

Evaluation of railway capacity

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1 Abstract

This paper describes the relatively new UIC 406 method for calculating capacity consumption on railway lines. The UIC 406 method is an easy and effective way of calculating the capacity consumption, but it is possible to expound the UIC 406 method in different ways which can lead to different capacity consumptions. This paper describes the UIC 406 method and how it is expounded in Denmark.

The paper describes the importance of choosing the right length of the line sections examined and how line sections with multiple track sections are examined. Furthermore, the possibility of using idle capacity to run more trains is examined.

The paper presents a method to examine the expected capacity utilization of future timetables. The method is based on the plan of operation instead of the exact (known) timetable.

At the end of the paper it is described how it is possible to make capacity statements of a railway network. Some of the aspects which have to be paid attention to making annual capacity statements are presented too.

2 Introduction

The UIC 406 leaflet from year 2004 [12] describes a simple, but fast and effective way to evaluate the capacity utilization of railway lines. The capacity analyses carried out during the last years using the UIC 406 method have been presented in a number of papers (e.g. [4], [9] and [14]). However, it is possible to expound the UIC 406 method in different ways which can lead to different results. In spite of that fact, hardly any analyses of the differences have been carried out.

This paper describes the UIC 406 method (cf. section 5) and a number of analyses carried out to generate a Danish consensus of expounding the UIC 406 leaflet for capacity analysis. A number of different analyses on relevant Danish railway lines have been carried out including:

- The length of the railway section examined (cf. section 6.1)
- The allowance of changing tracks on railway lines with multiple track sections (cf. section 6.2)
- The possibility of using idle capacity to run more trains (cf. section 6.3)
- The possibility of using the plan of operation instead of the exact timetable (cf. section 6.4)

In section 7 it is presented how it is possible to make annual capacity statements of the railway network and some paradoxes in the UIC 406 method. At the end of the paper some conclusions and perspectives of the UIC 406 method are listed (cf. section 8).

3 Definitions

This paper uses terminology usually used in the railway literature. However, since the terminology differs from country to country, an overview of the terminology used in this paper is provided in table 1.

Term	Explanation
Block occupation time (<i>Blokbesættelsestid</i>)	The time a block section (the length of track between two block signals, cab signals or both) is occupied by a train
Buffer time (<i>buffertid</i>)	The time difference between actual headway and minimum allowable headway
Headway distance (<i>togfølgeafstand</i>)	The distance between the front ends of two consecutive trains moving along the same track in the same direction. The minimum headway distance is the shortest possible distance at a certain travel speed allowed by the signalling and/or safety system
Headway time (<i>togfølgetid</i>)	The time interval between two trains or the (time) spacing of trains or the time interval between the passing of the front ends of two consecutive (vehicles or) trains moving along the same (lane or) track in the same direction
Running time supplement (<i>køretidstillæg</i>)	The difference between the planned running time and the minimum running time
Secondary delay (<i>følgeforsinkelse</i>)	A delay caused by a delay or cancellation of one or more other trains

Table 1: Short description of terminology [8].

Some of the terms described in table 1 are further illustrated in figure 1.

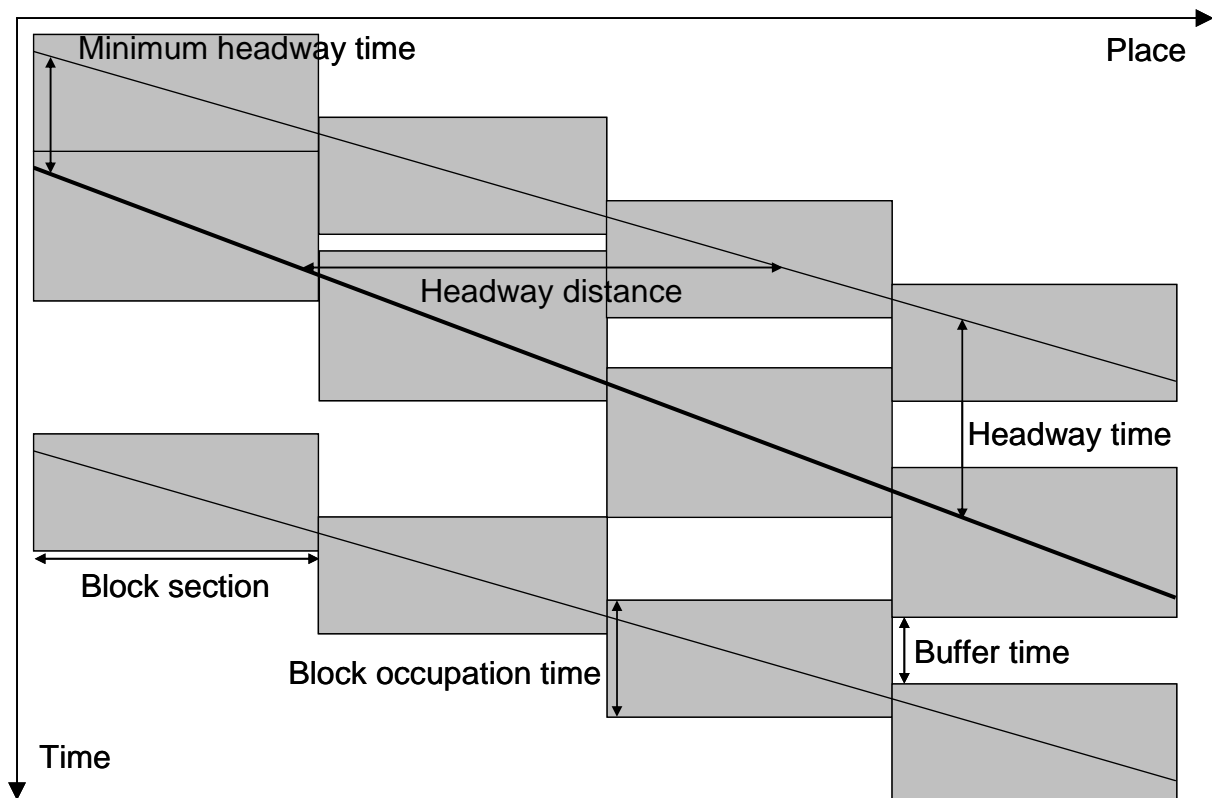


Figure 1: Definitions [10].

4 Railway capacity

It is relatively easy to determine the capacity on roads – the capacity is normally just determined as vehicles per hour. Capacity on railways is, however, more difficult to determine since the capacity depends on both the infrastructure and the timetable. Over the years railway capacity has been defined in different ways, e.g.:

- The capacity of an infrastructure facility is the ability to operate the trains with an acceptable punctuality [5]
- Capacity can be defined as the capability of the infrastructure to handle one or several timetables [2]
- Capacity as such does not exist. Railway infrastructure capacity depends on the way it is utilized [12]

The reason that it is difficult to define railway capacity is that there are several parameters that can be measured, cf. figure 2. The parameters seen in figure 2 (Number of trains, stability, heterogeneity and average speed) are dependent of each other.

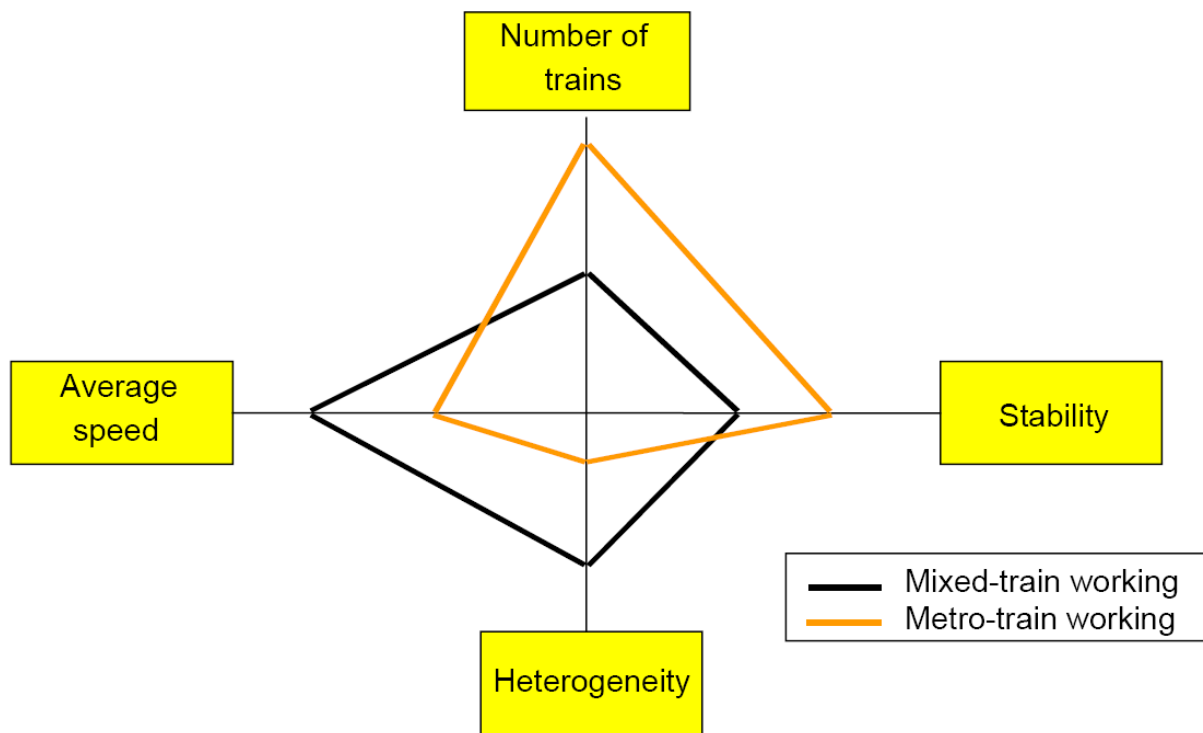


Figure 2: The balance of railway capacity [12].

