be found out by the application of the analytical compression method.

5 Conclusion

In summary, several different problems result from applying UIC Code 406. On the one hand, concerning the problems described in this paper, there are still open questions of how the compression method could be applied. To constrict different interpretations, the Code should be concretized by some 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. Also in the enrichment process, the consideration of market suitability can influence the maximum number of trains significantly. Users of UIC Code 406 only get information about the possibility of enriching the original timetable. Although in UIC Code 406 not mentioned, it is not expedient to concentrate purely on infrastructure evaluations outside the stations. The Code does not contain anything about station evaluations. That led to the question, if it is possible to apply the compression method in station areas. The paper shows that this is necessary, experience has shown that in many cases, occupancy problems rather occur in stations than outside the stations.

At each point of changing train number, i.e. at each switch, a further compression partition limit has to be located. That could lead to a very high number of compression partitions in a station. Although a compression might be complex, this part of the Code method might be applied. Much more problems can be found in the application of the enrichment process. In normal case, several station routes can be used synchronized. The maximum capacity is mainly based on the train structure. For getting significant results, all routes would have to be considered synchronized. This structure would not be found out by the application of the analytical compression method.

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