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1st edition, September 2004	First edition
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Contents

Summary

In view of the different concepts and procedures concerning railway infrastructure capacity and the resulting calculations applied by infrastructure managers, this leaflet provides a unique approach to capacity evaluation in the shape of the compression method, which is recommended for those infrastructure managers that use IT support in their evaluations. Unlike the theoretical concepts developed, the compression method is applied to real timetables with practical measurements intended to establish a common understanding of infrastructure capacity. For the first time, a methodology is presented enabling the calculation of nodes capacity based on the same principles.

The primary goal of this leaflet is to provide an international standard for evaluating capacity, to be used towards developing common values for international corridors sharing different railway networks in different countries.

Application of this leaflet will ensure that capacity can be evaluated according to uniform principles.

The use of other methods can be agreed by the infrastructure managers involved.

1 - Purpose of *UIC Leaflet 406*

Different railway environments represent different capacity needs, and this can easily lead to different interpretations and misunderstandings. The purpose of this leaflet is to provide guidelines for calculating capacity. The approach is to calculate capacity consumption by compressing a timetable and to evaluate the number of possible train paths for a line, node or corridor. A workflow process is outlined for capacity evaluation and additional time values are given to determine the capacity limit.

A variety of examples and illustrations can be found in the appendices. The explanations of the calculation method illustrated in this leaflet can be used as a basis for communication among professionals from different sectors.

This facilitates close scrutiny of bottlenecks and the planning of efficient timetables with high punctuality. The leaflet provides a first step towards standardised capacity calculation at national and European level.

2 - Capacity analysis methodology

This chapter briefly describes various capacity analysis methodologies for infrastructure planning and timetabling processes, and introduces the method of calculating capacity by timetable compression.

2.1 - Capacity planning

Infrastructure managers (IMs) offer infrastructure capacity to railway undertakings (RUs). There is traffic demand from RUs, and IMs supply the infrastructure capacity.

For planning new or upgrading existing infrastructure, the process normally begins 3-10 years in advance (or even longer). To perform an infrastructure study, the traffic volume has to be predicted. The traffic volume is based on traffic strategies (market analysis, traffic scenarios, etc.) and the studies are focused on infrastructure and on identifying bottlenecks.

The process for tactical and operational traffic planning usually begins 3 years in advance and continues until operations commence. When performing a timetable study, the infrastructure is known. The studies are focused on bottlenecks, timetable structure, timetable alternatives and quality of service.

Infrastructure planning and bottleneck analysis

1. Dimensioning new lines and stations and upgrading existing infrastructure.

2. Technical infrastructure planning (additional tracks, switches or signals, etc.) on existing infrastructure.

Timetabling

3. Tactical traffic planning: traffic demand is known; infrastructure and infrastructure restrictions due to construction work are known. Study of different timetable alternatives.

4. 1-year timetable application process from RU´s, construction of a timetable. Major maintenance works are known.

5. Operational process handling minor changes in infrastructure and/or timetable.

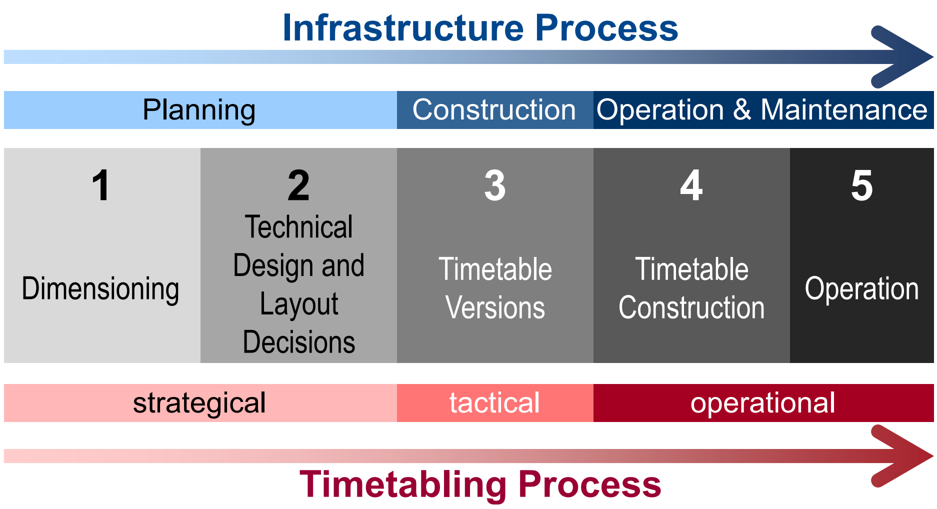

Fig. 1 - Timeline diagram for infrastructure and timetabling process

2.2 - Capacity study aspects

The views and circumstances for calculating capacity depend on various aspects, including:

- future or existing infrastructure,
- scope of the analysed infrastructure (large network or switch area),
- static model or stochastic model,
- capacity model and data processing,
- traffic simulation system,
- purpose of the study.

A brief description of these aspects is given below.

Future infrastructure scenarios - strategic (high level) view
Future infrastructure scenarios are subject to limited information on traffic and infrastructure conditions. The accuracy required to evaluate the capacity of future infrastructure scenarios thus depends on the purpose of the study.

Existing infrastructure scenarios - tactical (more detailed) view
Existing infrastructure scenarios involve day-to-day operations. The availability of corresponding information is unlimited and more accessible. Infrastructure capacity can thus be accurately evaluated and requires the appropriate software tools / IT support to accurately manage the required information.

The area dimension: large network vs. a switch area
If the capacity analysis covers a national network or a European corridor, the methodology chosen for the study is important. To accomplish such a study, a commonly agreed method involving a strategic view and for some parts ("bottlenecks") a tactical view should be used. If the capacity analysis covers just a small "bottleneck" section, like a switch area, the method can be more detailed.

Analytical methods and traffic simulations
Analytical methods include static and stochastic models. Most capacity models are static and do not contain a probability function for disruptions. Static models are often sufficient and it is possible to draw conclusions from the analysis they supply. To study the relationships between infrastructure, timetable and punctuality a stochastic model is necessary. The most effective model is a traffic simulation model which has a wide variety of disruption possibilities. Traffic simulation models have a good theoretical underpinning and offer the possibility of interaction and graphical presentation. The main disadvantage is that this method can be time-consuming.

Compression method
The compression method provides information on the capacity usage of the infrastructure. It requires only the existing data in the timetable and can be applied relatively easily.

Using the methods
The compression method should be used in particular to examine international infrastructure corridors. The use of other methods can be agreed by the IMs involved.

2.3 - Introduction to the compression method

The compression method is a generalised method for calculating capacity consumption section by section. It is enhanced by involving nodes and by including further descriptions of capacity calculation procedures.

Capacity calculation by compression can be summarised in four steps. In the following points the compression method will be described in detail.

Step 1: Defining infrastructure and timetable boundaries **(see point 3.1 - page 6)**
The first step emphasises the importance of establishing boundary conditions according to needs. This involves establishing the benchmark area most important to a railway network and excluding areas of minor importance.

Similarly, defining timetable boundaries involves determining the parts of a train's operation which are important for the evaluation. The availability of information, along with the train's operational characteristics, can play an important role in this step.

Step 2: Defining sections for evaluation **(see point 3.2 - page 10)**
The second step is to define desired sections appropriate for evaluating capacity; initially by defining sections where market demand for additional train paths is most likely to occur, also referred to as "train path line sections". On the basis of these train path line sections, representative sections for evaluating the capacity consumption, referred to as "line sections", are defined.

Step 3: Calculating capacity consumption **(see point 4 - page 19)**
The third step uses the defined line sections to generate values representing the degree of infrastructure utilisation as a percentage, referred to as "capacity consumption".

Step 4: Evaluating capacity consumption **(see point 5.2 - page 29)**
Capacity consumption values reflect the basic principles of capacity expressed through timetable characteristics along defined train paths, and are also used to identify bottlenecks.

Step 5: Evaluating available capacity **(see point 5.3 - page 34)**
Evaluating available capacity uses the capacity consumption values from the representative line sections and tries to fill up the train path line section with additional train paths until a specific capacity consumption value is reached.

3 - Compression Method - Definitions

3.1 - Defining infrastructure and timetable boundaries (Step 1)

The first step of the general approach defined in point 2 - page 3 involves defining a railway network suitable for the methodology in this leaflet and the needs of infrastructure managers.

Using the conceptual approaches outlined in point 2.1 - page 3, the following criteria describe each main component of a railway network and its suitability for the capacity calculation methodology contained in this leaflet, thus aiding infrastructure managers to define the infrastructure and timetable boundaries of a railway network (see Fig. 7 - page 9).

3.1.1 - Defined railway network

The area of investigation must be defined in order for a capacity calculation to be initiated. Infrastructural and timetable boundaries are to fit with one another. Thus every infrastructural boundary (station/node) should be a timetable boundary as well.

3.1.2 - Corridors

For the purpose of this leaflet, corridors form the main structure of a railway network and are also considered to be a railway network's main source of revenue. Corridors represent the main international and national connections and thus usually stretch over several hundred kilometres. Hence the same methodology should be applied on either side of borders. Corridors may also overlap with one another, i.e. the overlapping section has to be evaluated within both corridors. Consequently only part of an IM´s network will be covered by corridors (see Fig. 2).

The timetable characteristics of a corridor consist mainly of through traffic and stopping traffic in major stations.

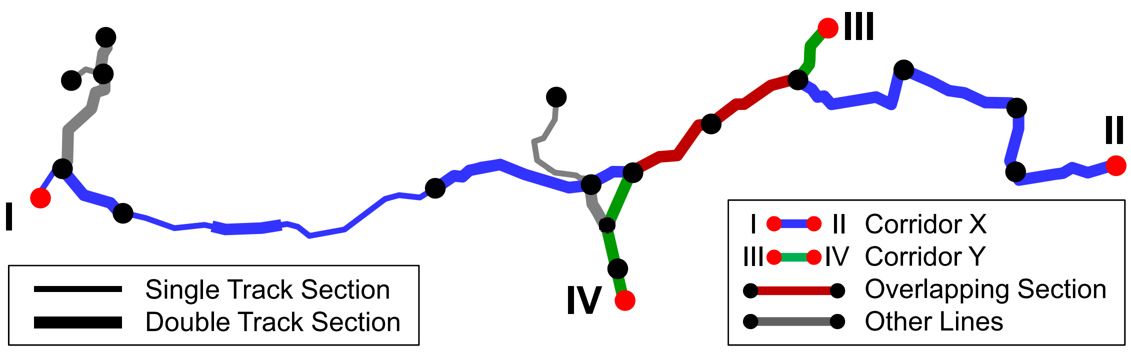

Fig. 2 - Example for establishing corridors

3.1.3 - Lines

Lines are parts of a network for which each IM has its own definition. In general, the whole network is defined by lines and usually lines do not overlap since this definition is used for the allocation of trackside projects, maintenance, operational inspections, etc. (see Fig. 3).

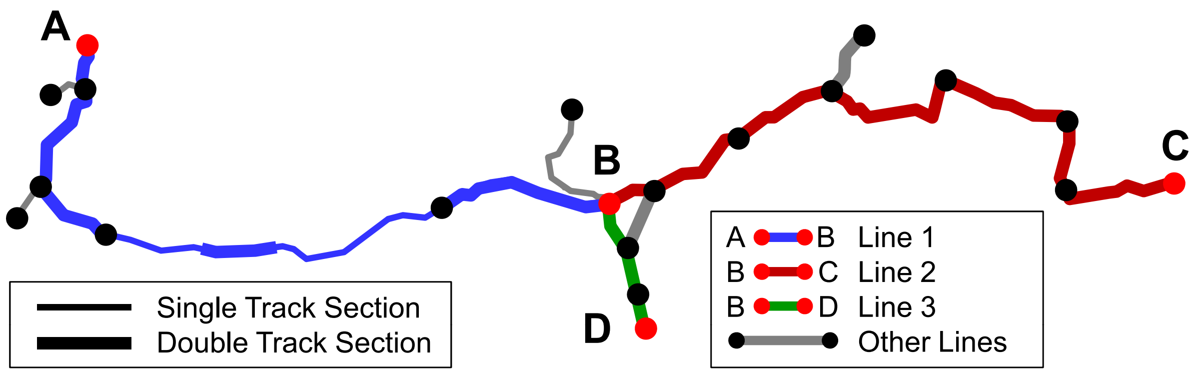

Fig. 3 - Lines of a network

3.1.4 - Interlockings

For the purposes of this leaflet, three types of interlockings are to be distinguished:

3.1.4.1 - Stations

Stations are smaller interlockings which are situated within a train path line section. Most often they have only a limited number of tracks, which are used for through and stopping train paths and, if necessary, also for crossing and overtaking. From the point of view of capacity evaluation they are considered to be a part of the line section (see Fig. 4).

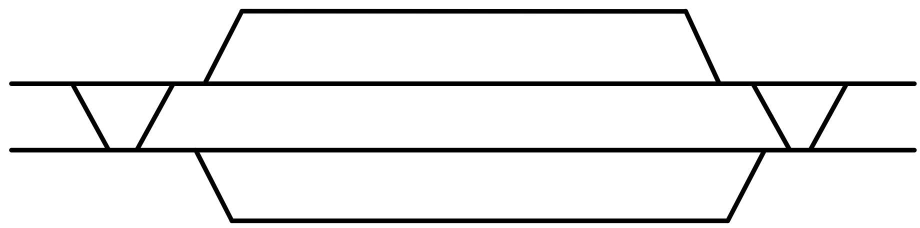

Fig. 4 - Station

3.1.4.2 - Nodes

Nodes are those larger interlockings situated on the edge of train path line sections or line sections. Very often, multiple corridors and train path line sections converge at nodes.

They usually have a higher number of tracks, which serve not only for through and stopping train paths and for crossing and overtaking, but also for starting and terminating services, changing locomotives, shunting, etc. (see Fig. 5). The capacity of nodes is to be evaluated separately, so that mutual interaction between train paths from different corridors and train path line sections can be taken into consideration.

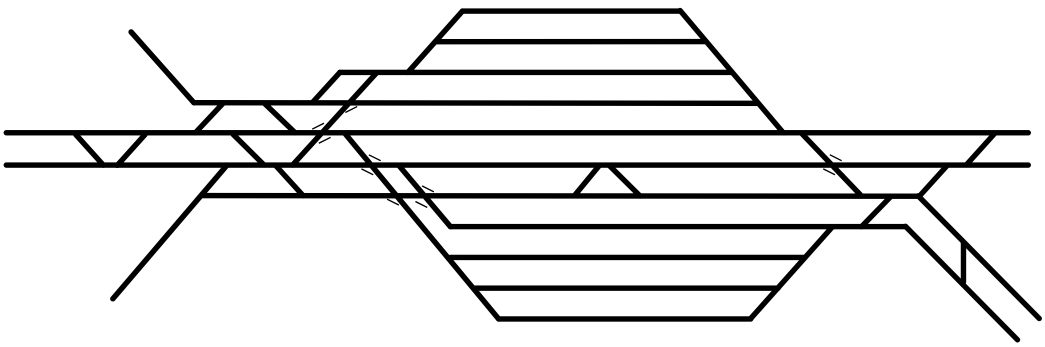

Fig. 5 - Node

3.1.4.3 - Junctions

Junctions consist only of one switch area. Trains can wait in front of, but not within the junction (see Fig. 6). In some cases junctions are also equipped with platforms. Only train movements (no shunting movements) occur within a junction.

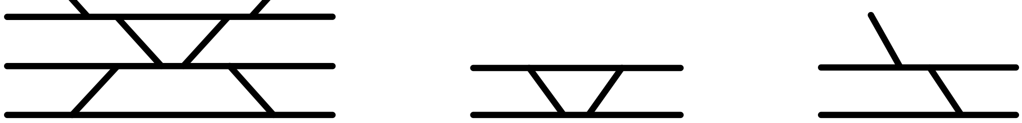

Fig. 6 - Junctions

3.1.5 - Areas excluded from the defined railway network

3.1.5.1 - Hump yards

Hump yards are independent from the rest of the railway network, and are areas where incoming traffic and outgoing traffic act as interfaces to the "defined railway network". Hump yards incorporate unique railway operational and capacity characteristics. The methodology of this leaflet deals with hump yard capacity by establishing their interfacing conditions, but does not independently evaluate them.

3.1.5.2 - Storage yards

Like hump yards, storage yards usually are connected to the "defined railway network" within interlocking areas or large stations. In contrast to hump yards they generally interact with the network via shunting movements and not via train movements. Hence it is necessary to take them into account when assessing the related nodes.

3.1.5.3 - Logistics and/or intermodal terminals

When dealing with terminals it is necessary to consider the points at which they connect to the network. They can be connected to nodal areas as well as to line sections. Whereas their train or shunting movements have to be considered when assessing the adjacent nodes, their connections to line sections generally lead to additional necessities in defining line sections.

3.1.5.4 - Adjacent properties

This point encompasses private sidings, lines operated by another IM, etc. As mentioned in the points above, they have to be considered in relation to their impact on the defined network.