Figure 2 shows that capacity is a balanced mix of the number of trains, the stability of the timetable, the high average speed achieved and the heterogeneity of the train system. It is for instance possible to achieve a high average speed on a railway network like the Danish by having a high heterogeneity – a mix of fast InterCity Express, InterCity and slower Regional trains serving all stations. However, the cost of having high average speed with a high heterogeneity is that it is not possible to run as many trains with a high stability (punctuality) than if all trains ran with the same speed. If it is wanted to run more trains it is necessary to run with less mixed traffic and thereby have a lower average speed as it is known from e.g. the suburban railway network in Copenhagen or metro systems.

4.1 Number of trains

If the capacity is measured as the number of trains per hour, the capacity in a cross section can be calculated as:

Formula 1: $K = q_{\max} \cdot n$ [5]

Where: K is the capacity
 q_{\max} is the maximum traffic intensity [trains/h]
 n is the number of train paths

When running many trains per hour it is not always possible to combine trains stopping at all stations and faster through going trains. This is due to the fact that the faster trains will catch up with the slower trains which causes conflicts, cf. figure 3. Hence fast trains catch up with

slower trains all trains will have the same stopping pattern when close to the maximum capacity – the timetable will be homogeneous.

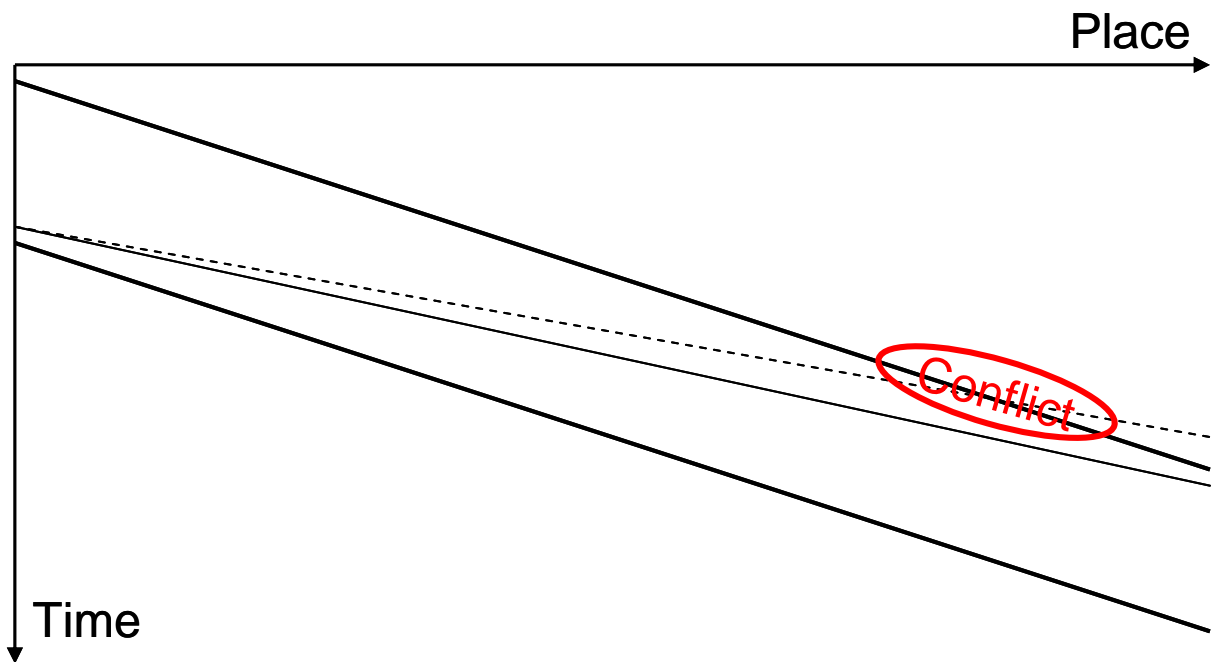


Figure 3: Fast train catching up with a slower train

4.2 Heterogeneity

A timetable is heterogeneous (or not homogeneous) when a train catches up another train. The result of a heterogeneous timetable is that it is not possible to run as many trains as if the timetable was homogeneous – all trains running at the same speed and having the same stopping pattern (cf. figure 4).

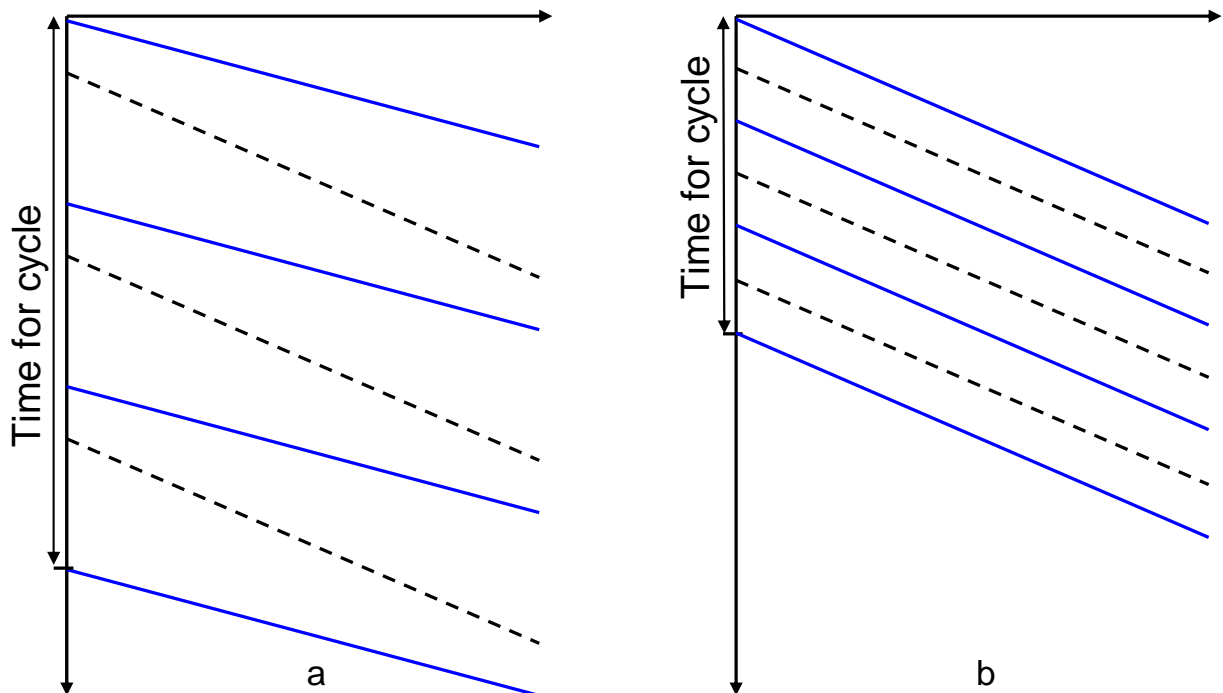


Figure 4: Heterogeneous (a) and homogeneous (b) timetable

To evaluate the heterogeneity of a timetable the SSHR and SAHR presented in [13] can be used. SSHR – Sum of Shortest Headway time Reciprocals – describes both the heterogeneity of the trains and the spread of trains over the hour:

$$\text{Formula 2: } \text{SSHR} = \sum_{i=1}^N \frac{1}{h_{t,i}^-} \quad [13]$$

Where: $h_{t,i}^-$ is the shortest headway time observed between two trains
 N is the number of trains in the cycle observed

Since fast trains can be caught behind a slower train (cf. figure 3) it is important to have enough headway time at the arrival at the end of the line section to avoid secondary delays. The SAHR – Sum of Arrival Headway time Reciprocals – describes the spread of trains over the hour at the arrival station

$$\text{Formula 3: } \text{SAHR} = \sum_{i=1}^N \frac{1}{h_{t,i}^A} \quad [13]$$

Where: $h_{t,i}^A$ is the headway time observed between two trains at the end of the line section
 N is the number of trains in the cycle observed

SAHR will always be smaller than or equal to the SSHR. The SAHR is only equal to SSHR in case of a homogeneous timetable and the difference will increase the more heterogeneous the timetable is. A measurement of the homogeneity can therefore be found by combining formula 2 and formula 3:

$$\text{Formula 4: } \text{Homogeneity} = \frac{\text{SAHR}}{\text{SSHR}} = \frac{\sum_{i=1}^N \frac{1}{h_{t,i}^-}}{\sum_{i=1}^N \frac{1}{h_{t,i}^A}}$$

The homogeneity is then equal to 1 when the timetable is completely homogeneous and opposes 0 when the heterogeneity increases.

4.3 Average speed

A train consumes a different amount of capacity at different speeds. When a train stands still, the train consumes all the capacity since it occupies the block section for an infinite amount of time. When the train speeds up the train occupies the block section for shorter time whereas more trains can pass the same block section – more capacity is gained. However, when

increasing the speed also the braking distance is increased which means that the headway distance – and headway time – is increased whereas capacity is lost, cf. figure 5.