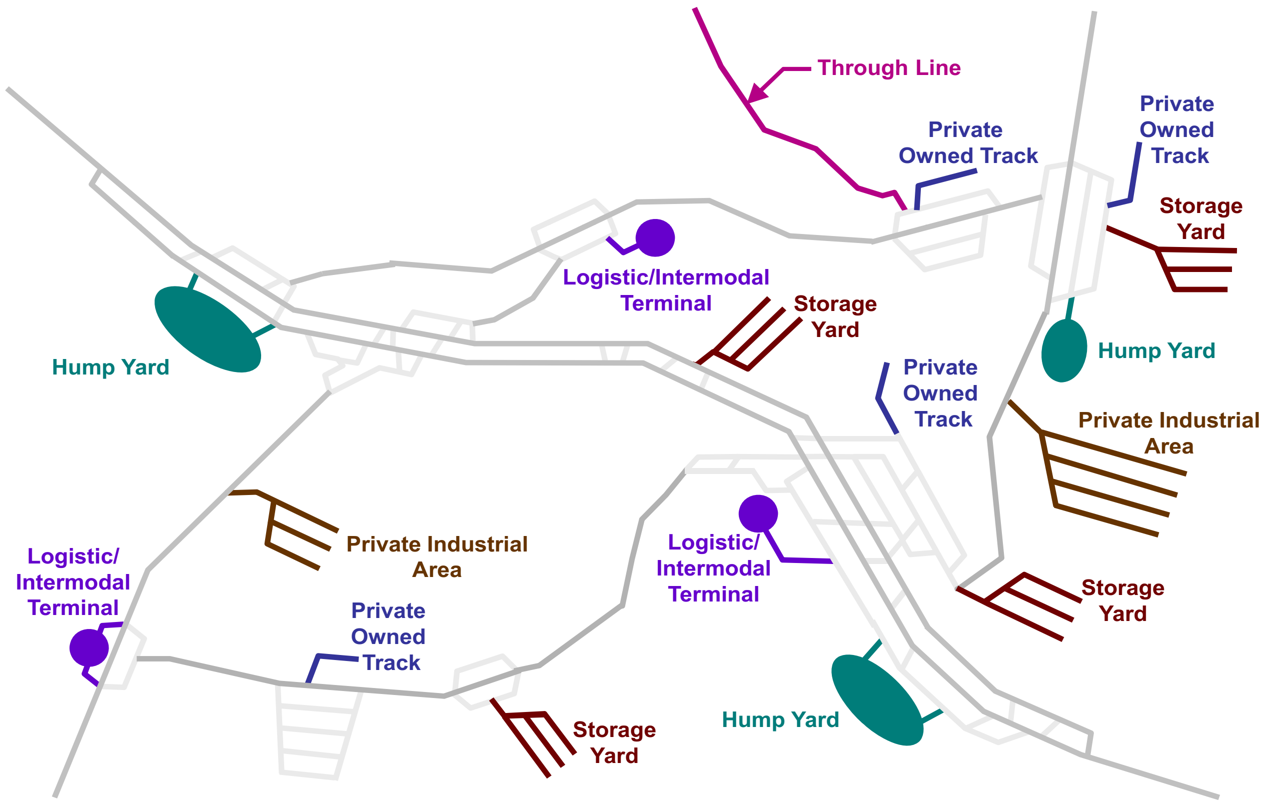

Fig. 7 - Defining excluded areas

3.2 - Defining sections for calculation and evaluation (Step 2)

There are two types of section to consider:

- **Train path line sections**, referring to market conditions, are used for measuring capacity by inserting or excluding train paths. They are those parts of the line in which sequences of long-distance trains are defined within a timetable.

- **Line sections** are used to measure capacity consumption by compressing the timetable. They are those parts of the line for which - depending on the timetable structures - the associated capacity consumption is calculated.

3.2.1 - Determining "train path line sections"

For the purposes of this leaflet, train path line sections are defined in order to evaluate available capacity for additional services. Train path line sections are based on the train paths with the highest demand and are defined along a specific route and track. Double-track lines operate with one-directional traffic (i. e. each track serves traffic in one direction only) and usually have the same market conditions for both directions. Therefore, train path line sections on double-track lines are usually identical in both directions. Train path line sections should extend to wherever marketable train paths can be inserted. This may include especially the interlockings where the particular type of train will terminate (e.g. cargo terminals for freight trains, major passenger stations for long-distance passenger trains).

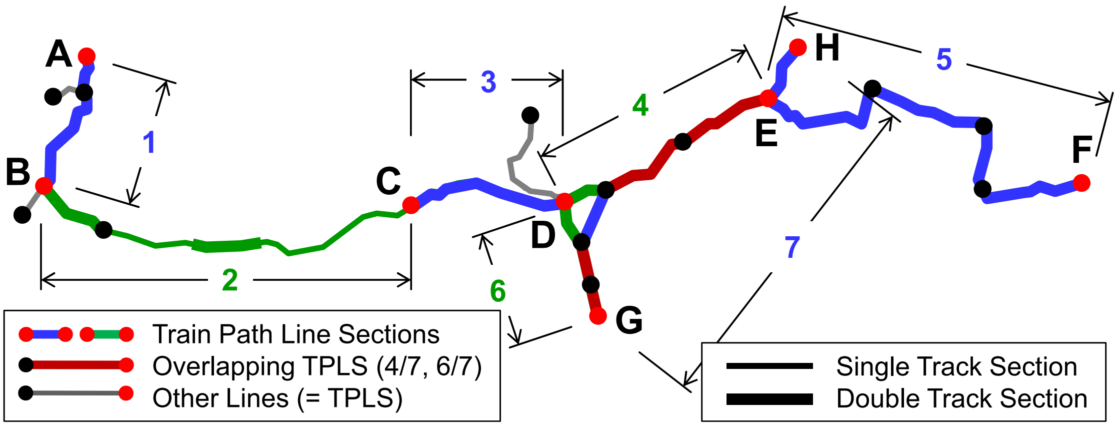

Fig. 8 - Defining train path line sections for a railway network

Like corridors, train path line sections may also overlap, since it is their task to determine the number of available train paths (see Fig. 8).

3.2.2 - Determining "line sections"

The purpose of determining line sections is to determine capacity consumption that reflects the needs of timetable planning by using priority train services which are critical to a timetable's structure and stability.

Train path line sections should be broken down into line sections if any of the following criteria are applicable.

- Establish areas where the infrastructure conditions differ significantly (see Fig. 9):

  - Signalling system
  - Number of tracks in the line section
  - Branching lines

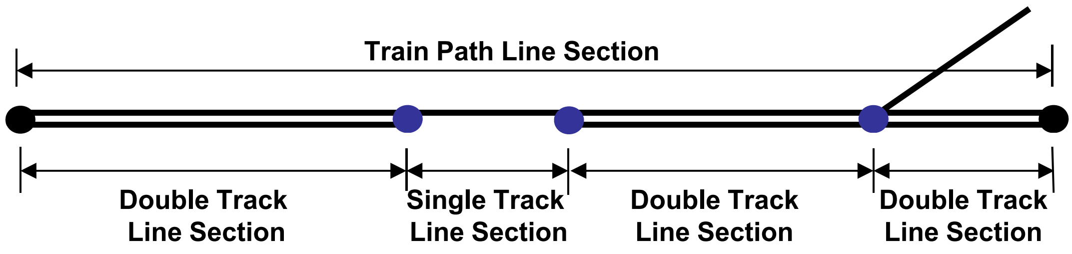

Fig. 9 - Defining line sections due to infrastructure differences

- Establish areas where significant timetable or traffic operation differences occur (see Fig. 10):

  - Beginning or ending services
  - Different number of trains
  - Train mixture and/or train sequence
  - Crossing trains

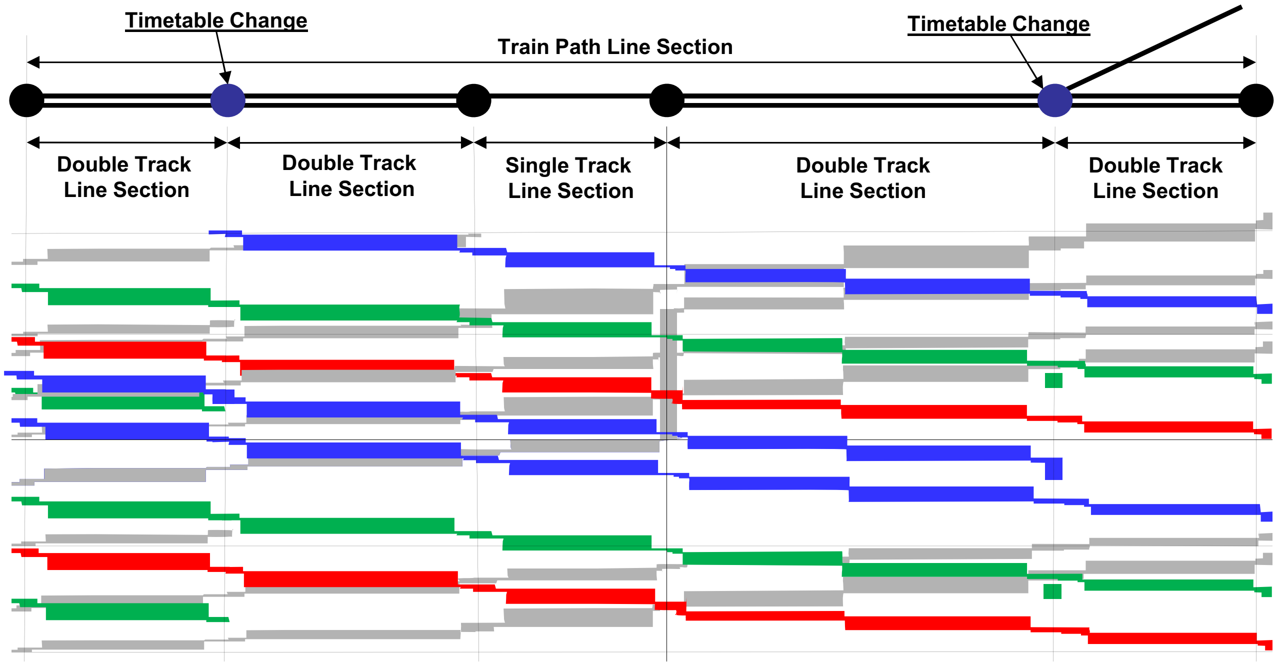

Fig. 10 - Defining line sections due to timetable differences

- Line sections along single-track lines are defined by the corresponding adjacent interlockings where trains can cross or overtake (see Fig. 11).

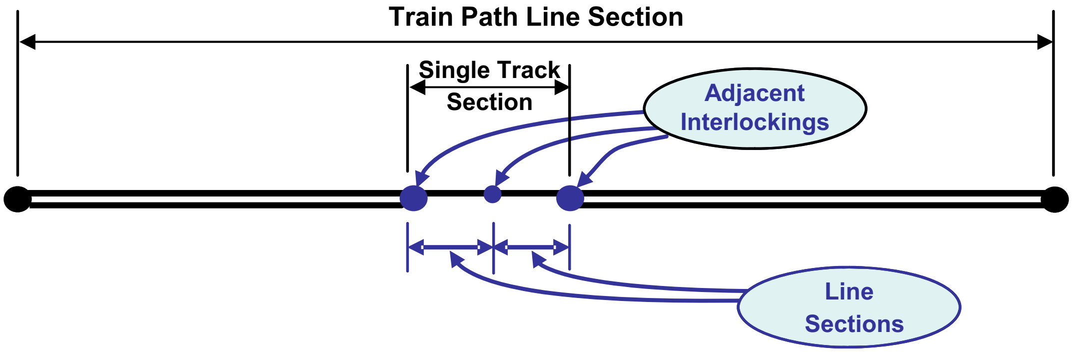

Fig. 11 - Defining line sections on a single-track section

By observing the above criteria, the whole network subject to capacity calculation is divided into line sections (see Fig. 12).

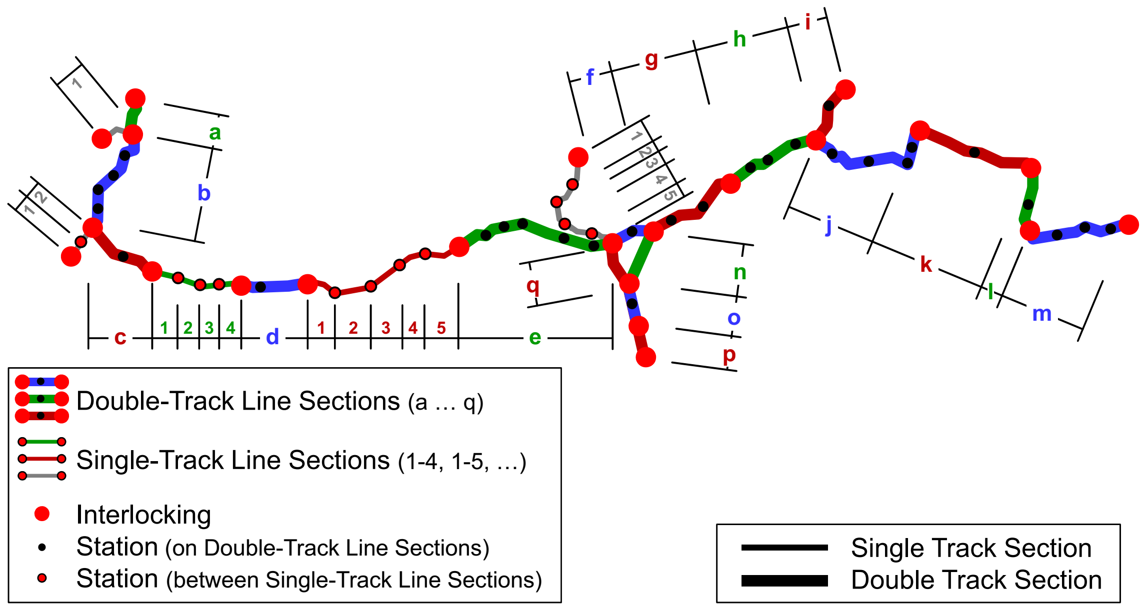

Fig. 12 - Covering a network with line sections

A train path line section can either be divided into several line sections or can be covered entirely by one line section (e. g. train path line section 3 in Fig. 8 - page 10 and line section e). Since capacity consumption is a physical attribute of line sections, they can be combined in different ways (e. g. n-o-p or q-o-p) to fit with train path line sections.

3.3 - Defining capacity consumption

Building upon the characteristics of line sections as defined in point 3.2 - page 10, capacity consumption represents the utilisation of an infrastructure's physical attributes along a given section, measured over a defined time period.

$$\text{Capacity Consumption [\%]} = \frac{\text{Occupancy Time} + \text{Additional Times *}}{\text{Defined Time Period}} \times 100$$

*) any time value added to secure quality of operation (buffer time, quality time, etc.) - see point 5.2 - page 29.

3.3.1 - Parameters and criteria

Capacity consumption is measured over a defined time period using the following parameters and criteria:

3.3.1.1 - Representative day

Before evaluating capacity for the desired railway network(s), a day representing the timetable characteristics is chosen. This can vary by time of year, mainly based on fluctuating demands for freight transport. Timetables for passenger traffic are usually more stable, though in some cases it is necessary to take into account their seasonal changes.

For the purposes of evaluating the needs presented by further timetable improvements or possible infrastructure adjustments, it is recommended to select a heavily-travelled weekday.

3.3.1.2 - Representative time period

In applying the compression method, it is highly recommended to use time periods not shorter than two hours for calculating capacity values. This covers cases of heterogeneous timetables with speed variances and a variety of services, as well as peak traffic periods. In calculating network or corridor capacities, however, the time period should be increased to the operation time of the related line section.

3.3.1.3 - Timetable within a defined time period

For the purposes of this leaflet and one-directional traffic, the train paths to be included start at the beginning of the line section within the defined time period. Train paths which enter the line section before the beginning or after the termination of the defined time period will be excluded (e.g. path #1 and #3). On the other hand, train paths must be included completely should their starting point lie within the defined time period (e.g. path #2 - see Fig. 13 - page 14).

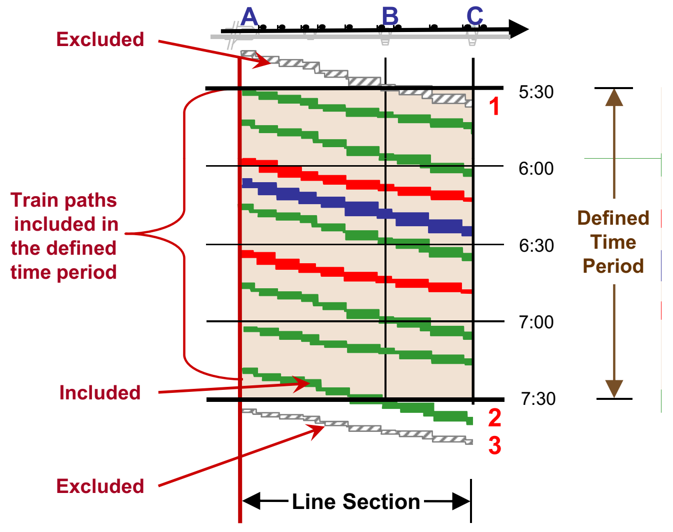

Fig. 13 - Timetable definition

3.3.1.4 - Point of capacity consumption measurement

The capacity consumption of a line section is measured where the time between the start of occupancy of the first train and the end of occupancy of the last train in the compressed defined timetable shows its maximum value.