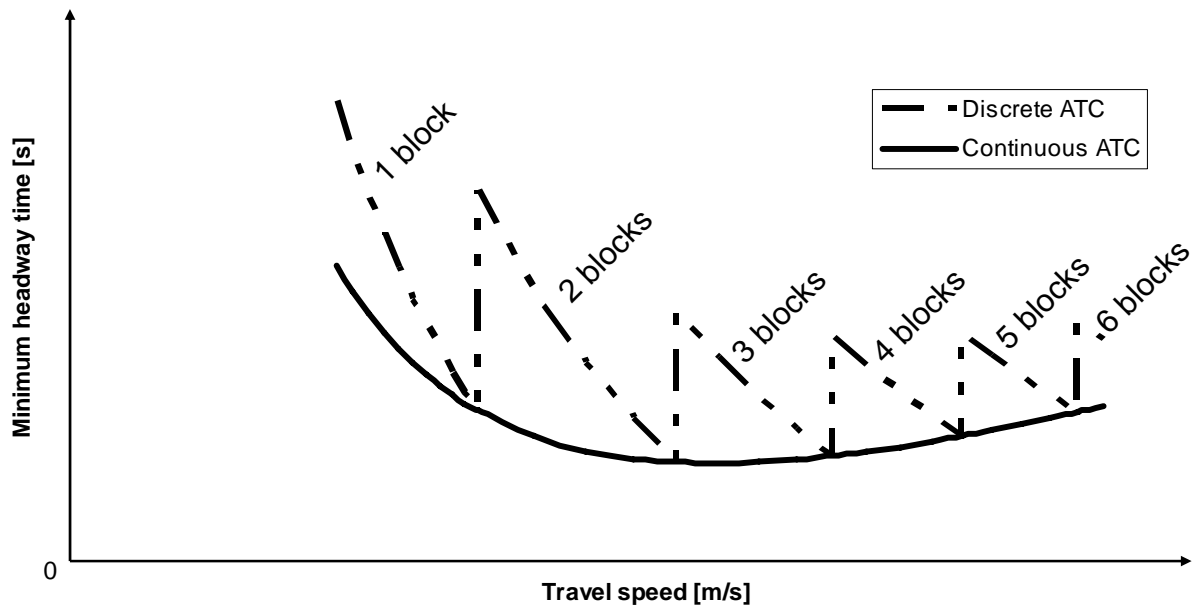


Figure 5: Minimum headway time according to the speed of the train [10]

As figure 5 shows is the minimum headway time – and thereby the capacity – dependent of the speed of the train. For railway lines with discrete ATC (or no ATC system) the speed is even more important than continuous ATC systems since the function of the minimum headway time is discrete.

When both fast and slower local trains are running on the same railway line it is possible to achieve a high average speed. However, if the railway line has lack of capacity it might not be possible for the fast trains to run at the maximum speed cf. figure 6.

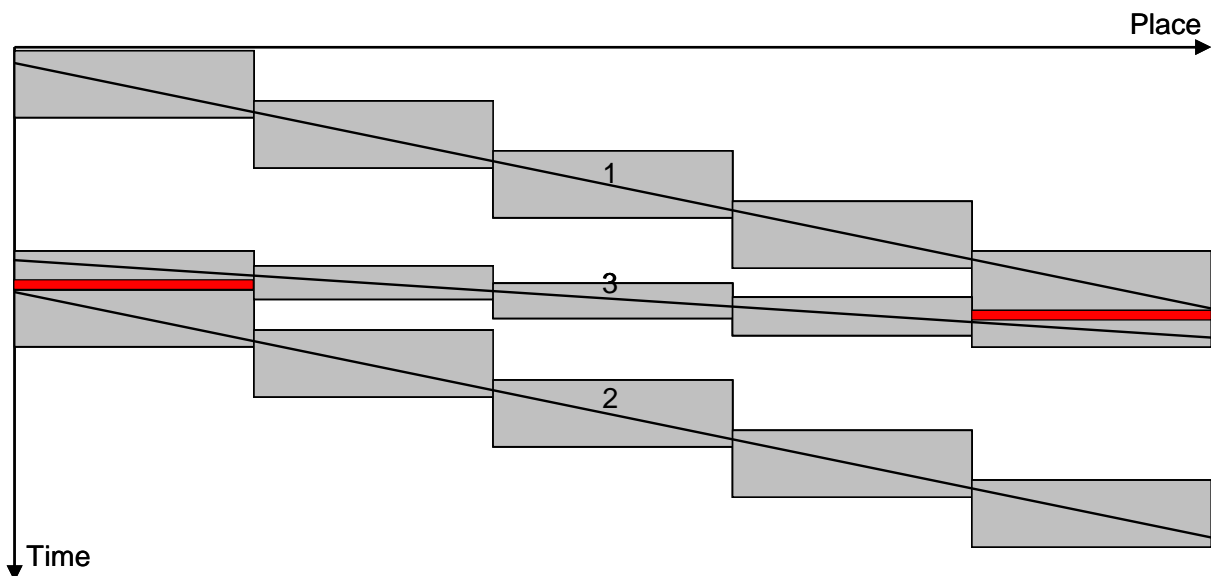


Figure 6: The fast train (train 3) has to reduce the speed due to conflicts

4.4 Stability

When discussing railway capacity it is important to look at the stability of the railway system too. The stability of the railway system is difficult to work out as such. The punctuality of the trains is, however, derived from the stability.

It is difficult to evaluate the stability – or punctuality – of a planned timetable not yet put in operation. Experienced planners might, however, have an idea of how changes in a timetable or the infrastructure might affect the punctuality. It is only possible to estimate the punctuality of smaller changes in the timetable or infrastructure using the experience. If the punctuality of larger changes in the infrastructure and/or timetable have to be estimated it is necessary to use simulation tools such as RailSys. Even though it is difficult to predict the future punctuality a general rule of thumb is that the punctuality will drop when the capacity utilization increases, cf. figure 7.

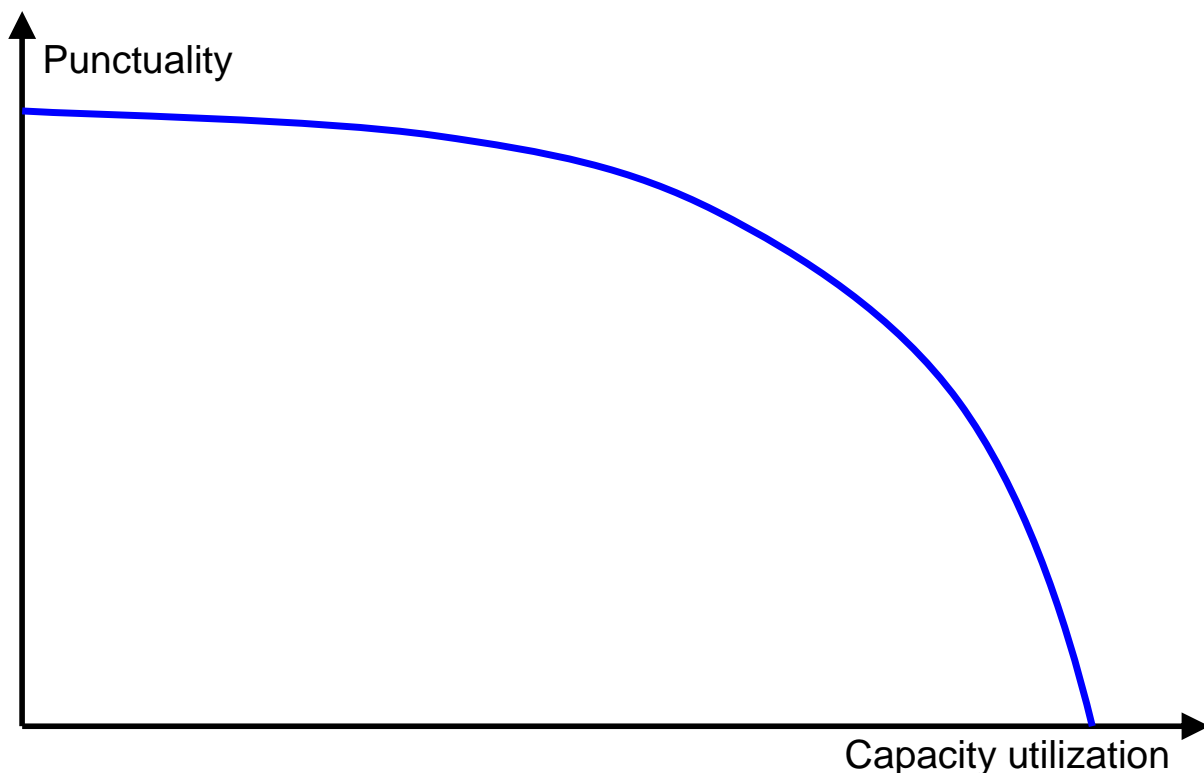


Figure 7: The coherence between punctuality and capacity utilization (Based on [6]).

Even though it is possible to achieve higher capacity utilization on a railway line it is often said that there is no more capacity if the punctuality drops below a certain limit. Changing the timetable for the railway line examined may increase the punctuality so that it is possible to have higher capacity utilization before dropping below the punctuality level where it is said that there is no more capacity. This is due to the fact that the capacity for a given railway infrastructure is based on the interdependencies existing between the number of trains, the average speed, the stability (or punctuality) and the heterogeneity (differences in the speed) of the trains [12] (cf. figure 2, page 4).

5 Determination of capacity according to the UIC 406 method

A detailed description of the UIC 406 method for capacity calculation is given in [12]. However, a brief description of the UIC 406 method will be given here.

Capacity consumption on railway lines depends on both the infrastructure and the timetable. Therefore, the capacity calculation according to the UIC 406 method is based on an actual timetable.

Timetables are created for the entire network and not only the line or line section which is of interest according to the capacity analysis. This means that the timetable in the analysis area depends on the infrastructure and timetable outside the analysis area – the so-called network effects [1][2][8]. These so-called network effects are not taken into account in the capacity analysis, why the capacity used according to the UIC 406 method will be less than or equal to the actual capacity consumption.

The capacity calculation is based on the compression of timetable graphs on a defined line or line section. All single train paths are pushed together to the minimum headway time, so that no buffer times are left. The compression of the timetable graph has to be done with respect to the train order and the running times. This means that neither the running times, running time supplement, dwell times or block occupation times are allowed to be changed. Furthermore, only scheduled overtakings and scheduled crossings are allowed!!