Usually the point of measurement lies at that endpoint of a line section where the first train path begins. Along double-track sections, the point of measurement is taken as that at which the direction of traffic begins. If other points along the line section are critical, such as incorporated interlocking sections or trains starting within the line section, the point of measurement must be adjusted accordingly. In either case, the point of measurement is the critical and representative point of the line section.

Practical procedure:

For practical reasons, the first train path may be added as an (additional) final train path at the end of the sequence. The starting point of this final train path is the end point of the occupancy time, i.e. the occupancy time of the final train path itself is not included. When applying this procedure, occupancy time may be measured at any position in the line section (see Fig. 14).

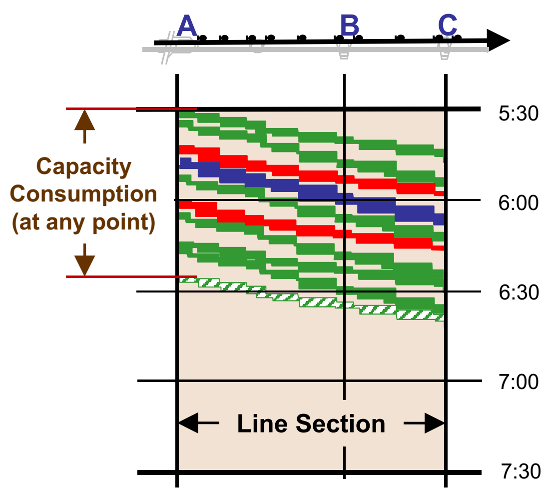

Fig. 14 - Practical procedure for capacity consumption measurement

3.3.2 - Occupancy time

3.3.2.1 - Occupancy time of a single block section

The basic physical attributes are determined by each train path as functions of the track capability, signal operations, and dynamic behaviour of the train. The signal block is an infrastructure attribute that defines a train path and helps evaluate capacity. Fig. 15 hereafter illustrates the physical attributes of a signal block.

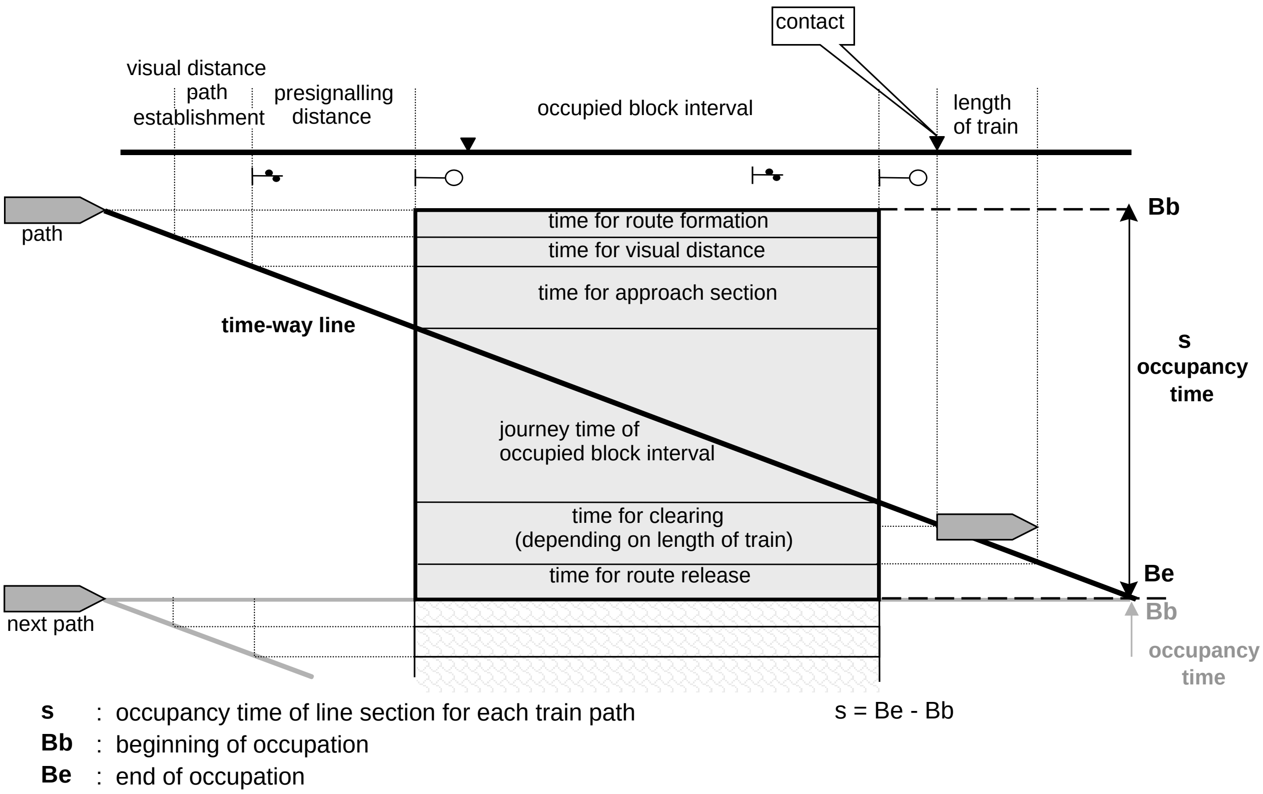

Fig. 15 - Physical attributes of a block section

The parameter used for evaluating capacity is "s", occupancy time, illustrated between "Bb" and "Be". Occupancy time is the total time required for one train to pass through a single block, which includes the following:

- Safety margin of time required before the train physically enters the block (illustrated as "time for route formation", "time for visual distance", and "time for approach section"),
- The time the head of the train passes the block (illustrated as "journey time of occupied block interval"),
- Time required for clearing the block (illustrated as "time for clearing"),
- Time required for switching of signals to allow occupancy of the next train (illustrated as "time for route release").

3.3.2.2 - Occupancy time of a line section

Using the basic physical attributes mentioned in point 3.3.1 - page 13, capacity consumption is calculated by compressing all block sequences along the train paths within a defined timetable to an infrastructure's physical limits. The resulting value, measured along a time scale between the first and last train paths after compressing the timetable, is referred to as the occupancy time. As shown in Fig. 16, the line section length affects the occupancy time. How to handle this phenomenon is further discussed in point 5.2.2.2 - page 33.

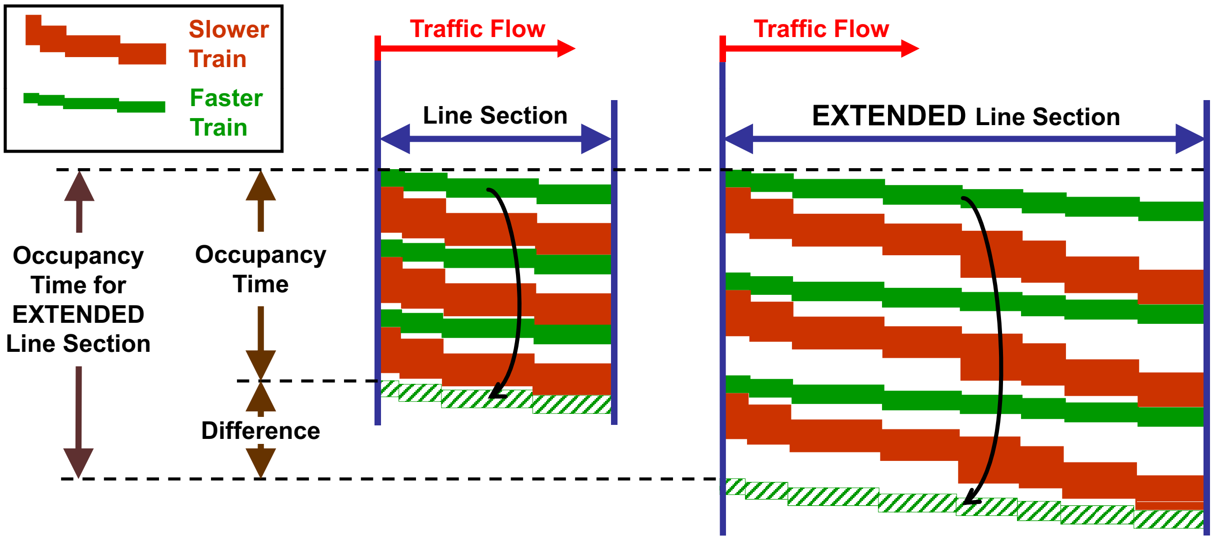

Fig. 16 - Increasing occupancy time by extending the line section

3.3.3 - Additional times

Since the occupancy time is calculated without any spaces between the compressed train paths, time has to be added to secure a specific level of service. Generally, this is done by limiting the permitted capacity consumption by a given percentage (see Table 2 - page 30). In order also to cope with specific situations (maintenance work, different timetable situations during the day, highly sensitive trains), additional times may be required, which it will be necessary to insert. However, supplements added during the timetabling process do not affect these additional times (see point 5.2 - page 29).

3.3.4 - Defined time period

Capacity may be analysed over a longer period, even though compression of the timetable is performed over a shorter "defined time period". For example, it might be useful to analyse a given timetable over a whole day, whereas capacity consumption is calculated for the peak hours only. Thus, the analysed time period may be 24 hours and the defined time period (for calculation) may be four hours only.

3.4 - Definitions for evaluating capacity consumption and available capacity

Once capacity consumption is calculated, the next and final step is to perform the evaluation. If the capacity consumption value lies beneath the accepted 100 % value (see Equation point 5.2.1.3 - page 30), a distinct amount of a line section´s capacity is still unused (see Fig. 17). Since the line section with the highest capacity consumption determines the train path line section´s capacity consumption, this value can also be assumed to be the relevant value for the train path line section.

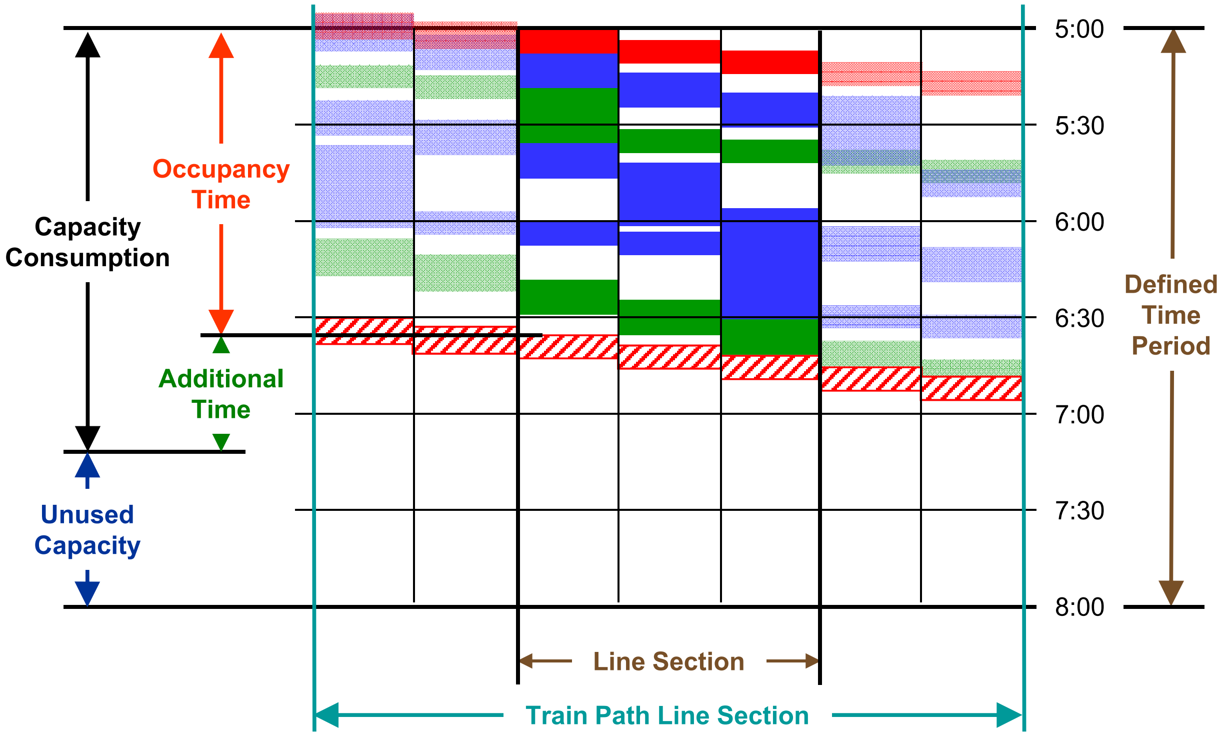

Fig. 17 - Capacity consumption and residual capacity of a line section

The recommended workflow process is to insert or exclude train paths into the train path line section until the capacity consumption of the considered line section has reached 100 % or no additional train path can be inserted.

When analysing a train path line section, the possibility to increase traffic by inserting additional train paths can be examined. The infrastructure can be utilised by different types of trains in different ways. By using the compression method, it is possible to assess capacity consumption for every line section and to obtain information on available and lost capacity (see Fig. 18 - page 18).

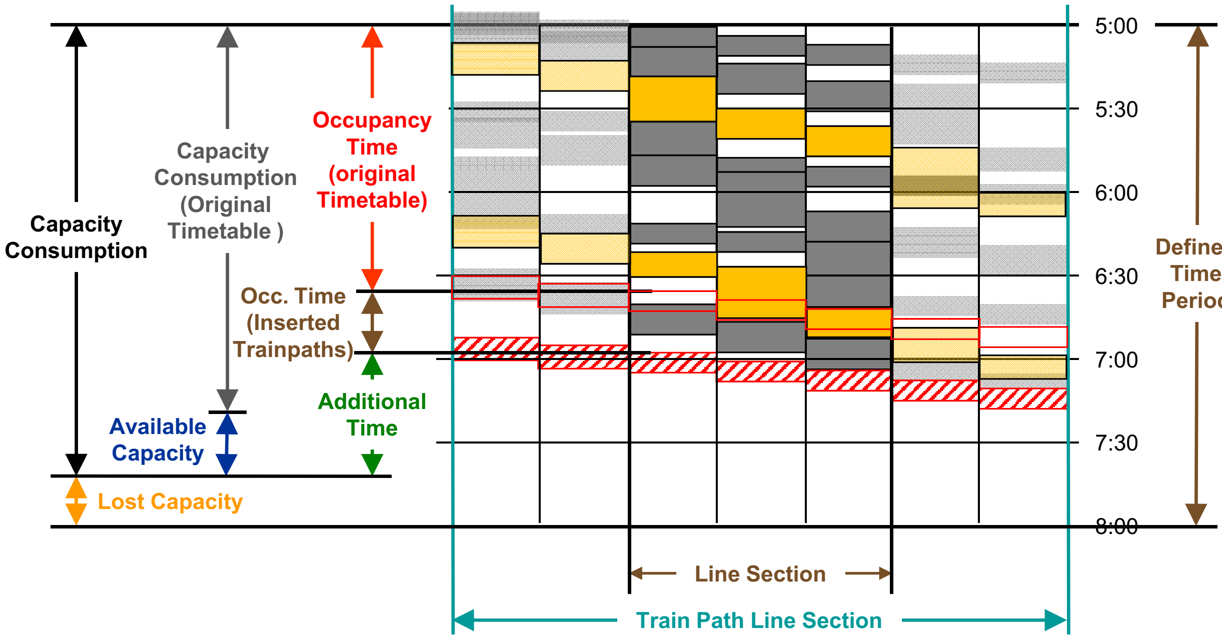

Fig. 18 - Available and lost capacity after inserting additional train paths

When examining an international corridor, the IMs involved must agree upon comparable line sections and train path line sections matching the aim of the study. Capacity consumption is firstly calculated, following which further evaluation can be performed by inserting or excluding train paths (see point 5 - page 29).

4 - Compression method - Calculation (Step 3)

4.1 - Introduction

Point 4 describes capacity calculation by timetable compression for single-track lines, double-track lines and nodes. This results in capacity consumption expressed as a percentage value characterising infrastructure utilisation. This helps to identify bottlenecks.

When investigating a corridor or major line, general calculations are appropriate for double-track and single-track lines and for nodes. Sometimes a more detailed view is needed. For that reason, special cases of the compression process are described.

The simplest type of train path used to calculate capacity consumption is that running along a line without consideration of interlockings. Capacity calculation is performed for line tracks and through-tracks in stations accordingly. Compression is done for these tracks only.