To evaluate the capacity utilization it is necessary to know both the infrastructure and the timetable. Therefore, the first steps of evaluating the railway capacity are to build up the infrastructure and create/reproduce the timetable. To evaluate the railway capacity according to the UIC 406 method, the railway network has to be divided into line sections. For each line section the timetable has to be compressed so that the minimum headway time between the trains is achieved.

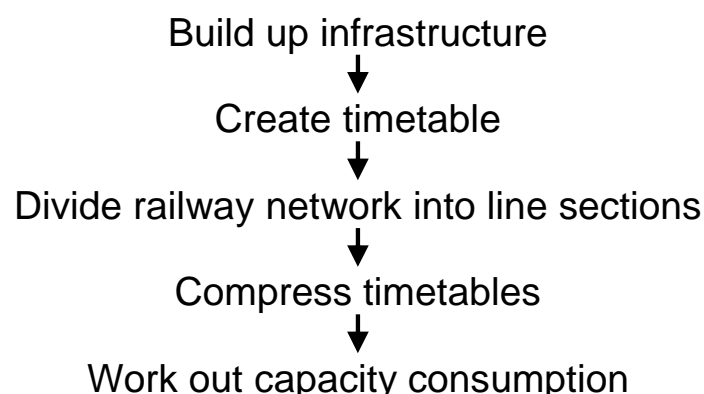


Figure 8: Workflow of the UIC 406 method

When the timetable has been compressed it is possible to work out the capacity consumption of the timetable by comparing the cycle times. The workflow of the capacity evaluation can

be seen in figure 8. Different timetabling software such as RailSys has already implemented the UIC 406 capacity method. Using e.g. RailSys, it is, therefore, easy to calculate the railway capacity.

The UIC 406 capacity method is described in the UIC 406 capacity leaflet. This means that the method acts as a reference but not either a law or a norm [15]. Since the UIC 406 method acts as a reference and the fact that not two railway lines are identical some adaptations and interpretations have to be done for each analysis. The following sections describe some of the adaptations and interpretations made in Denmark to use the UIC 406 method.

6 The Danish interpretation of the UIC 406 method

According to the UIC 406 capacity method railway lines have to be divided into smaller line sections which are further examined. The railway lines have to be divided at each junction, when the number of tracks changes (e.g. from double track to single track) and on each crossing station on a single track line. Furthermore, the railway lines have to be divided into line sections where the number of trains changes (e.g. end stations where trains turns around) and at stations where one train takes over another train. figure 9 shows a schematic track layout and where the railway line has to be divided into line sections according to the UIC 406 capacity method.

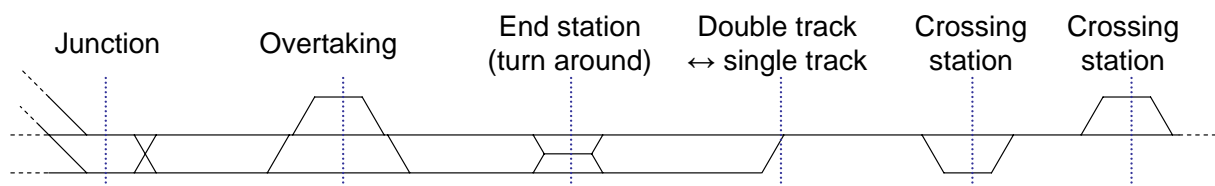


Figure 9: Dividing railway line into line sections

The many small line sections are not always an advantage when examining railway capacity. E.g. when examining the capacity of a whole railway line where some trains run all the way to the end of the line while other trains turn around before the end of the line a low capacity utilization is found (cf. section 6.1).

6.1 The length of the railway section examined

The capacity calculation is based on compression of timetable graphs on defined line sections as described in section 5 and in [12]. However, the timetable graphs can only be compressed as the critical block section(s) allows. Therefore, it is important not to split the railway line into several smaller line sections uncritically, while the critical block section(s) thereby might be excluded from the analysis.

The critical block section is the block section which is occupied for the longest time. For homogenous traffic the critical block section can be anywhere on the line, but normally the critical block section is located close to a station or halt due to the reduced speed [5]. For

inhomogeneous traffic like the Coast Line (Kystbanen) in Denmark (cf. figure 10) the critical block section is usually located where the fast trains catch up with the slower trains.

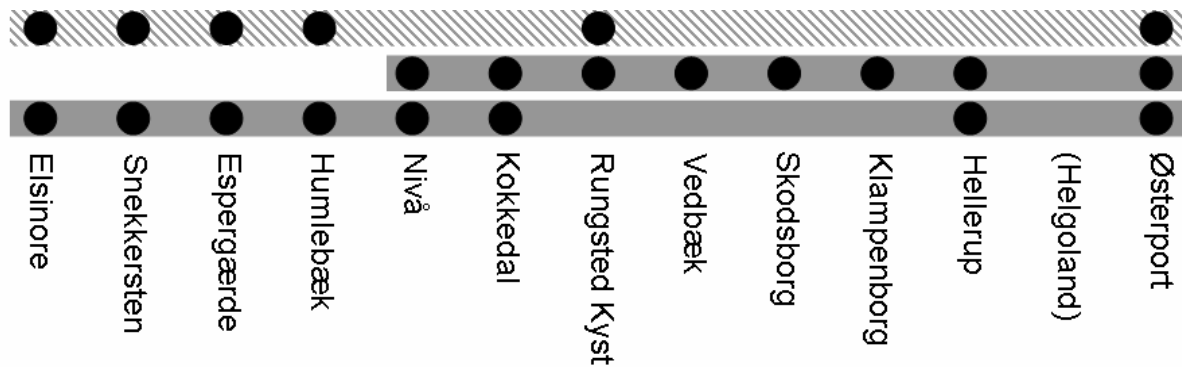


Figure 10: Train stopping patterns for the Coast Line in the rush hours (20 min service).

On the railway line between Copenhagen (Østerport) and Elsinore – the Coast Line – there is an inhomogeneous traffic (cf. figure 10). The critical block sections or bottlenecks on the Coast Line are at Nivå and Hellerup where the trains catch up with each other. To analyse the capacity utilization of the bottlenecks it was decided to use the UIC 406 method, cf. figure 11.

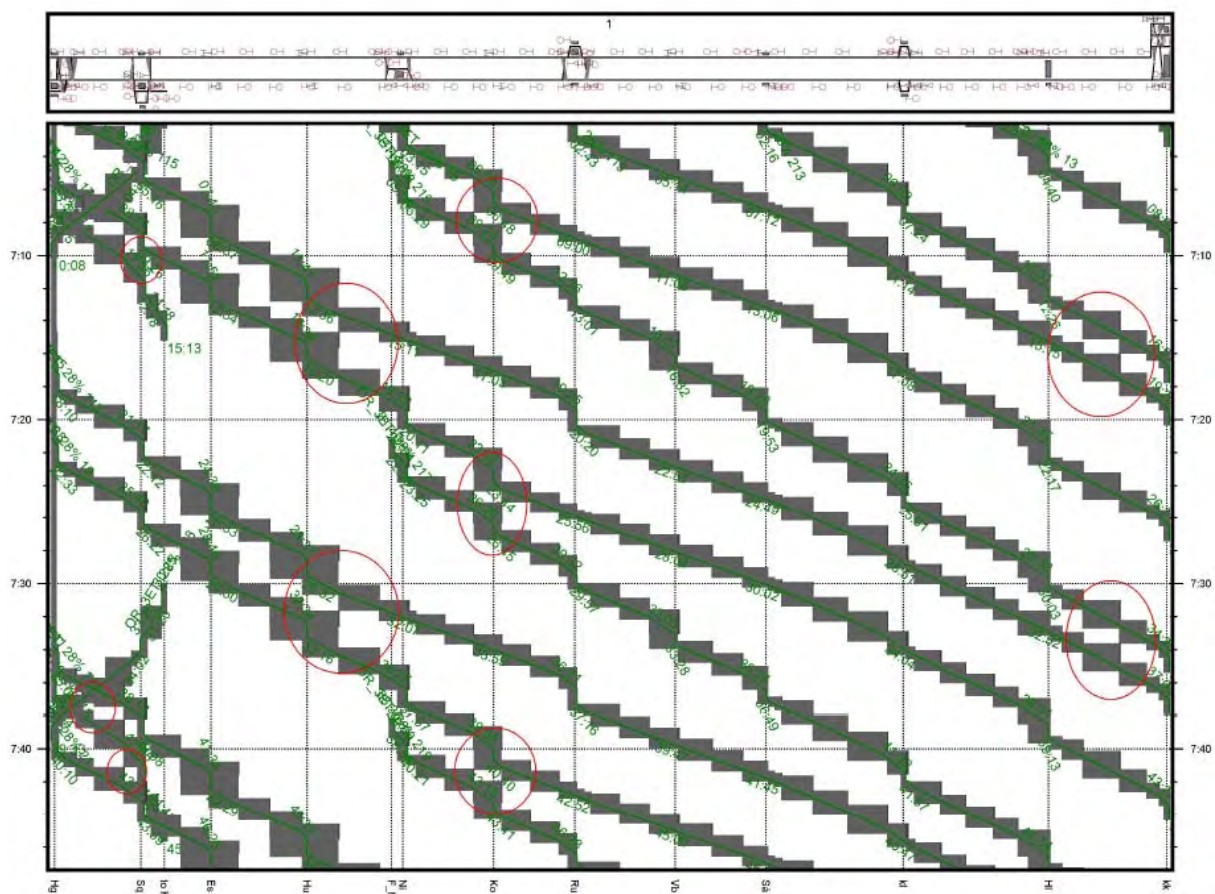


Figure 11: Timetable graph compression according to the UIC 406 method [9]

To test the UIC 406 method, 3 different line sections were examined. The 3 line sections were Kokkedal-Humlebæk, Helgoland-Klampenborg and the whole line section between Helgoland and Elsinore. The results from the analysis show a big difference in the capacity utilization at the bottlenecks, cf. figure 12.