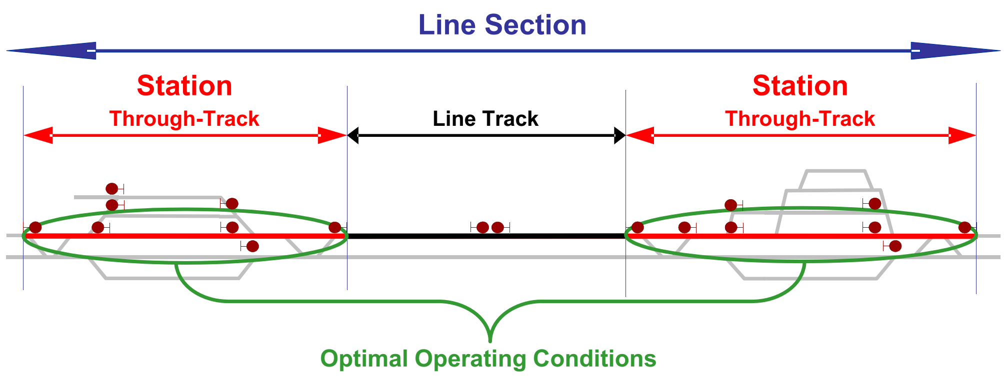

Fig. 19 - Evaluation of capacity on line tracks and through-tracks only, without considering operating activities in stations

Next step to evaluating lines is to include all necessary activities associated with through-track areas.

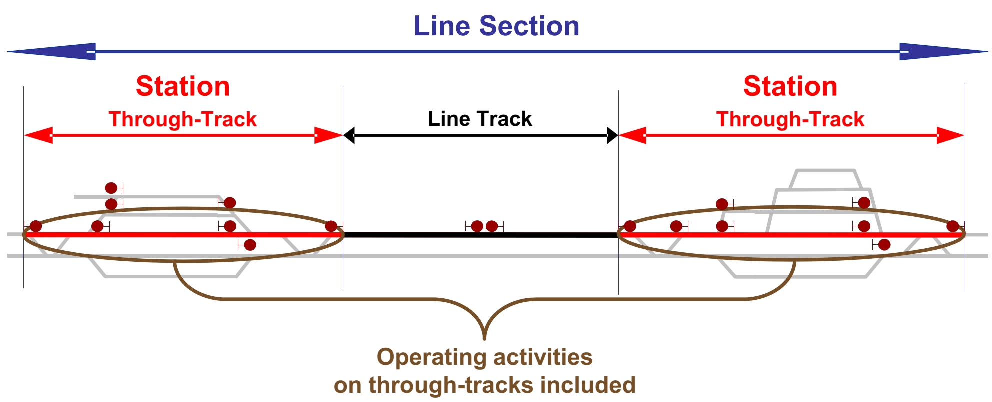

Fig. 20 - Evaluation of capacity on line tracks and through-tracks with consideration of operating activities in stations

4.2 - Compression of a single track line

A single-track line is generally used for bidirectional traffic. As defined in point 3.2.2 - page 11, the physical infrastructure characteristics do not allow trains to be operated in opposite directions along the defined line section at the same time (see Fig. 21 and Fig. 22).

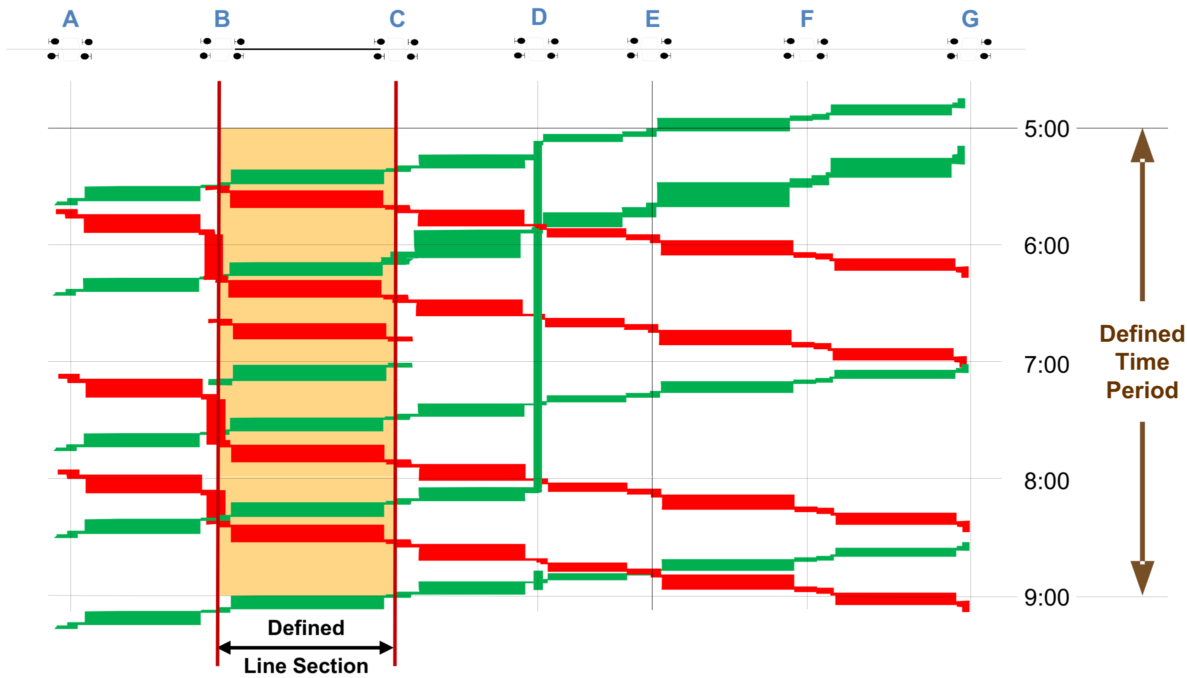

Fig. 21 - Single-track line section before compression

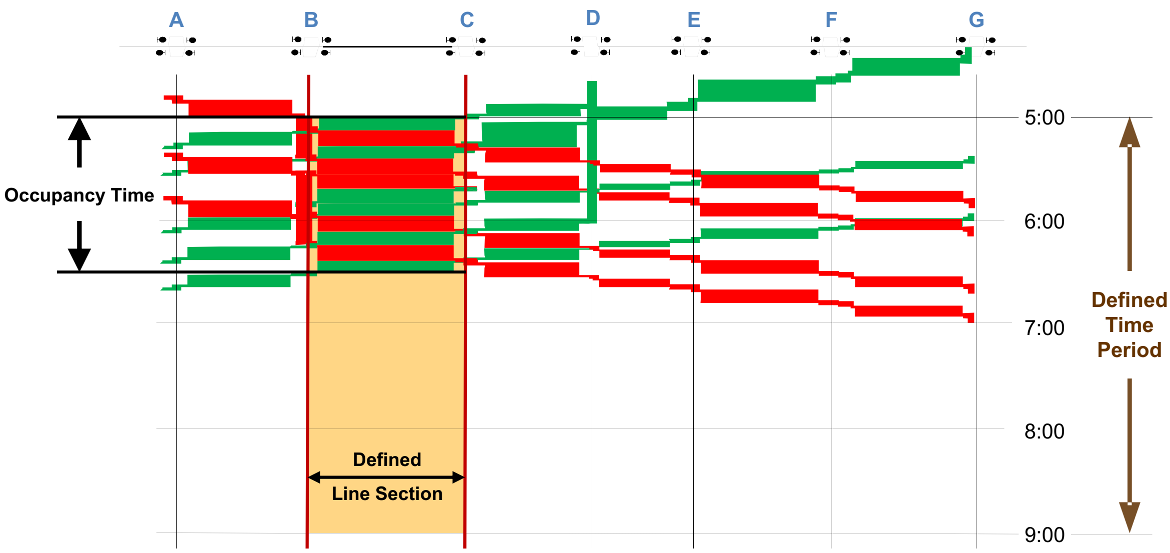

Fig. 22 - Single-track line section after compression

4.3 - Compression of a single-track line, special case

Single-track line profiles may include circumstances whereby tracks are not available for crossing or overtaking for a lengthy period of time (i.e. trains occupying non-through tracks, station closures, sidings with insufficient length). Under such circumstances, the defined line section is to be temporarily extended to the following adjacent interlocking area which is available for crossing or overtaking until the occupied track is free for crossing or overtaking. Fig. 23 illustrates a timetable with a train stopping in interlocking "D" for more than three hours. When evaluating capacity consumption within the timeframe planned for stopping under such circumstances, the defined line section is to be extended accordingly up to the next available interlocking.

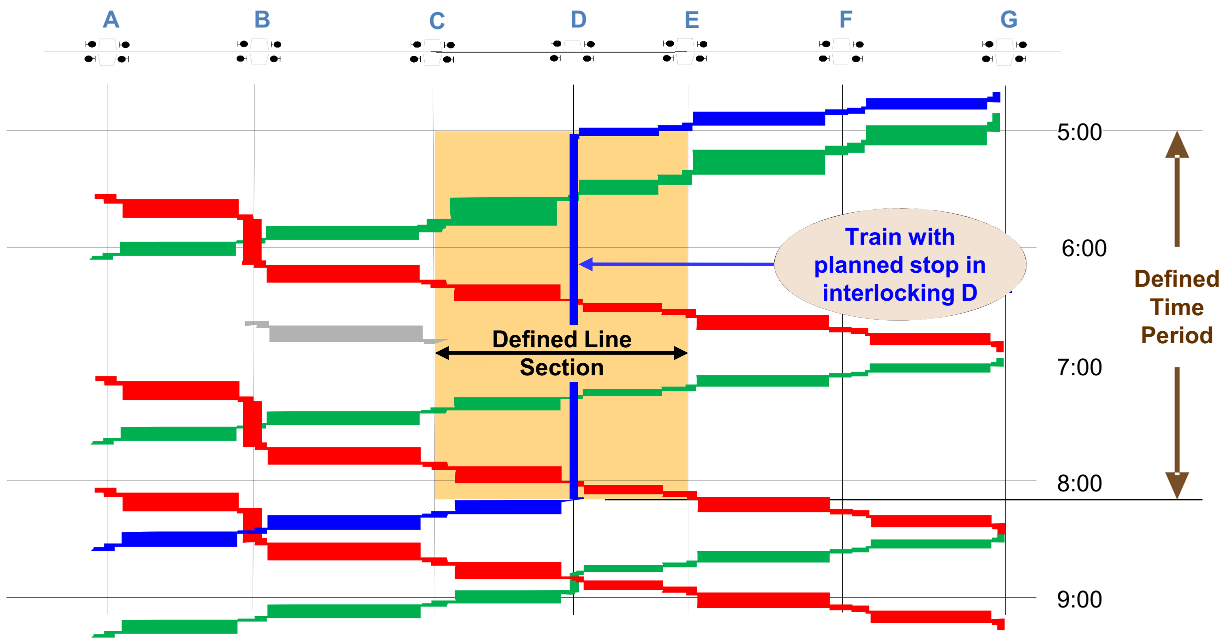

Fig. 23 - Temporarily extended line section

In the compression process, all train paths during the defined time period have to be compressed within the boundaries of the defined (extended) line section. This defines the new compressed time period and marks the starting time for any further timetable compressions of the original line sections. Thus, the three-hour train stopping time will be shortened when compressing but must be allowed for when inserting additional train paths (see Fig. 24 - page 22).

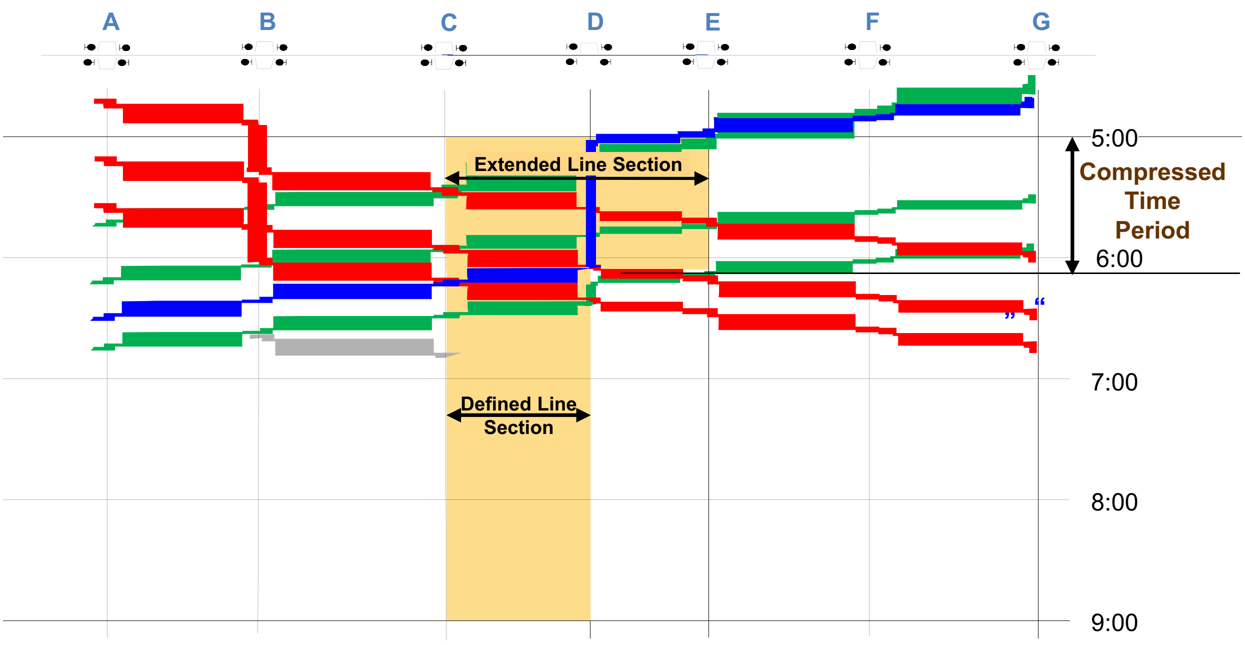

Fig. 24 - Compression including a temporarily extended line section

4.4 - Compression of a double-track line

Double track lines are usually operated with one-directional traffic on each track. Even on lines where bidirectional traffic on either track is possible, each of the tracks is usually assigned to one direction. Fig. 25 illustrates an example of the double-track line section from interlocking "A" to "C" over a defined time period. This example assumes ideal conditions (through-traffic only) within the interlocking areas.

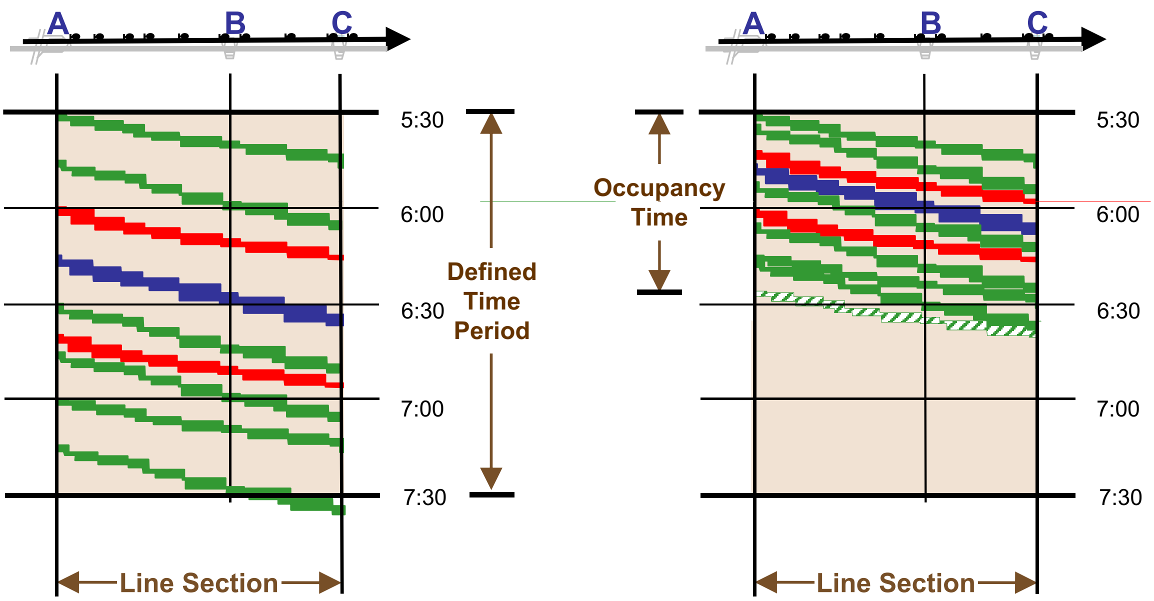

Fig. 25 - Timetable on a double-track line section before and after compression

4.5 - Compression of a double-track line, special cases

4.5.1 - Trains stopping for longer periods

In this case it is the railway expert´s decision whether to define a new line section or not (see point 3.2.2 - page 11). Trains with planned long stops adhere to their scheduled sequence and allow overtaking accordingly. Fig. 26 illustrates a line section using the following criteria:

- One planned stop - long-distance freight train (highlighted in blue) at interlocking "G".
- Overtaking - long-distance passenger train (highlighted in red) at interlocking "G".

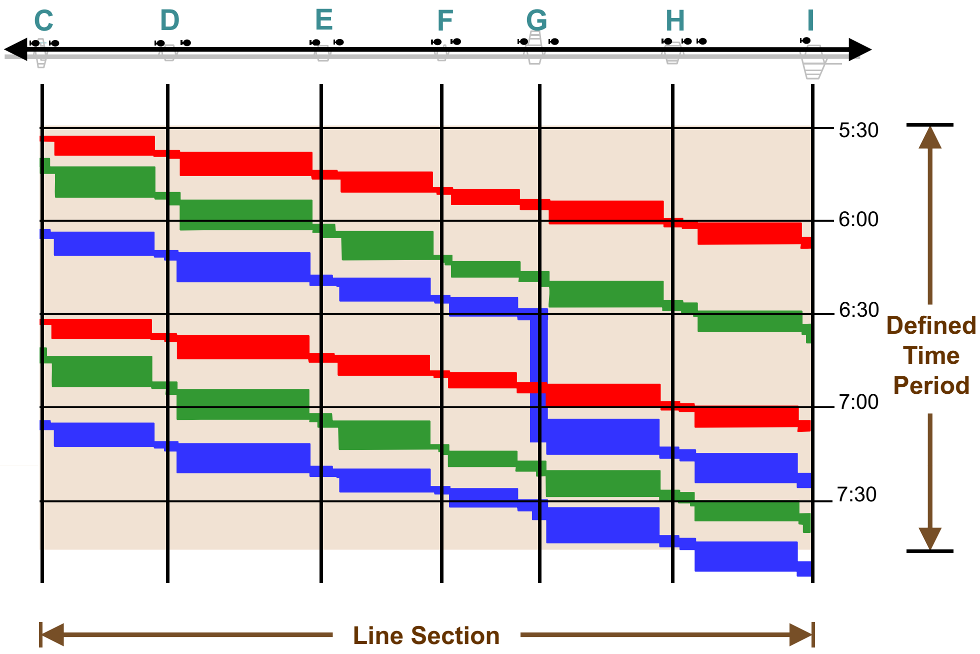

Fig. 26 - Timetable on a line section with overtaking

Fig. 27 - page 24 illustrates the double-track section after compression. In this case the stopping time does not affect the timetable structure and is therefore not included.

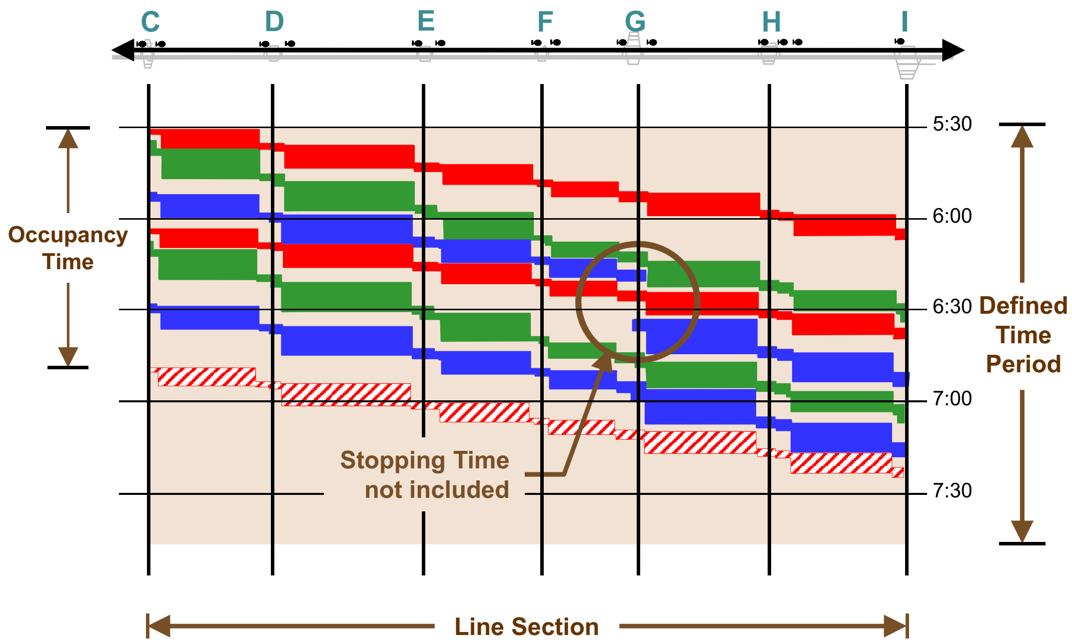

Fig. 27 - Timetable with overtaking train after compression

4.5.2 - Crossing Traffic

Crossing traffic is a vital consideration in evaluating the viability of through-traffic. Fig. 28 illustrates the impacts on the line section when compressing the timetable by appropriately measuring the occupancy time.

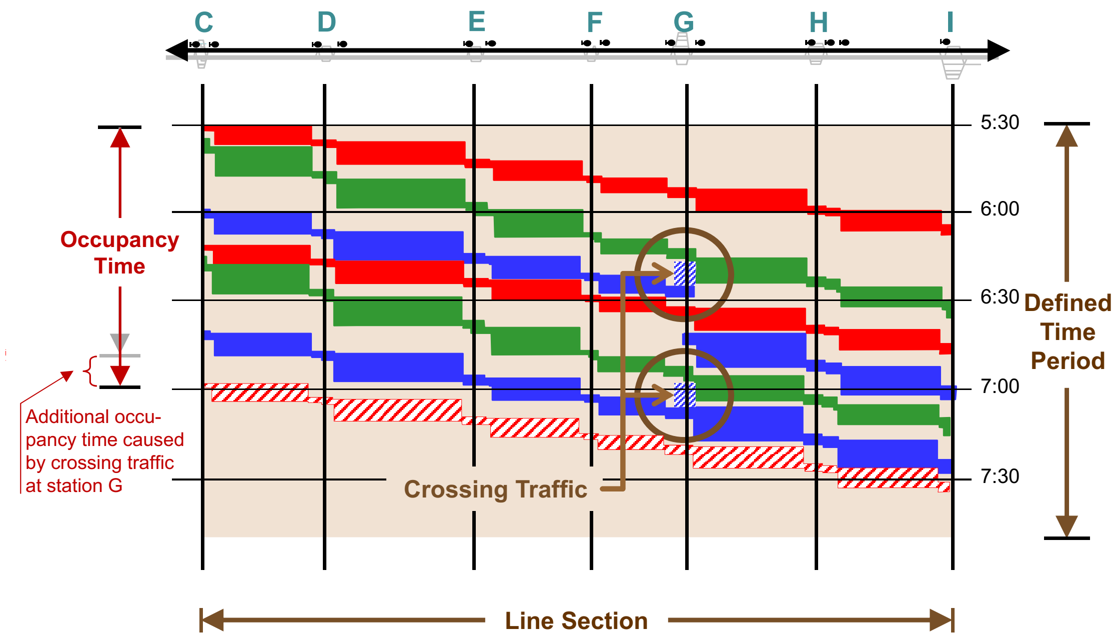

Fig. 28 - Timetable with crossing traffic after compression

4.6 - Compression of a node

4.6.1 - Areas of a node

In general, a station or node consists at least of two switch areas and one track area in between. The task of the switch area is to link the line tracks to the track areas of the station or the node. The task of the track area is to enable trains to be moved or stored. Some of the tracks may also be equipped with platforms (see Fig. 29).

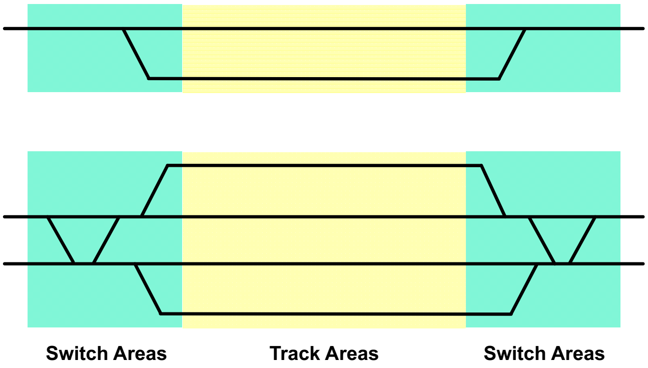

Fig. 29 - Standard stations with two switch areas

Terminus stations usually consist of only one switch area and one track area (see Fig. 30).

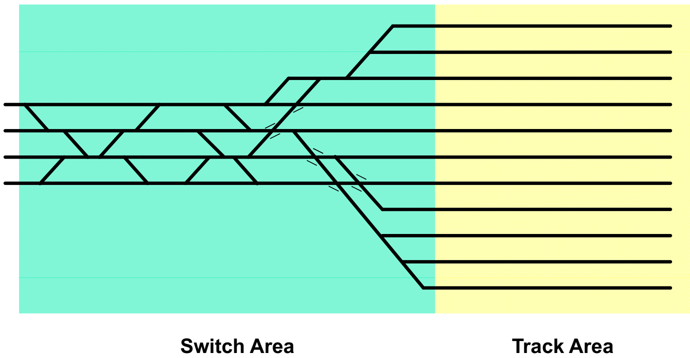

Fig. 30 - Terminus station with one switch area

Special cases are switch areas on open line e.g. at junctions (see Fig. 31).

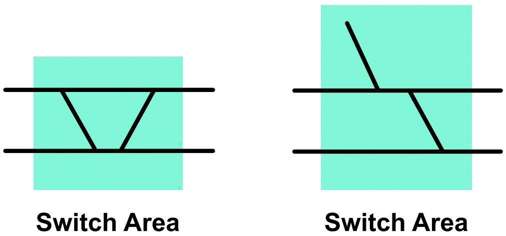

Fig. 31 - Switch areas on open line

4.6.2 - Compression process for switch areas

The compression method can be applied to investigate the capacity of switch areas using the following approach. Firstly, the various assignable routes through the switch areas under examination are extracted (e.g. Fig. 32). In general, each of these eight routes may be used bidirectional. Routes B⇔3/B⇔4 and A⇔1/A⇔2 may be used simultaneously. Routes A⇔3, A⇔4, B⇔1 and B⇔2 conflict with each of the other routes and therefore cannot be combined with any of the others.

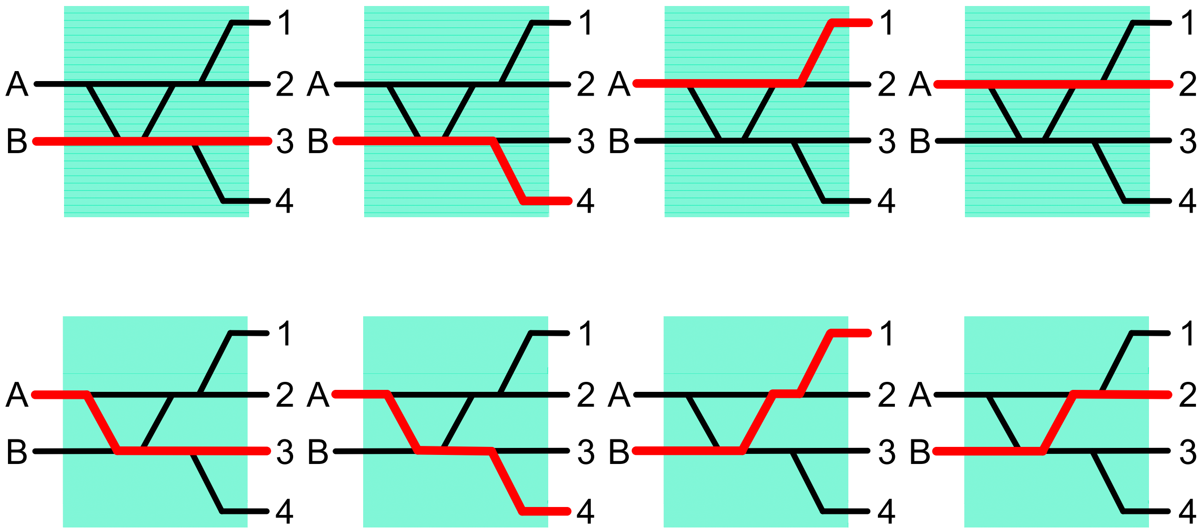

Fig. 32 - Possible routes through a simple switch area

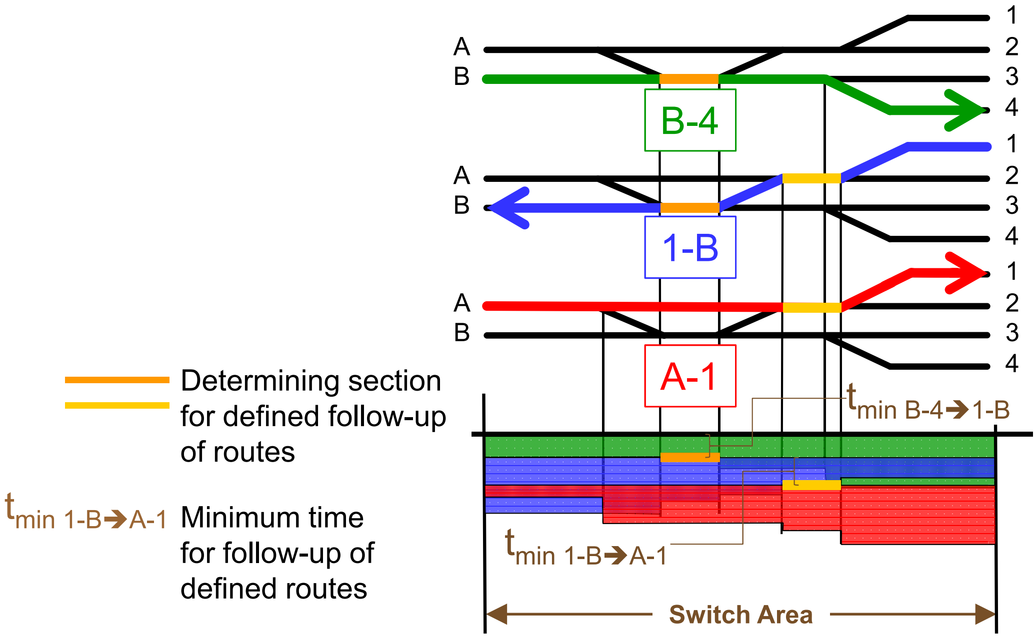

Fig. 33 - Train movements through a switch area and associated compressed timetable

Trains pass through the switch area in a distinct sequence of routes, in accordance with a defined timetable. The times indicated in timetables may be, for instance, the times at which the trains pass the signals to meet the route, in which case the occupancy starts in accordance with the aforementioned occupancy time conditions. The occupancy by the next train path begins as soon as possible, i.e. at the end of the period excluded by a previous train path (see Fig. 33 - page 26). By this procedure, a compression is achieved.

Some feasible train paths on parallel routes are simultaneous with other train paths. The total time required for all train paths to be scheduled results from the individual time values needed for concatenated train paths (i.e. time-dependent on each other). For practical reasons, the first train path may be added as an (additional) final train path at the end of the sequence. The capacity consumption results from the total time required for all train paths in relation to the period under examination. For permissible capacity consumption values, refer to point 5 - page 29. For a suggested practical applicable procedure using a calculation sheet, refer to Appendix A - page 39.

For subsequent trains running on the same line track, instead of using values resulting from the actual exclusion of the switch area, exclusion periods of the adjacent block section may be used. These take into account the different occupancy times needed by trains to reach a crossing or overtaking station or a block signal (see Fig. 34).

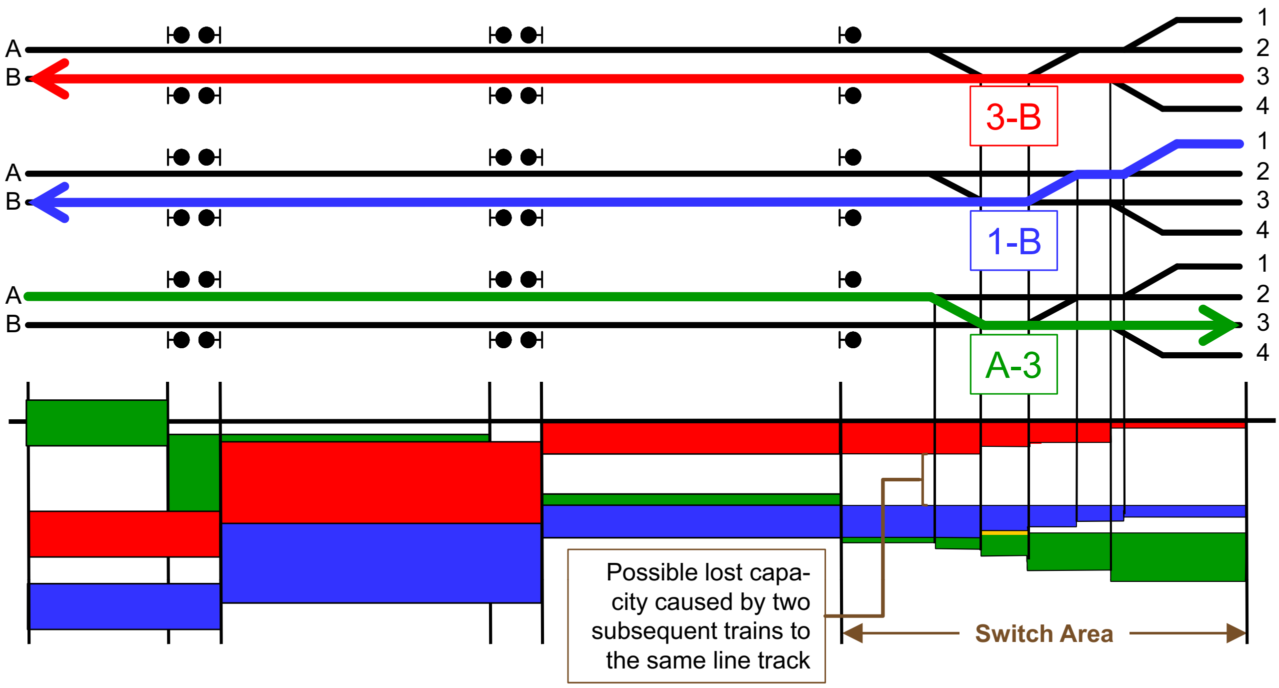

Fig. 34 - Possible lost capacity within a switch area caused by two subsequent trains to the same line track

In some cases very long headways may occur (e.g. on lines with distant crossing stations), resulting in long exclusion periods. Compression of the switch area may then be less relevant. This usually occurs if only one line is connected with the switch area. Inserting additional train paths with other routings, however, could be used more widely.