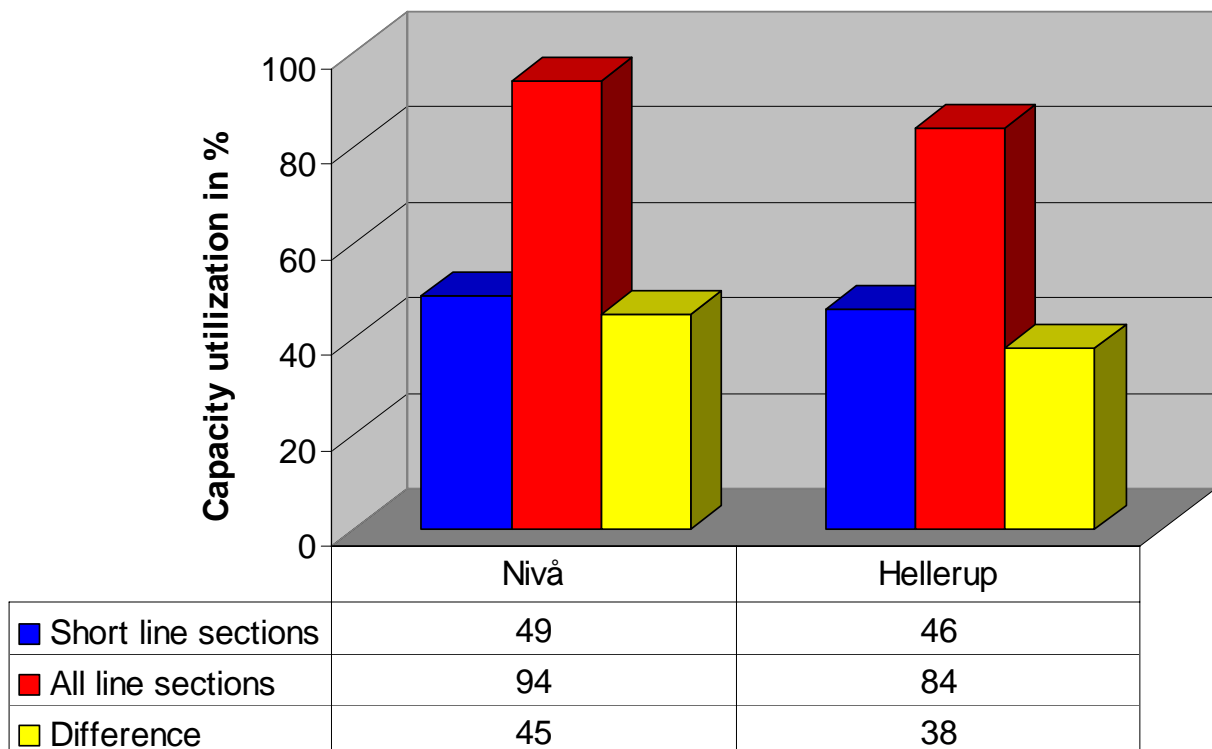


Figure 12: Capacity utilization on the Coast Line according to the UIC 406 method during the rush hour [9].

Figure 12 shows that the short line sections give much lower capacity consumption than the whole line section. The low capacity utilization at the short line sections can lead to the wrong conclusion that there is room enough to run more trains. However, running more trains will make it more or less impossible to keep a good punctuality (see section 6.3).

Based on the results from the Coast Line it can be concluded that it is important to examine the whole railway line and not just a smaller area when capacity analyses are carried out. However, it is not always possible to examine a whole railway line due to the analysis resources. Therefore, the effort has to focus on the analysis examining where the railway line can be divided into smaller line sections. Furthermore, it is necessary to be careful when comparing capacity utilizations and only compare relatively.

6.2 Changing between tracks at stations and at lines with more than two tracks

Compressing timetable graphs according to the UIC 406 method can lead to discussions on line sections with more than two tracks. An example from the Capacity analysis of the line between Copenhagen and Ringsted [11] illustrates the problem. A freight train is running from Ringsted to the freight terminal at Høje Taastrup. Simultaneously with the freight train

passing Roskilde, a regional train from Lejre towards Copenhagen leaves Roskilde, cf. figure 13.

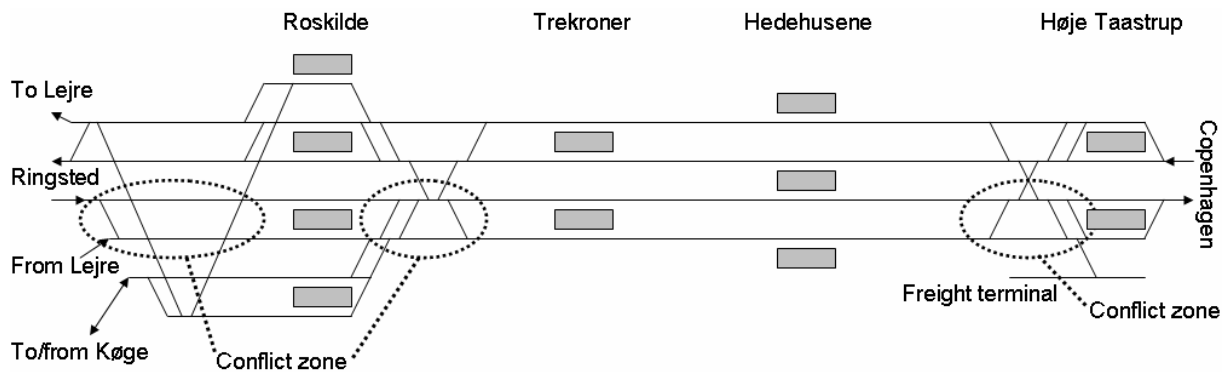


Figure 13: Conceptual track layout for the line section Høje Taastrup – Roskilde.

When compressing the timetable graphs there will inevitably be a conflict because the trains have to change use of track at either Roskilde or Høje Taastrup station. The capacity consumption of the line section depends on which train runs on which track between Roskilde and Høje Taastrup and thereby where the conflict between the trains occurs, cf. figure 13.

Using the UIC 406 method on line sections with more than two tracks it has (in Denmark) been decided to give priority to the track occupations of the actual timetable or a timetable with a minimum number of conflicts. In the Danish method it is only allowed to move one or more trains from one track to another if there is an unequal utilization of the tracks. Not until then is the consideration of passenger preferences taken into account. The passenger preferences are only taken into account late in the process, since the UIC 406 method is used for capacity analysis.

Quadruple track sections are usually used for fast trains to overtake slower trains. In the Danish way of using the UIC 406 method for capacity analysis, it has been decided that the order of the trains has to be the same as in the reference timetable (cf. figure 14 part a) in both ends of the line section when compressing the timetable graph (cf. figure 14 part b). The train order has to be the same in both ends of the line section even though the timetable graphs can be compacted more if the trains change the order (cf. figure 14 part c). The train order has to be the same due to the limitations of the infrastructure and timetable outside the analysis area – the so-called network effects [1][2][8].

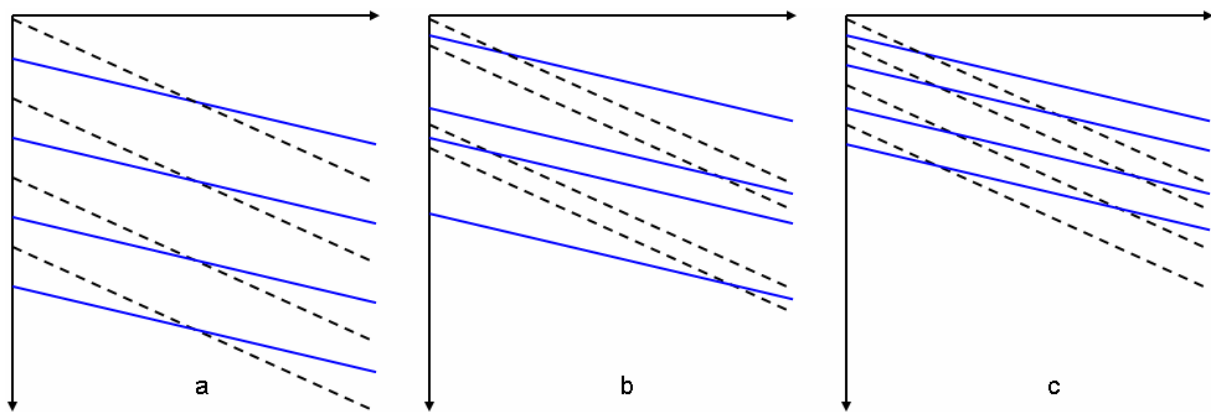


Figure 14: Actual timetable for quadruple track (a) and the same timetable compressed keeping the train order (b) and optimizing the train order (c).

A situation similar to the quadruple track sections can be found when two double track railway lines run parallel, cf. figure 15. When the UIC 406 method is followed stringently the infrastructure should be divided in two line sections A-C-B and A-D-B. However, if line section A-C-B and A-D-B is only separated by a short distance it will be obvious to examine it as one quadruple track section as described above.