4.6.3 - Compression process for track areas

Track areas are infrastructure components of a station or node between switch areas, which include the through tracks, platform tracks, overtaking tracks and sidings. Scheduled and unscheduled stops and dwells take place in these areas. The occupation of the individual tracks in a track area is defined by using the track occupation graph.

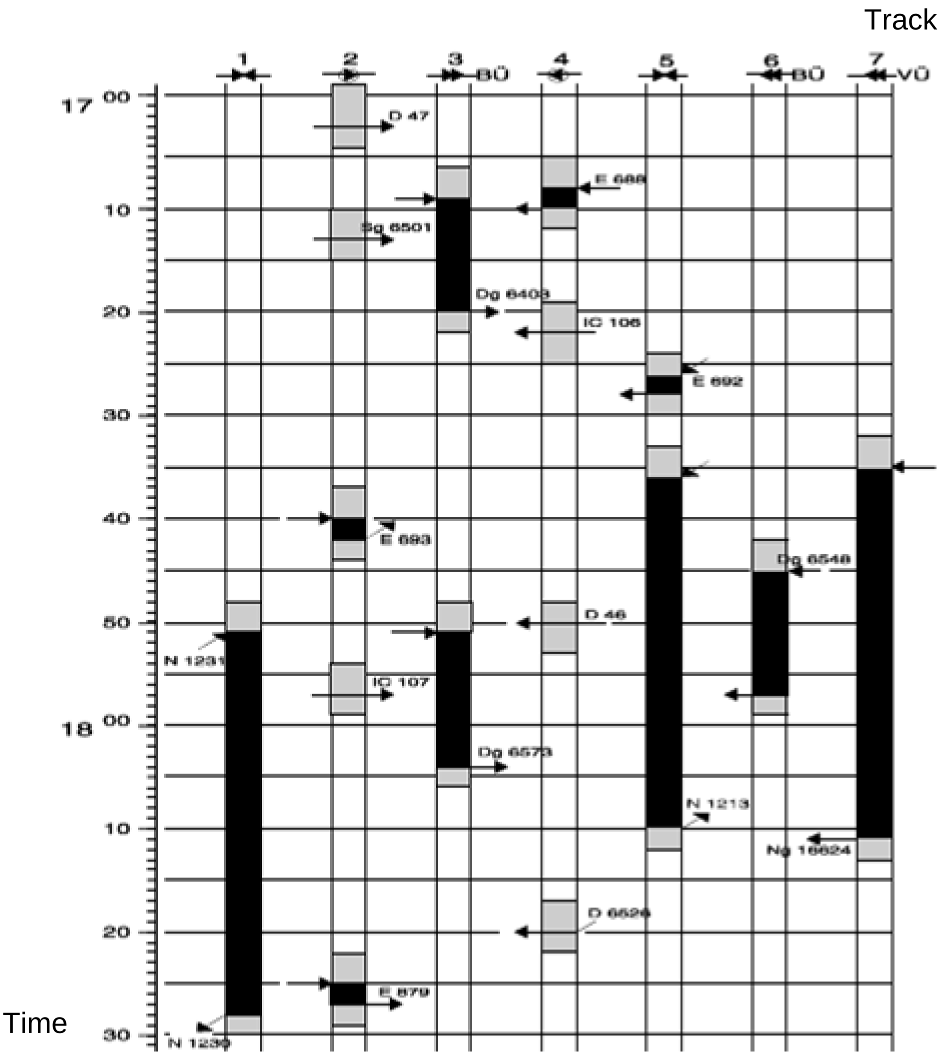

Fig. 35 - Section of a track occupation graph

It should be noted that the track occupation (not the physical occupation of the track) starts with the occupation of the switch area (the time as of which other train movements on the track concerned are prohibited) and ends with the clearing of the adjacent switch area or sub-switch area.

Compression

The compression is to be performed separately for every individual track, in the same way as on open line. The capacity consumption of each track is more or less independent of the capacity consumption of the others (in some cases disruptions may result from the switch areas); parallel use of the tracks is thus potentially viable. A degree of capacity consumption can thus be calculated for a single track or a track area.

5 - Compression method - Evaluation

5.1 - Introduction

Starting with the result of the compression process for line sections and nodes, this point outlines the criteria to be applied in evaluating the capacity consumption (see point 5.2 - page 29) and the available capacity (see point 5.3 - page 34) of lines and corridors.

The capacity consumption values are used to establish boundary conditions for acceptable operational quality, and can be used as indicators for decision-making in all sectors to mitigate deteriorating operational quality. Furthermore, capacity consumption values are a basis for managing available capacities and their order of priority.

In most cases, the number of possible train paths on a given infrastructure will also be of interest. Depending on whether the capacity consumption value is lower or greater than 100 %, train paths may have to be added to or excluded from the original timetable. Whereas the criteria for defining additional train paths are proposed in point 5.3.1 - page 34, the procedure for excluding trains has to be handled on a more case-by-case basis and in close cooperation with the IM´s timetabling department.

5.2 - Evaluation of capacity consumption (Step 4)

5.2.1 - Evaluation of additional times using standard values

5.2.1.1 - Line sections

The background criteria required for accurately estimating additional time are based on the operating characteristics of existing timetables and respective delays. However, extrapolating the appropriate information may be very time-consuming or indeed impossible. In such cases, standard *Occupancy Time Rates* have been classified according to principal timetable characteristics and acceptable quality of services. The *Occupancy Time Rate* is the proportion of the occupancy time over the defined time period.

$$\text{Occupancy Time Rate [\%]} = \frac{\text{Occupancy Time}}{\text{Defined Time Period}} \times 100$$

The following tables provide a general summary indication of occupancy time rates and additional time rates according to the main timetable characteristics. These values should be used when applying the compression method.

Table 1 : Proposed occupancy time rates

Type of line	**Peak hour**	**Daily period**
Dedicated suburban passenger traffic	85 %	70 %
Dedicated high-speed line	75 %	60 %
Mixed-traffic lines	75 %	60 %

Derived from Table 1 - page 29, using equation below, in the following Table 2 provides time rates to be added to the occupancy time to achieve an acceptable quality of service.

$$\text{Additional Time Rate [\%]} = \left[\frac{100}{\text{Occupancy Time Rate}} - 1\right] \times 100$$

Table 2 : Proposed additional time rates for lines

Type of line	Peak hour	Daily period
Dedicated suburban passenger traffic	18 %	43 %
Dedicated high-speed line	33 %	67 %
Mixed-traffic lines	33 %	67 %

5.2.1.2 - Nodes

For switch areas and track areas there is little empirical data concerning appropriate occupancy time rates. These values must thus be confirmed by calculation before they are applied universally. Calculations therefore need to be performed and track occupation graphs drawn. These are then to be considered critical in determining the usability of the infrastructure for the accompanying timetable.

The following limit values are proposed:

Table 3 : Proposed occupancy rates and additional time rates for nodes

Type of node area	Concatenated Occupancy Rate	Additional Time Rate
Switch area	60 % … 80 %	67 % … 25 %
Track area	40 % … 50 %	150 % … 100 %

5.2.1.3 - General criteria

From the foregoing, the capacity consumption values can be calculated as follows:

$$\text{Capacity Consumption [\%]} = \frac{\text{Occupancy Time} \times (1 + \text{Additional Time Rate})}{\text{Defined Time Period}} \times 100$$

In order for capacity consumption values to best represent the corresponding infrastructure, the following conditions can be used as a guideline:

- The capacity consumption values reflect the infrastructure characteristics of the defined train path line sections.
- The line section with the highest capacity consumption value along the train path line section is the representative line section for the train path line section.
- Acceptable quality of service is represented by capacity consumption values of up to and including 100 %.

- Capacity consumption values beyond 100 % represent a bottleneck, which means a lower quality of service, and should be subject to timetable or infrastructure improvement measures.

- Capacity consumption values below 100 % represent available capacity and thus the potential for additional train paths along the defined train path line section.

The additional time values used in this leaflet are intended to reflect the required quality of service. The preferred solution for adding times is to insert them at the corresponding position in the timetable (e.g. buffer times after every train path). If this distribution of times is not manageable, additional time has to be considered collectively as a block.

The following criteria can be used for evaluating additional times resulting from:

- Buffer times to mitigate the impact of delays and to guarantee an acceptable level of service,

- Planned shunting movements, coupling and uncoupling, crossing traffic (if not considered in the compression process),

- Infrastructure maintenance,

- Long-distance trains, which affect the capacity consumption of two or more adjacent line sections or train path line sections.

5.2.2 - Evaluation of additional times - special cases

5.2.2.1 - Evaluation of additional times for infrastructure maintenance work

The following approaches can be used:

- Maintenance work is classified into appropriate tasks and representative time windows for desired corridor segments and additional time for the purposes of calculating capacity consumption is determined accordingly.

- Scheduled maintenance work is already integrated into the timetable and used in the compression methodology to calculate capacity consumption.

The fixed maintenance time windows included in the timetable must be taken into account when performing the timetable compression. Fig. 36 - page 32 illustrates an example of scheduled maintenance (e.g. tamping) between interlockings D and F.

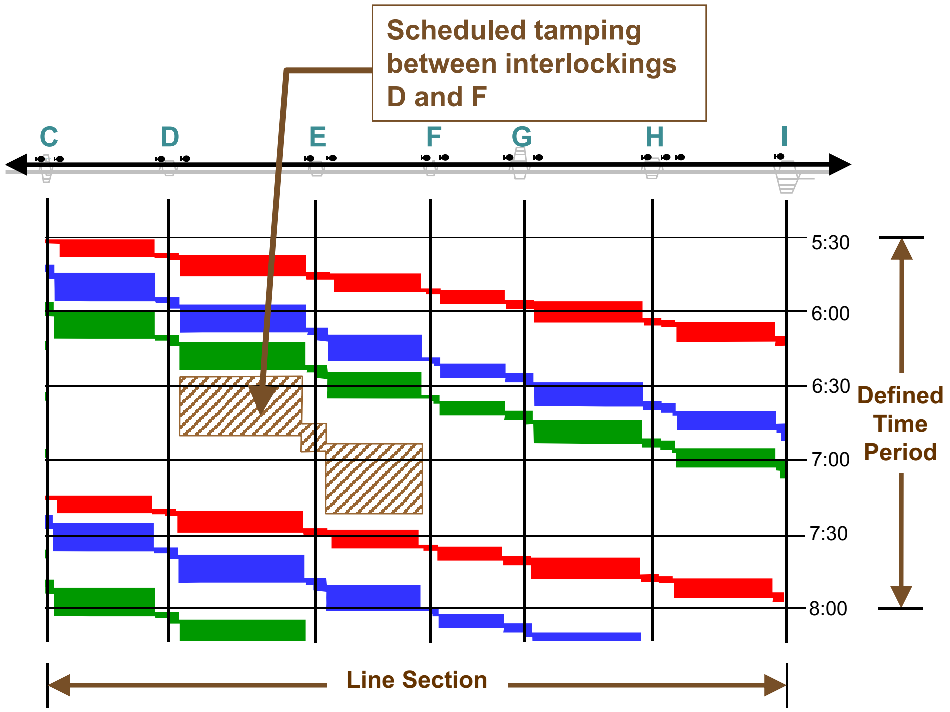

Fig. 36 - Timetable including scheduled maintenance before compression

During the compression, the maintenance time window has to be considered as a block and cannot be compressed. That means it has to be treated like a train path (see Fig. 37).

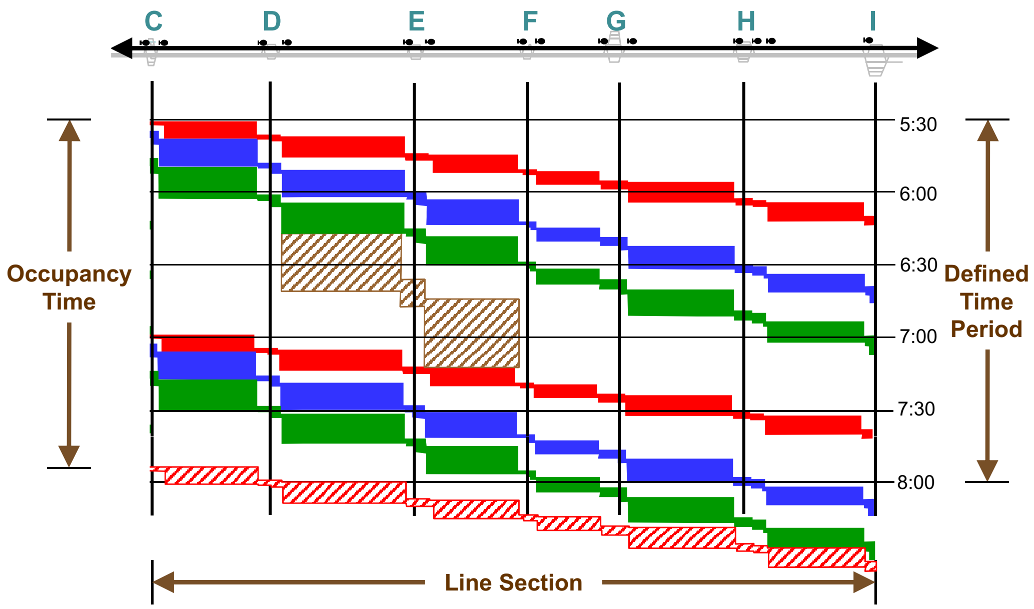

Fig. 37 - Timetable including scheduled maintenance after compression

5.2.2.2 - Evaluation of additional times for long-distance traffic

Other reasons for additional times are different requirements for long and short-distance traffic. Timetable changes and/or overtaking stations alone are sometimes not sufficient as criteria for determining line sections. In some cases it is thus necessary to assess the contradictory influences of different train services on capacity consumption on more than just one line section. The occupancy time can be illustrated in the following example for both short-distance and long-distance trains using the compression methodology (see Fig. 38).

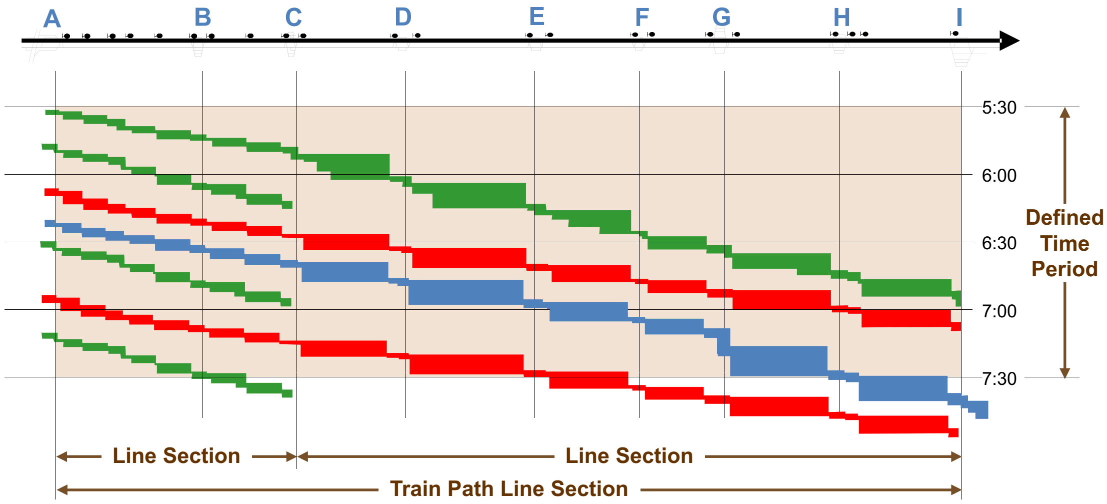

Fig. 38 - Timetable before compression

To evaluate the capacity consumption of each line section, there are two alternative options:

1. Overlapping of train paths outside the compressed line section is permitted (see Fig. 39). This assumes that new overtakings must take place within the train path line section, which then leads to altered train paths in this section. This introduction of additional overtakings contradicts the basic idea of the compression approach, namely to compress train paths without changing the timetable structure. To evaluate the capacity consumption, it is necessary to provide additional time indications, the value of which has to be calculated as a function of various parameters (e.g. distance between overtaking stations, velocity discrepancies - scissor effect).

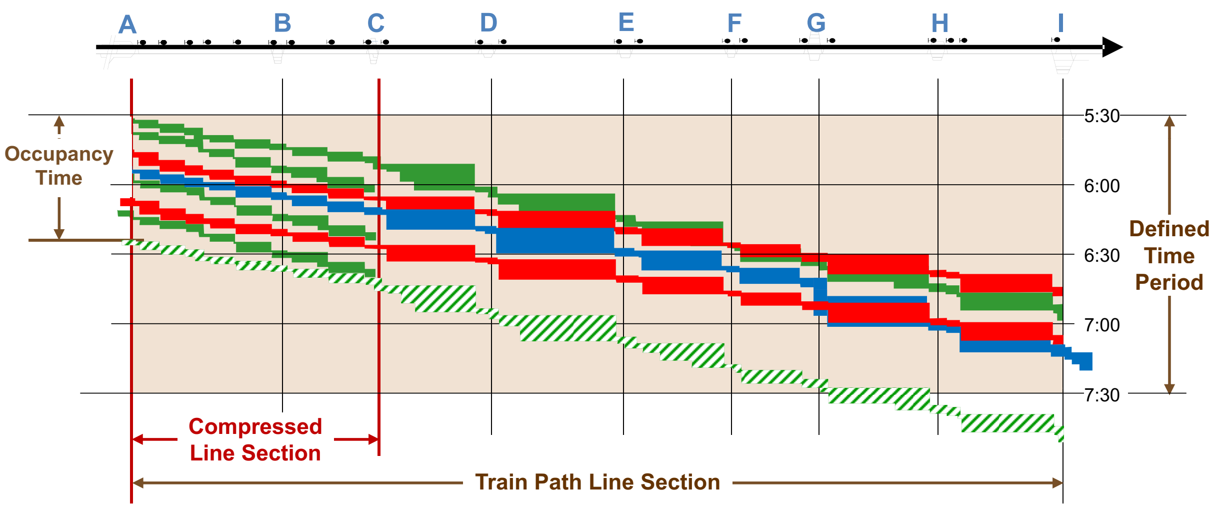

Fig. 39 - Compression of a short-distance train´s section

2. For long-distance trains, compression has to be performed for the entire train path line section (see Fig. 40). The timetable structure remains unchanged up to the adjacent major nodes at which higher-level trains may also be overtaken. The capacity consumption is evaluated using the occupancy time of the train path line section resulting by the trains using the line section.

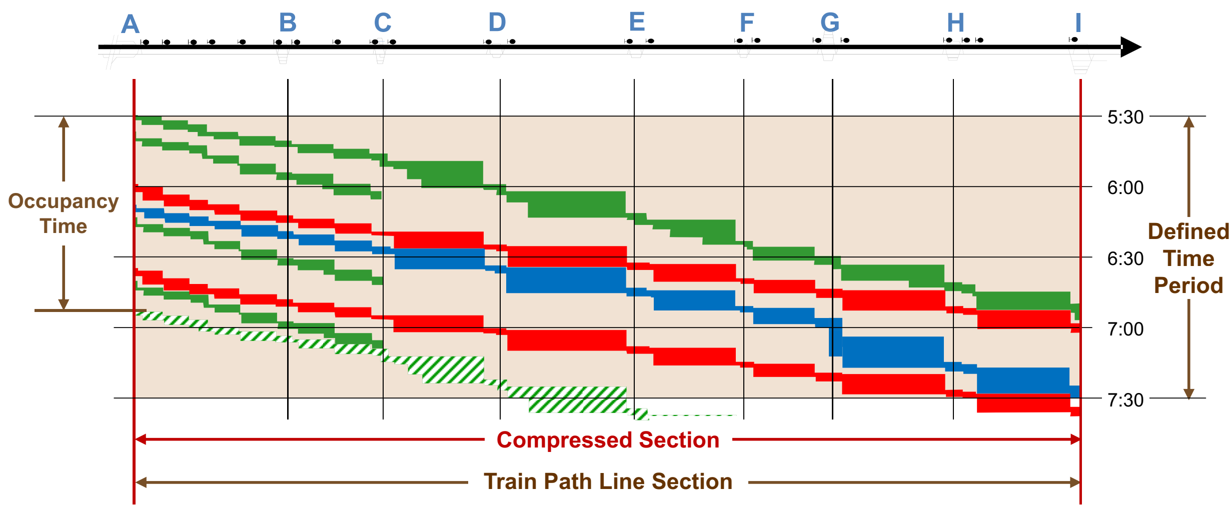

Fig. 40 - Compression of a long-distance train´s entire section

This solution makes it possible to obtain information on capacity utilisation on existing infrastructure and on the timetable structure.

5.3 - Evaluating available capacity (Step 5)

5.3.1 - General criteria

Using the capacity consumption results, the corresponding train path line section with values less than 100 % is subject to additional available capacity. Available capacity is the amount of additional potential activity available within a timetable, defined over a train path line section and time period.

This chapter aids decision-making with the following guidelines and conditions:

1. **General parameter for available capacity**
The general parameter measuring the available capacity for a train path line section is the number of additional train paths which can be inserted into a timetable.

2. **Establishing representative trains to fill available capacity**
Train consists and their dynamic behaviour can have significant impacts on the outcome of the available capacity evaluation. In order to simplify the assessment of a wide spectrum of train consists, an average representative train consist is constructed for each type of train service i.e. commuter trains, regional passenger trains, freight trains, etc.

3. **Establishing the travel times of representative trains**
Filling additional capacity by inserting train paths in a timetable with a representative train increases its traffic density, which may lead to lengthy stops to avoid conflicts. The resulting travel times may be significantly greater than that normally travelled by the representative train and may no longer be marketable. The limit of extensions to the travel time of the representative train can be defined as a percentage value of its original travel time. The limit value for the travel time extension can be defined for various categories of train paths individually (e.g. close to 0 % for passenger train paths).

For example:

Travel time normally travelled by representative train:	2 hours
Travel time extension limit:	50 % = 1 hour
Maximum travel time for additional representative trains:	3 hours

4. **Establishing intervals for inserting train paths**
Timetable structures with varying characteristics over a defined time period may have significant impacts on the intervals at which train paths are inserted.
This may be most apparent when evaluating available capacity over 24-hour periods with fluctuating train cycles during peak and off-peak periods.
In this case, the timetable can be divided into peak and off-peak time periods, where the inserted train paths reflect the chosen time period accordingly. Otherwise, establishing intervals (e.g. one inserted train path per hour) may best reflect 24-hour capacity.

5.3.2 - Evaluating available capacity using capacity consumption rates

Evaluating available capacity covers a broad spectrum of different railway markets. This enables a spectrum of available train paths to be drawn on in order to fulfil the potential market demand.

When the capacity consumption rate is less than 100 %, the appropriate defined train paths are to be inserted as additional train paths. The capacity consumption is re-evaluated after each successful train path insertion until the capacity consumption value approaches or equals 100 %. If a train path cannot be successfully inserted without conflicts or without extending its travel time beyond its specified limits, the evaluation is complete.

This analysis should also include assessment of switch and track areas within junctions and stations and nodes.

To simplify evaluation of the available capacity with capacity consumption rates, the following workflow process can be used as a guideline (see Fig. 41 - page 36).

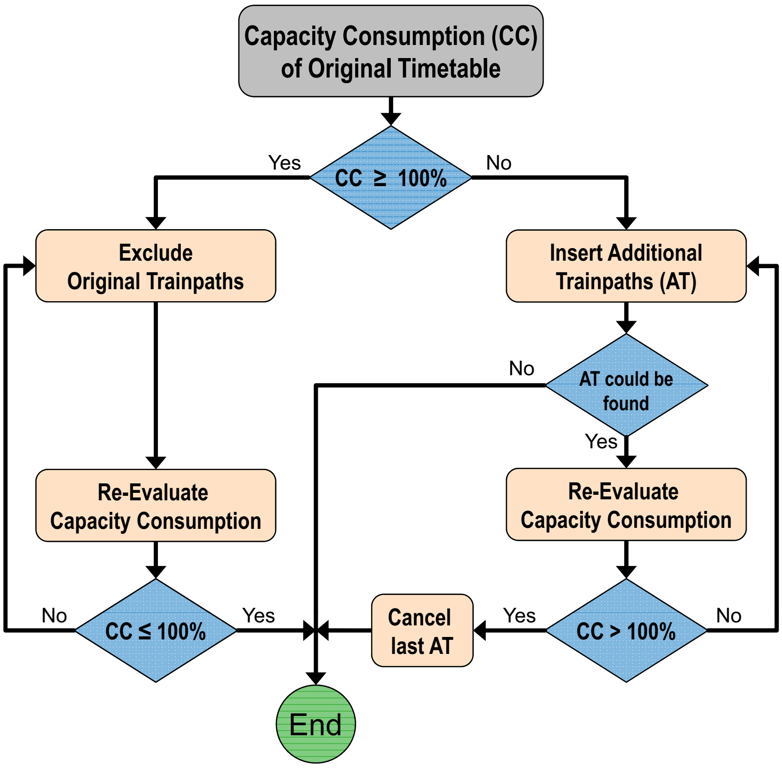

Fig. 41 - Determining capacity (train paths) - workflow process

Possible approach
In the following possible approach, the first step is to evaluate long-distance traffic and the second short-distance traffic. Other approaches are also possible according to the purpose of the analysis.

First step - evaluating long-distance through-services
The first step towards evaluating available capacity using capacity consumption rates is to accommodate the need for long-distance trains.

To this end, the following conditions can be used as a guideline:

- Long-distance freight services are generally appropriate for evaluating available capacity due to their nature (planned at short notice).
- Long-distance passenger services are planned annually and are built into the annual timetable structure, thus posing little need to evaluate interim available capacity.
- Long-distance services should be evaluated according to market demand.

Second step - evaluating short-distance services
Once available capacity has been evaluated and the train paths are adjusted accordingly, short-distance services can be evaluated in the same manner. Similarly, the resulting values can be used for decisions accommodating demand for short distance services (i.e. regional demand for commuter services or individual demand for local freight activities and individual train movements servicing private companies).

5.3.3 - Evaluating available capacity - example

Fig. 42 illustrates a defined train path line section with capacity consumption values. A critical line section occurs between interlockings A and C (83 %). The other line section C - D is 60 % before evaluating available capacity.

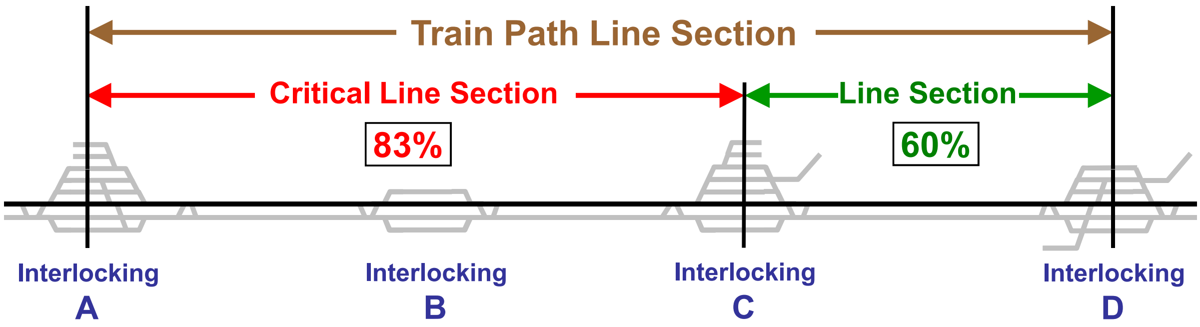

Fig. 42 - Capacity consumption on a train path line section

After inserting train paths - long-distance services
After inserting additional train paths for long-distance services (e.g. six additional long-distance freight trains), the capacity consumption rates increase from 83 % to 93 % and from 60 % to 72 % (see Fig. 43), but do not approach 100 % because further additional long-distance train paths could not be inserted without going beyond the agreed travel time limit.

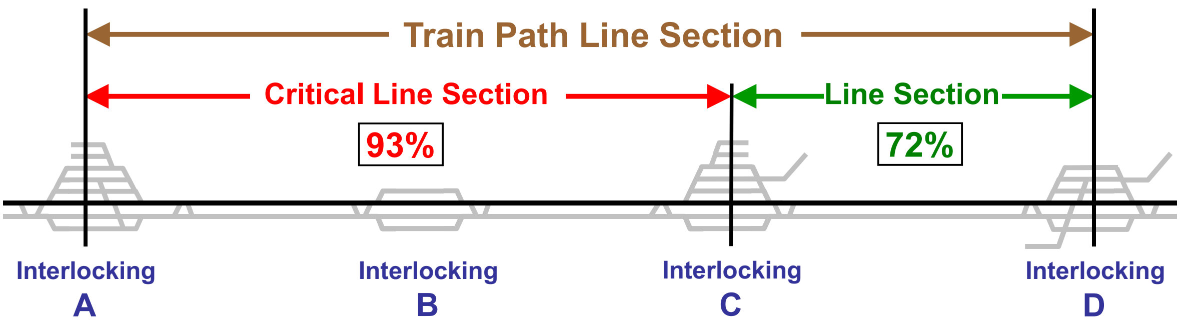

Fig. 43 - Capacity consumption after inserting additional long-distance-train paths

After inserting train paths - short-distance services
After inserting additional train paths for short-distance services (20 additional regional trains C to D, i.e. one additional passenger service per hour), the capacity consumption increases from 72 % to 95 % (see Fig. 44 - page 38).

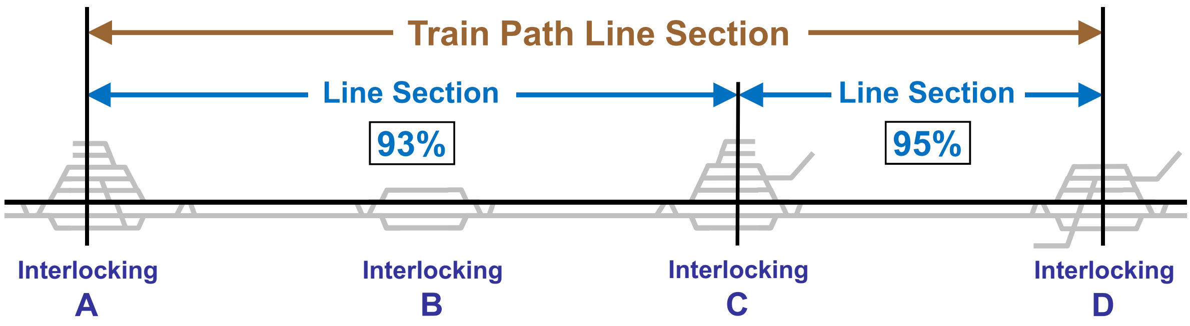

Fig. 44 - Capacity consumption after inserting additional short-distance-train paths

The results of this evaluation of available capacity are six additional freight trains A to D and 20 additional regional trains C to D.

The resulting unused capacity in this case study is 7 % from A to C and 5 % from C to D after adding long-distance and short-distance services.

Appendix A - Compression of a node

A.1 - Compression of a switch area - practical procedure

As already mentioned in point 4.6.2 - page 26 the compression of a switch area can be carried out by a simple procedure on a sheet of paper or with a calculation-software. DB-Netz has provided an example[1], which is shown on the following pages:

The switch area shown in below:

- has no waiting positions,
- contains possible parallel routes.

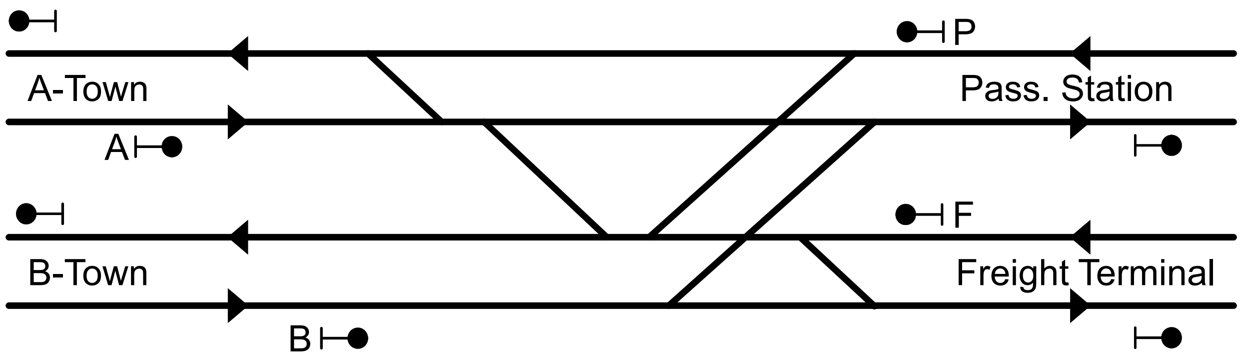

Fig. 45 - Layout of a switch area to be investigated

The train movements have been marked following the scheme (examples):

- pA: from signal P (in Pbf) to A-Town,
- aP: from signal A (in A-Town) to Pbf.

1. Skript Eisenbahnbetrieb (TU Darmstadt 2006).

First needed minimum time ranges have to be defined, in which a considered train movement is excluded by another movement.

Table 4: Minimum follow-up-times between the possible routes of a switch area

		Excluded Trip k							
		pA	pB	aP	aF	fB	fA	bF	bP
Actual Trip i	pA	1,7	1,4				1,7		
	pB	1,4	1,7	1,4	1,4	1,7	1,4		
	aP		1,5	1,8	1,3		1,3		1,8
	aF		2,4	2,2	2,9	2,4	2,4	2,9	2,4
	fB		2,4		2,0	2,4	2,0		2,0
	fA	2,4	2,0	2,1	2,1	2,0	2,4		2,0
	bF				2,3			2,3	1,7
	bP			1,8	1,5	1,5	1,5	1,5	1,8

For example route aF may not start earlier than 1,3 minutes after the start of route aP.