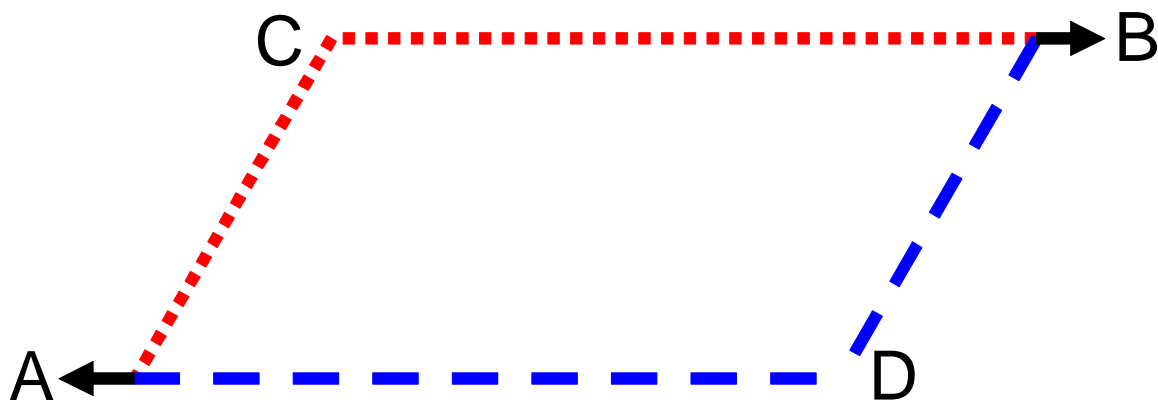


Figure 15: Infrastructure for two line sections running parallel.

If the tracks on figure 15 is separated so that C and D represent two different cities the analysis should normally be carried out on two different line sections – A-C-B and A-D-B. If the overall capacity between A and B is to be evaluated it could, however, be useful to evaluate the network as a quadruple track section. By evaluating the network as a quadruple track section it is possible to move through going trains (no stop between A and B) from one track to another to achieve an equal utilization as described above and thereby evaluate the overall capacity between A and B.

When evaluating the overall capacity between A and B on figure 15 it is sometimes necessary to compromise the principles of the UIC 406 method. If e.g. some trains turn around at C (cf. figure 15) the line section ought to be divided at C. However, it is not possible to evaluate the overall capacity when there are more than two line sections because (the above described) method does not allow moving through going trains from one track to another to achieve an

equal capacity utilization. When dividing one of the line sections into several smaller line sections, it makes it difficult to compare the capacity utilization of the two lines (A-C-B and A-D-B) since capacity utilization depends on the length of the line sections examined – cf. section 6.1. It is possible to compare the capacity utilization on the two parallel railway lines if the railway lines are divided in smaller line sections. But when comparing the parallel railway lines it is necessary to consider the splitting carefully in regard to the number of line sections and their length, so that the railway lines still are comparable.

6.3 The possibility of using idle capacity to run more trains

The UIC 406 method describes the amount of capacity used on a certain railway line. However, not used capacity can not always be used to run more trains. In figure 16 it is shown how the buffer times between the trains can give idle capacity by compressing the timetable graph and thereby make it possible to run an extra train.

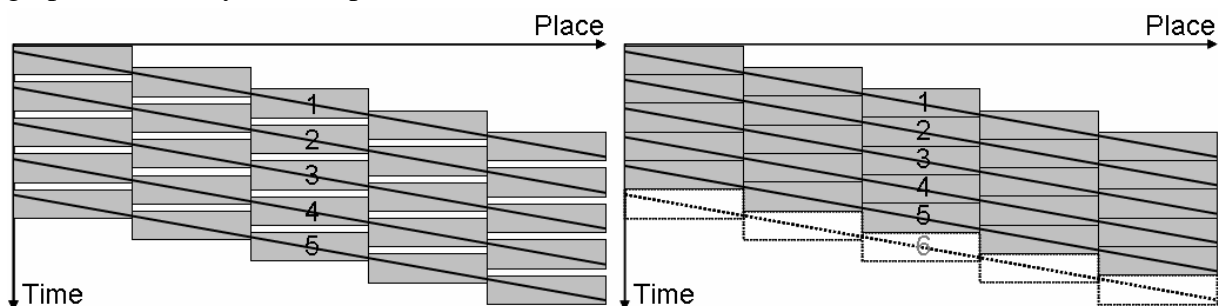


Figure 16: Usage of idle capacity.

It is, however, not always possible or wise to use the idle capacity or buffer time to run more trains. If there is a longer block section outside the evaluation area, it is not always possible to run an extra train due to the lack of capacity outside the evaluation area, cf. figure 17.

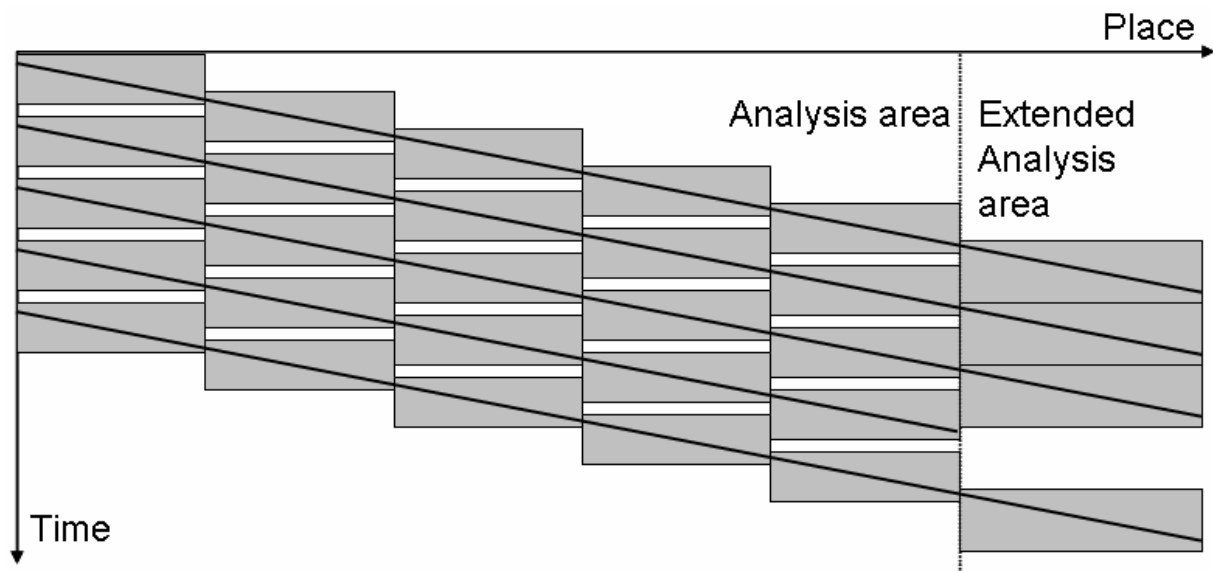


Figure 17: Limited possibility of compressing timetable graph.

Even though it is possible to run more trains, it is not always wise to do so because it will reduce the buffer times. By reducing the buffer times, the risks of secondary delays are

increased. Furthermore, the dispatching of the trains is made more difficult due to more trains in the system. Everything considered, the idle capacity can not always be used to run more trains.

6.4 The possibility of using the plan of operation instead of the exact timetable

It is difficult to analyse the capacity of a railway line which has not yet been built since the timetable for the opening year is unknown. Furthermore, the timetable can be changed over time. Therefore, examining the capacity utilization based on the plan of operation instead of the final timetable for the opening year is preferred. Since the capacity utilization is influenced by the order of the trains, it is necessary to make some assumptions of the train order or use methods used for successive calculation.

Using successive calculation, the average capacity utilization can be calculated as a weighted average of one (or more) likely value(s), the maximum value and the minimum value as shown in formula 5:

Formula 5:
$$\text{Average} = \frac{\text{MinValue} + (3 \cdot \text{SuggestedValue}) + \text{MaxValue}}{5}$$

The minimum value (MinValue) and the maximum value (MaxValue) of a plan of operation can be found by arranging the trains, so that the trains utilize as little or much capacity as possible, cf. figure 18.

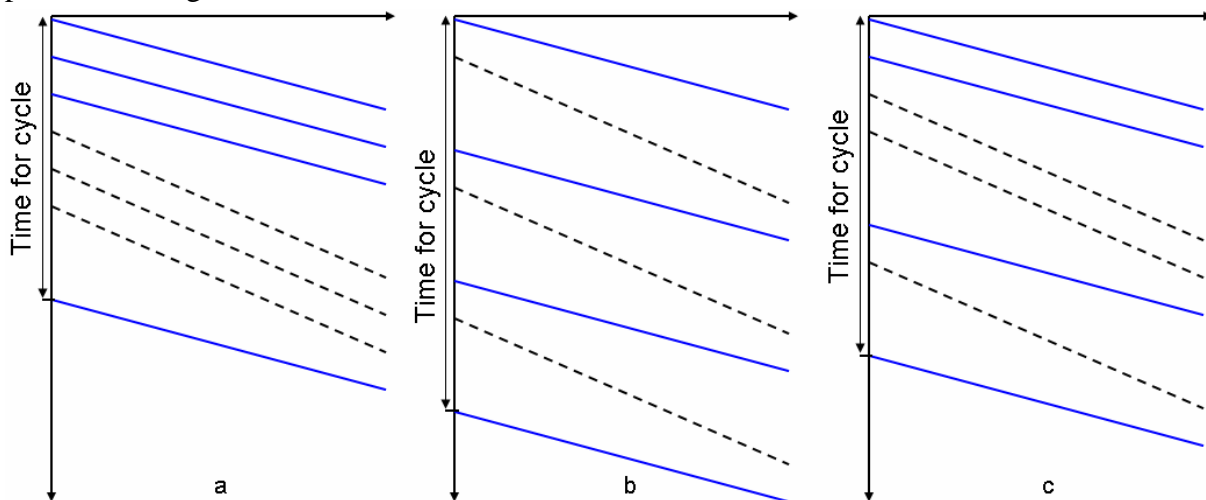


Figure 18: Plan of operation utilizing as little (a), as much (b) capacity as possible and a “suggested” capacity consumption (c).

Beside the values for the minimum and maximum capacity utilization it is also necessary to calculate a suggested value for the capacity utilization, cf. formula 5. This is due to the fact that the infrastructure outside the section of examination can limit the number of ways the trains can be ordered.

7 Capacity statement

Infrastructure managers are often asked to create maps showing the capacity utilization of the railway network. Using the UIC 406 method it is easy to calculate the capacity utilization for railway lines and create maps showing the capacity utilization, cf. figure 19. In this way it is easy to explain e.g. politicians where there is lack of capacity in the railway network.

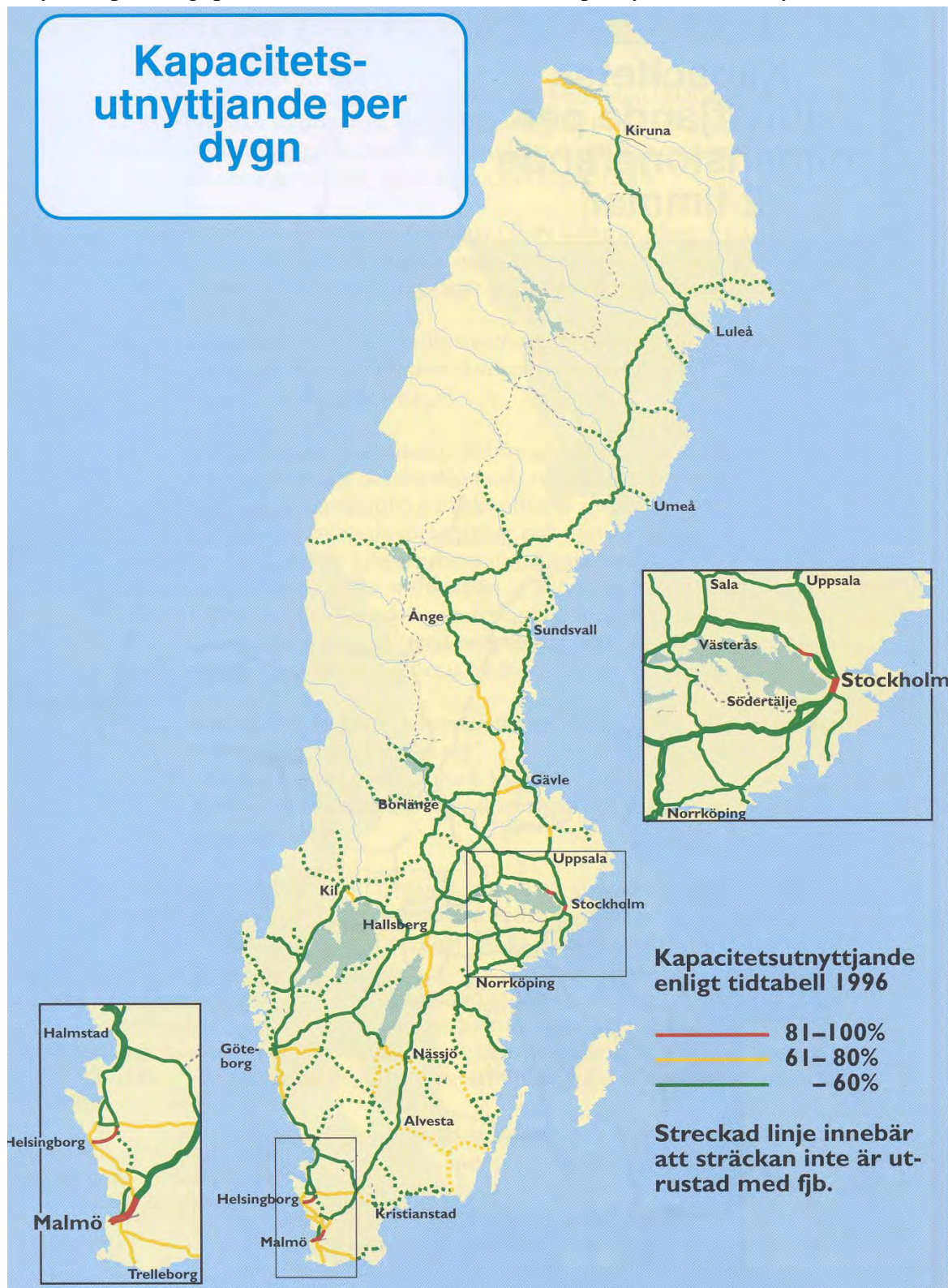


Figure 19: Capacity utilization in Sweden [3].

7.1 Overtaking

Using the UIC 406 method strictly, railway lines have to be divided into line sections at all junctions and each time an overtaking or turn around takes place. Dividing railway lines into line sections each time an overtaking or turn around takes place can result in different criteria's for the capacity statement since the lengths of the line sections is varying. By changing the lengths of the line sections also the capacity utilization will vary. In this way it is possible to gain capacity by letting a fast InterCity Express train overtake a slower freight train since the line section then have to be split in two.

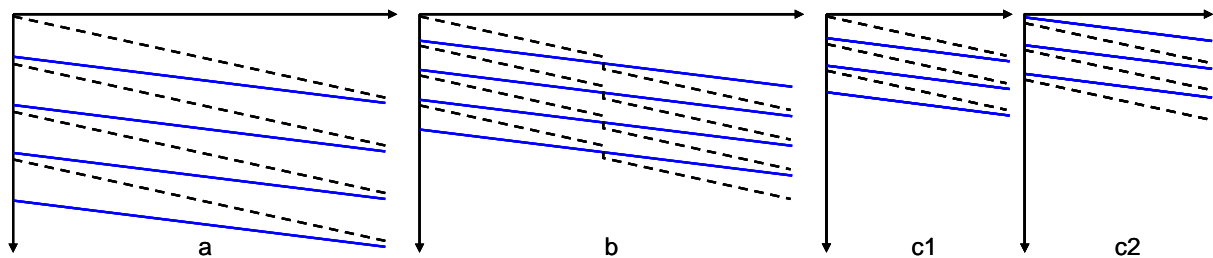


Figure 20: Capacity utilization for line section (a), line section with overtaking (b) and divided line section due to overtaking (c1 and c2).

It is commonly known that an overtaking can gain some extra capacity on a railway line with high capacity utilization since fast trains can overtake slower trains (compare figure 20 part a and b). However, using the UIC 406 method cogently the line section should be divided into two line sections due to the overtaking (cf. figure 20 part c1 and c2). By dividing the line section into two smaller line sections the capacity utilization is even less (compare figure 20 part b and c).

The less capacity utilization by dividing the line section into smaller line sections due to the overtaking is a paradox of the UIC 406 method the planner should be aware of. The paradox becomes even more distinct when it becomes clear that the overtaking (and thereby improved capacity) is coursed by lack of capacity.

Using the UIC 406 method when overtaking and not splitting the line section a new challenge occurs – how should the timetable graphs be compressed? Compressing the timetable graph in figure 21 part a without changing either the train order or the dwell time results in a situation where not much capacity is gained, cf. figure 21 part b. However, there is unused capacity so that it is possible for more trains to take over the dwelling train, cf. figure 21 part c.

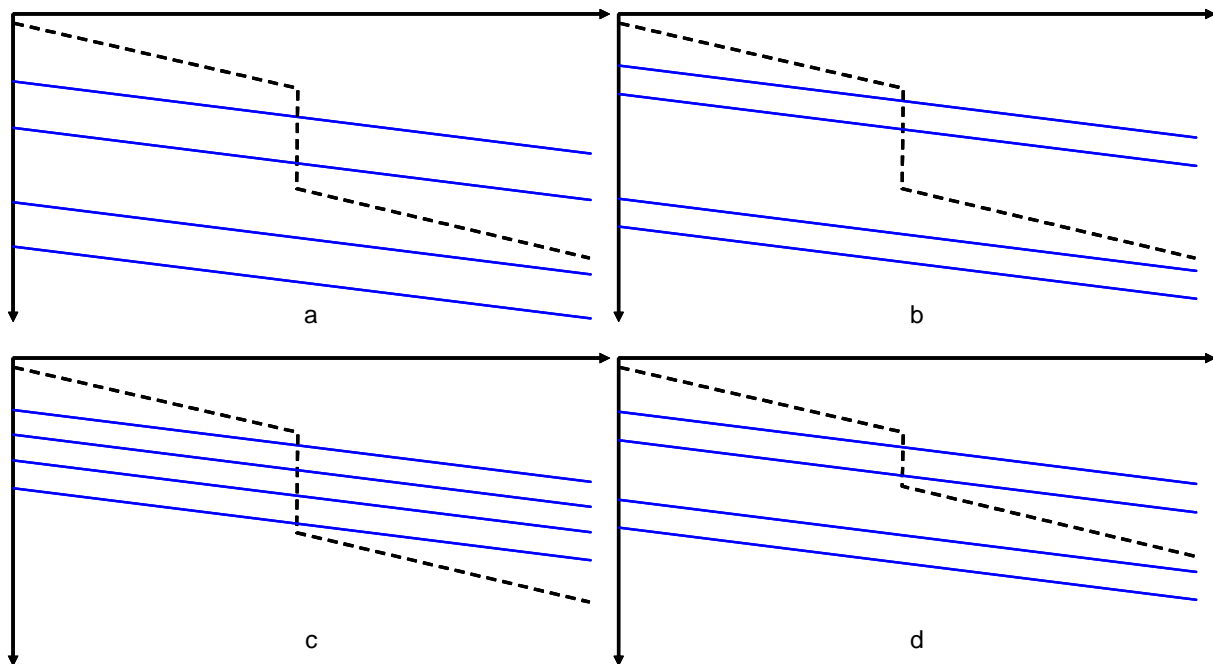


Figure 21: Timetable compression when overtaking.

If more trains than timetabled takes over a dwelling train the train order is changed at the end of the line. The changed train order can result in new conflicts outside the analysis area (or line section) if e.g. a planned timetable slot is not available. Therefore, the train order should remain fixed by compressing the timetable graphs.

Instead of changing the order of the trains it is possible to change the dwell time of the train which is overtaken, cf. figure 21 part d. Often e.g. freight trains have a longer dwell time than needed to secondary delays by adding buffer times. However, one has to be aware that it might take a while before a fully loaded freight train can start moving after a complete halt.

7.2 Extra trains

Another paradox of the UIC 406 method is that an extra train can result in less capacity consumption. If the UIC 406 method is used cogently to divide railway lines into line sections an extra train route with a new line-end station means that the railway line has to be divided into an extra line section. When the railway line is divided into an extra line section shorter line sections occur. Shorter line sections imply that it is possible to compress timetable graphs for mixed operation more than for a longer line section.

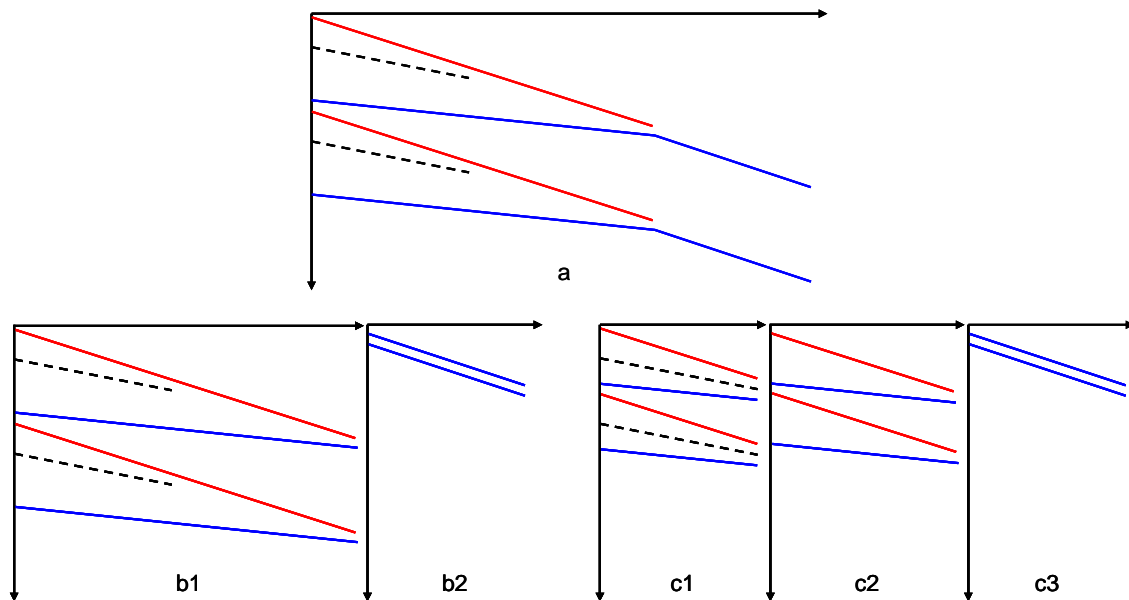


Figure 22: An extra train can result in less capacity utilization.

Figure 22 illustrates the paradox of an extra train resulting in less capacity consumption. Part a in figure 22 shows the timetable where the dotted trains are extra trains scheduled in the timetable. Part b in figure 22 shows how the timetable is compressed according to the existing line sections (the capacity consumption would have been the same without the new (dotted) trains). Due to the extra (dotted) trains the UIC 406 method requires that line section b1 is divided into two line sections (c1 and c2). Compressing the timetable graphs for line section c1 and c2 results in less capacity consumption than for line section b1. Since line section b1 – the most capacity consuming line section – has been divided into smaller line sections it seems that the railway line has got more capacity.

7.3 Working out the capacity statement

It has been shown that overtakings can reduce the capacity utilization (especially if the line section is divided) and that extra trains can result in less capacity consumption. Therefore, it is necessary to consider how the railway network is divided into line sections when presenting maps of the capacity utilization. To have uniform and comparable maps of the capacity utilization it is important to use the same line sections each year. When producing comparable maps of the capacity utilization it can therefore be necessary to ignore the UIC 406 guidelines to divide line sections when an overtaking or turnaround takes place.

Even though the railway network carefully has been divided into line sections it might be necessary to change the line sections. However, when changing the line sections it is not possible to see the trend of the capacity utilization. Therefore, it is necessary to have an overlap statement between the different line sections as seen in table 2.

	2000	2001	2002	2003
New	n/a	58%	60%	60%
Old	60%	62%	64%	n/a

Table 2: Change in line sections and capacity utilization

Examining table 2 it can be seen that the capacity utilization has grown 4% from year 2000 to 2003. However, if not there had been an overlap statement between the different line sections it would seem that the capacity utilization was the same in year 2000 and 2003 (60 %) and a little lower in year 2001 (58%).

8 Conclusion and perspectives

The paper has described the capacity theory for railway lines and how the capacity consumption can be evaluated for railway lines with two or more tracks. However, work still remains to be able to evaluate the capacity consumption for single track lines and junctions. Furthermore, quantitative methods to evaluate (and compare) capacity consumptions on railway lines in a fast and easy way have to be developed.

The analysis has shown that the capacity utilization on railway lines is very responsive to the network examined. Therefore, the capacity utilization should only be compared relatively. In Denmark it has not yet been decided where to split the railway lines into smaller line sections – this work still remains to be done.

When there is a quadruple track available, it has been decided that the track occupations of the actual timetable should be used. If there is no actual timetable the timetable with the minimum number of conflicts should be examined instead. It is furthermore only allowed to move a train from one track to another if there is an unequal utilization of the tracks. The conditions for passengers transferring to e.g. busses are not taken into account.

Even though the capacity analysis shows that it is possible to run more trains in the section analysed, it is not always possible. The analysed line section can be too short to see that it is not possible to run more trains (e.g. due to capacity restrictions outside the analysis area) – the so-called network effects.

Using the UIC 406 capacity method it is easy to make annual capacity statements on maps showing the capacity utilization on the railway network. Using the UIC 406 capacity method to make capacity statements it is important to use the same line sections each year to avoid the paradox that an extra train or an unwanted overtaking results in less capacity utilization.

All the analyses have been carried out in the timetable and simulation software RailSys, but can also be carried out in the timetabling system STRAX/TPS which is used by the Danish railway agencies [7]. The result of the analysis is a common Danish method to evaluate the capacity utilization of railway lines in Denmark.

References

- [1] Hansen, S., Landex, A. & Kaas, A.H., The Network effects of Railway Investments, *Proc. of the 10th International conference on Computers in Railways*, eds. J. Allan, C.A. Brebbia, A.F. Rumsey, G. Sciutto, S. Sone & C.J. Goodman, 2006
- [2] Hansen, S., Large Transport Infrastructure Investments and their Strategic Impacts with a Special Focus on Enterprises, *PhD. thesis at Centre for Traffic and Transport, Technical University of Denmark*, 2004 (in Danish).
- [3] The Swedish rail network, 1997, Banverket Planeringsavdelingen, Sweden (in Swedish).
- [4] Höllmüller, J. & Klahn, V., Implementation of the UIC 406 capacity calculation at Austrian railways (ÖBB). *Proc. Of the 1st International Seminar on Railway Operations Modelling and Analysis*, eds. I.A. Hansen, F.M.Dekking, R.M.P. Goverde, B. Hindergott, L.E. Meester, The Netherlands, 2005
- [5] Kaas, A. H., Methods to calculate capacity of railways, *PhD. thesis at Department of Planning, Technical University of Denmark*, 1998 (in Danish).
- [6] Kaas, A. H., Punctuality model for railways. *Proc. of the 7th International conference on Computers in Railways*, eds. J. Allan, R. J. Hill, C. A. Brebbia, G. Sciutto & S. Sone, pp. 853-860, 2000
- [7] Kaas, A. H. & Goossmann, R., Implementation of the Timetable Planning System STRAX/TPS in Denmark. *Proc. of the 9th International conference on Computers in railways*, eds. J. Allan, C.A. Brebbia, R.J. Hill, G. Sciutto & S. Sone, pp. 93-102, 2004
- [8] Landex, A., Kaas, A.H. & Hansen, S., Railway Operation, *Technical report at Centre for Traffic and Transport, Technical University of Denmark*, 2006
- [9] Landex, A., Kaas, A. H., Schittenhelm, B. & Schneider-Tilli, J., Practical use of the UIC 406 capacity leaflet by including timetable tools in the investigations, *Proc. of the 10th International conference on Computers in Railways*, eds. J. Allan, C.A. Brebbia, A.F. Rumsey, G. Sciutto, S. Sone & C.J. Goodman, 2006
- [10] Landex, A. & Kaas, A. H., Planning the most suitable travel speed for high frequency railway lines. *Proc. Of the 1st International Seminar on Railway Operations Modelling and Analysis*, eds. I.A. Hansen, F.M.Dekking, R.M.P. Goverde, B. Hindergott, L.E. Meester, The Netherlands, 2005
- [11] Strategic analysis of Copenhagen-Ringsted – Comparing solutions for extending the railway capacity; The Danish Rail Authority, October 2005, Online. http://www.trafikstyrelsen.dk/graphics/Synkron-Library/Trafikstyrelsen/Jernbane/Strategi/strategi_beslutningsgrundlag_.pdf, May 2006 (in Danish).
- [12] UIC leaflet 406, Capacity, 2004, UIC International Union of Railways, France
- [13] Vromans, M.J.C.M, Reliability of Railway Systems, *PhD. thesis at Erasmus Research Institute of Management, Erasmus University Rotterdam*, 2005
- [14] Wahlborg, M., Banverket experience of capacity calculations according to the UIC capacity leaflet. *Proc. of the 9th International conference on Computers in railways*, eds. C.A.- J. Allan, C.A. Brebbia, R.J. Hill, G. Sciutto & S. Sone, pp. 665-673, 2004
- [15] www.uic.asso.fr/etf/codex/informations.php#2, May 2006