An additional input is the sequence of routes as shown in the timetable. The timetable in Table 5 shows the passing of trains at the signal (minute values). Parallel routes may be used for pA and fB at minute 6.

Table 5 : Timetable for the sequence of routes during one hour period

min	03	06	06	09	09	12	15	18	21	24	27	27
route	pB	pA	fB	pA	fB	pA	bP	aP	fA	fB	aP	fB

min	33	33	36	39	42	45	48	51	51	54	54	57
route	pA	bF	bF	aF	pA	pB	aP	aP	bF	aP	bF	bP

Knowing the sequence of routes, a train path occupation plan of concatenated routes is feasible. An occupancy time value can be calculated using the following procedure:

Rules:

- Each route-occupation starts, considering the sequence of trains, as soon as possible after the preceding route regarding the referring exclusion time.
- Buffer times are not included.
- The total of all occupation times results as the sum of the excluding times of concatenated routes.
- Possible simultaneous train movements on parallel routes will be considered.

Workflow of a manual calculation:

1. Preparation of a calculation sheet (number of columns = number of different appearing routes + 2; number of lines = number of train movements within the defined time period + 1 (repetition of first train movement at the end) + 2).
2. Begin of occupation of the first train = 0,0.
3. Fill in the excluding times with regard to Table 4 - page 40 (see Fig. 46).

Trip	Begin of occupation	End of Occupation-/Exclusion							
		pA	pB	aP	aF	fB	fA	bF	bP
pB	0,0	1,4	1,7	1,4	1,4	1,7	1,4	*	*
pA									
fB									
pA									
fB									
pA									
bP									
aP									

Fig. 46 - Fill in calculation sheet - step 1

4. Begin of occupation for the next route = value of above field (0,0) + referring exclusion value of according column of above row (1,4).
5. Calculate the end of occupation by summarising the values from the above line and the according values of Table 4.
6. For fields marked with an * in Fig. 46: fill in the above value of the same column (see Fig. 47 - page 42).
7. If the value of the line above is higher than the actual value: overwrite with the higher value (see Fig. 51 - page 43).

Trip	Begin of occupation	End of Occupation-/Exclusion							
		pA	pB	aP	aF	fB	fA	bF	bP
pB	0,0	1,4	1,7	1,4	1,4	1,7	1,4	* / 0	* / 0
pA	1,4	1,4+1,7= 3,1	1,4+1,4= 2,8	* / 1,4	* / 1,4	* / 1,7	1,4+1,7= 3,1	* / 0	* / 0
fB									
pA									
fB									
pA									
bP									
aP									

Fig. 47 - Fill in calculation sheet - step 2

8. Repeat 4 - 7 until the end of the working sheet (see Fig. 48 to Fig. 53 - page 44)

Trip	Begin of occupation	End of Occupation-/Exclusion							
		pA	pB	aP	aF	fB	fA	bF	bP
pB	0,0	1,4	1,7	1,4	1,4	1,7	1,4	* / 0	* / 0
pA	1,4	1,4+1,7= 3,1	1,4+1,4= 2,8	* / 1,4	* / 1,4	* / 1,7	1,4+1,7= 3,1	* / 0	* / 0
fB	1,7	* / 3,1	1,7+2,4= 4,1	* / 1,4	1,7+2,0= 3,7	1,7+2,4= 4,1	1,7+2,0= 3,7	* / 0	1,7+2,0= 3,7
pA									
fB									
pA									
bP									
aP									

Fig. 48 - Fill in calculation sheet - repeating step 2

Trip	Begin of occupation	End of Occupation-/Exclusion							
		pA	pB	aP	aF	fB	fA	bF	bP
pB	0,0	1,4	1,7	1,4	1,4	1,7	1,4	* / 0	* / 0
pA	1,4	1,4+1,7= 3,1	1,4+1,4= 2,8	* / 1,4	* / 1,4	* / 1,7	1,4+1,7= 3,1	* / 0	* / 0
fB	1,7	* / 3,1	1,7+2,4= 4,1	* / 1,4	1,7+2,0= 3,7	1,7+2,4= 4,1	1,7+2,0= 3,7	* / 0	1,7+2,0= 3,7
pA	3,1	3,1+1,7= 4,8	3,1+1,4= 5,5	* / 1,4	* / 3,7	* / 4,1	3,1+1,7= 4,8	* / 0	* / 3,7
fB									
pA									
bP									
aP									

Fig. 49 - Fill in calculation sheet - repeating step 2

Trip	Begin of occupation	End of Occupation-/Exclusion							
		pA	pB	aP	aF	fB	fA	bF	bP
pB	0,0	1,4	1,7	1,4	1,4	1,7	1,4	* / 0	* / 0
pA	1,4	1,4+1,7= 3,1	1,4+1,4= 2,8	* / 1,4	* / 1,4	* / 1,7	1,4+1,7= 3,1	* / 0	* / 0
fB	1,7	* / 3,1	1,7+2,4= 4,1	* / 1,4	1,7+2,0= 3,7	1,7+2,4= 4,1	1,7+2,0= 3,7	* / 0	1,7+2,0= 3,7
pA	3,1	3,1+1,7= 4,8	3,1+1,4= 5,5	* / 1,4	* / 3,7	* / 4,1	3,1+1,7= 4,8	* / 0	* / 3,7
fB	4,1	* / 4,8	4,1+2,4= 6,5	* / 1,4	4,1+2,0= 6,1	4,1+2,4= 6,5	4,1+2,0= 6,1	* / 0	4,1+2,0= 6,1
pA									
bP									
aP									

Fig. 50 - Fill in calculation sheet - repeating step 2

Trip	Begin of occupation	End of Occupation-/Exclusion							
		pA	pB	aP	aF	fB	fA	bF	bP
pB	0,0	1,4	1,7	1,4	1,4	1,7	1,4	* / 0	* / 0
pA	1,4	1,4+1,7= 3,1	1,4+1,4= 2,8	* /1,4	* / 1,4	* / 1,7	1,4+1,7= 3,1	* / 0	* / 0
fB	1,7	* / 3,1	1,7+2,4= 4,1	* /1,4	1,7+2,0= 3,7	1,7+2,4= 4,1	1,7+2,0= 3,7	* / 0	1,7+2,0= 3,7
pA	3,1	3,1+1,7= 4,8	3,1+1,4= 5,5	* /1,4	* / 3,7	* / 4,1	3,1+1,7= 4,8	* / 0	* / 3,7
fB	4,1	* / 4,8	4,1+2,4= 6,5	* /1,4	4,1+2,0= 6,1	4,1+2,4= 6,5	4,1+2,0= 6,1	* / 0	4,1+2,0= 6,1
pA	4,8	4,8+1,7= 6,5	4,8+1,4= ~~6,2~~ 6,5	* /1,4	* / 6,1	* / 6,5	4,8+1,7= 6,5	* / 0	* / 6,1
bP									
aP									

Fig. 51 - Fill in calculation sheet - repeating step 2

Trip	Begin of occupation	End of Occupation-/Exclusion							
		pA	**pB**	**aP**	**aF**	**fB**	**fA**	**bF**	**bP**
pB	**0,0**	**1,4**	**1,7**	**1,4**	**1,4**	**1,7**	**1,4**	*** / 0**	*** / 0**
pA	**1,4**	1,4+1,7= **3,1**	1,4+1,4= **2,8**	* / 1,4	* / 1,4	* / 1,7	1,4+1,7= **3,1**	* / 0	* / 0
fB	**1,7**	* / 3,1	1,7+2,4= **4,1**	* / 1,4	1,7+2,0= **3,7**	1,7+2,4= **4,1**	1,7+2,0= **3,7**	* / 0	1,7+2,0= **3,7**
pA	**3,1**	3,1+1,7= **4,8**	3,1+1,4= **5,5**	* / 1,4	* /3,7	* / 4,1	3,1+1,7= **4,8**	* / 0	* / 3,7
fB	**4,1**	* /4,8	4,1+2,4= **6,5**	* / 1,4	4,1+2,0= **6,1**	4,1+2,4= **6,5**	4,1+2,0= **6,1**	* / 0	4,1+2,0= **6,1**
pA	**4,8**	4,8+1,7= **6,5**	4,8+1,4= ~~6,2~~ 6,5	* / 1,4	* / 6,1	* / 6,5	4,8+1,7= **6,5**	* / 0	* / 6,1
bP	**6,1**	* /6,5	* / 6,5	6,1+1,8= **7,9**	6,1+1,5= **7,6**	6,1+1,5= **7,6**	6,1+1,5= **7,6**	6,1+1,5= **7,6**	6,1+1,8= **7,9**
aP									

Fig. 52 - Fill in calculation sheet - repeating step 2

Trip	Begin of occupation	End of Occupation-/Exclusion							
		pA	**pB**	**aP**	**aF**	**fB**	**fA**	**bF**	**bP**
pB	**0,0**	**1,4**	**1,7**	**1,4**	**1,4**	**1,7**	**1,4**	*** / 0**	*** / 0**
pA	**1,4**	1,4+1,7= **3,1**	1,4+1,4= **2,8**	* / 1,4	* / 1,4	* / 1,4	1,4+1,7= **3,1**	* / 0	* / 0
fB	**1,7**	* / 3,1	1,7+2,4= **4,1**	* / 1,4	1,7+2,0= **3,7**	1,7+2,4= **4,1**	1,7+2,0= **3,7**	* / 0	1,7+2,0= **3,7**
pA	**3,1**	3,1+1,7= **4,8**	3,1+1,4= **5,5**	* / 1,4	* / 3,7	* / 4,1	3,1+1,7= **4,8**	* / 0	* / 3,7
fB	**4,1**	* / 4,8	4,1+2,4= **6,5**	* / 1,4	4,1+2,0= **6,1**	4,1+2,4= **6,5**	4,1+2,0= **6,1**	* / 0	4,1+2,0= **6,1**
pA	**4,8**	4,8+1,7= **6,5**	4,8+1,4= ~~6,2~~ 6,5	* / 1,4	* / 6,1	* / 6,5	4,8+1,7= **6,5**	* / 0	* / 6,1
bP	**6,1**	* / 6,5	* / 6,5	6,1+1,8= **7,9**	6,1+1,5= **7,6**	6,1+1,5= **7,6**	6,1+1,5= **7,6**	6,1+1,5= **7,6**	6,1+1,8= **7,9**
aP	**7,9**	* / 6,5	7,9+1,5= **9,4**	7,9+1,8= **9,7**	7,9+1,3= **9,2**	* / 7,6	7,9+1,3= **9,2**	* / 7,6	7,9+1,8= **9,7**

Fig. 53 - Fill in calculation sheet and pursuing backwards

Calculation of the compression value and the number of concatenations:

- In Table 6 - page 45 the pathways leading to the according start times of the trips are shown in the same colour. Only the red one leads down to the last trip of the timetable.

- For the calculation of the compression value it is proposed to insert the first trip at the bottom of the calculation table again (last trip). Hence there is no "open end".

- If the repetition of the first trip is not excluded by the last trip of the defined time period, the second or even the third trip has to be added. Calculating the exclusion values (displayed in light grey) however is not necessary anymore.

- Assuming the start of an additional trip 26,3 minutes after starting the first trip and regarding 60 minutes evaluation time, the compression value (occupancy time rate) equals:

$$\text{OTR (Occupancy Time Rate)} = \frac{26,3}{60,0} \times 100 = 43,8\ \%$$

Table 6 : Complete calculation table for example above

Trip/ Route	Begin of Occupation	End of Occupation/Exclusion							
		pA	pB	aP	aF	fB	fA	bF	bP
pB	0,0	1,4	1,7	1,4	1,4	1,7	1,4	*	*
pA	1,4	3,1	2,8	*	*	*	3,1	*	*
fB	1,7	*	4,1	*	3,7	4,1	3,7	*	3,7
pA	3,1	4,8	4,5	*	*	*	4,8	*	*
fB	4,1	*	6,5	*	6,1	6,5	6,1	*	6,1
pA	4,8	6,5	(6,2)	*	*	*	6,5	*	*
bP	6,1	*	*	7,9	7,6	7,6	7,6	7,6	7,9
aP	7,9	*	9,4	9,7	9,2	*	9,2	*	9,7
fA	9,2	11,6	11,2	11,3	11,3	11,2	11,6	*	11,2
fB	11,2	*	13,6	*	13,2	13,6	13,2	*	13,2
aP	11,3	*	(12,8)	13,1	(12,6)	*	(12,6)	*	(13,1)
fB	13,6	*	16,0	*	15,6	16,0	15,6	*	15,6
pA	11,6	13,3	(13,0)	*	*	*	(13,3)	*	*
bF	7,6	*	*	*	(9,9)	*	*	9,9	(9,3)
bF	9,9	*	*	*	(12,2)	*	*	12,2	(11,6)
aF	15,6	*	18,0	17,8	18,5	18,0	18,0	18,5	18,0
pA	13,3	15,0	(14,7)	*	*	*	(15,0)	*	*
pB	18,0	19,4	19,7	19,4	19,4	19,4	19,4	*	*
aP	19,4	*	20,9	21,2	20,7	*	20,7	*	21,2
aP	21,2	*	22,7	23,0	22,5	*	22,5	*	23,0
bF	18,5	*	*	*	(20,8)	*	*	20,8	(20,2)
aP	23,0	*	24,5	24,8	24,3	*	24,3	*	24,8
bF	20,8	*	*	*	(23,1)	*	*	23,1	(22,5)
bP	24,8	*	*	26,6	26,3	26,3	26,3	26,3	26,6
(pB)	24,5	25,7	26,2	(25,9)	(25,9)	(26,2)	(25,9)	*	*
(pA)	19,4	27,6	27,3	*	*	*	27,6	*	*
(fB)	26,3	*	28,7	*	28,3	28,7	28,3	*	28,3

- Furthermore the number of concatenations K and the concatenation value φ can be calculated.

  - The number of concatenations can be obtained by pursuing the starting points (earliest possible start based on relevant excluding ending times) backwards from the latest begin of occupation until the first begin of occupation (see Table 7 - page 46). The coloured cells show different possible branches originating from the three annexed trips; they all merge to the pathway of black cells.
  - In the case that this backward pursuance of concatenations does not merge with the first trip, additional trips have to be annexed at the bottom of the sheet.

- The number of concatenations in our example equals K = 14 regarding Z = 24 trips.

- Hence the concatenation rate equals:

$$\varphi(\text{Concatenation Rate}) = \frac{K}{Z} = \frac{14}{24} \times 100 = 58{,}3\ \%$$

Table 7 : Finding the number of concatenations

Trip/ Route	Begin of Occupation	End of Occupation/Exclusion							
		pA	pB	aP	aF	fB	fA	bF	bP
pB	0,0	1,4	1,7	1,4	1,4	1,7	1,4	*	*
pA	1,4	3,1	2,8	*		*	3,1	*	*
fB	1,7	*	4,1	*	3,7	4,1	3,7	*	3,7
pA	3,1	4,8	4,5	*	*	*	4,8	*	*
fB	4,1	*	6,5	*	6,1	6,5	6,1	*	6,1
pA	4,8	6,5	(6,2)	*	*	*	6,5	*	*
bP	6,1	*	*	7,9	7,6	7,6	7,6	7,6	7,9
aP	7,9	*	9,4	9,7	9,2	*	9,2	*	9,7
fA	9,2	11,6	11,2	11,3	11,3	11,2		*	11,2
fB	11,2	*	13,6	*	13,2	13,6	13,2	*	13,2
aP	11,3	*	(12,8)	13,1	(12,6)	*	(12,6)	*	(13,1)
fB	13,6	*	16,0	*	15,6	16,0	15,6	*	15,6
pA	11,6	13,3	(13,0)	*	*	*	(13,3)	*	*
bF	7,6	*	*	*	(9,9)	*	*	9,9	(9,3)
bF	9,9	*	*	*	(12,2)	*	*	12,2	(11,6)
aF	15,6	*	18,0	17,8	18,5	18,0	18,0	18,5	18,0
pA	13,3	15,0	(14,7)	*	*	*	(15,0)	*	*
pB	18,0	19,4	[illegible]	19,4	19,4	19,4	19,4	*	*
aP	19,4	*	20,9	21,2	20,7	*	20,7	*	21,2
aP	21,2	*	22,7	23,0	22,5	*	22,5	*	23,0
bF	18,5	*	*	*	(20,8)	*	*	20,8	(20,2)
aP	23,0	*	24,5	24,8	24,3	*	24,3	*	24,8
bF	20,8	*	*	*	(23,1)	*	*	23,1	(22,5)
bP	24,8	*	*	26,6	26,3	26,3	26,3	26,3	26,6
(pB)	24,5	25,7	26,2	(25,9)	(25,9)	(26,2)	(25,9)	*	*
(pA)	19,4	27,6	27,3	*	*	*	27,6	*	*
(fB)	26,3	*	28,7	*	28,3	28,7	28,3	*	28,3

A.2 - Compression of a bottleneck area

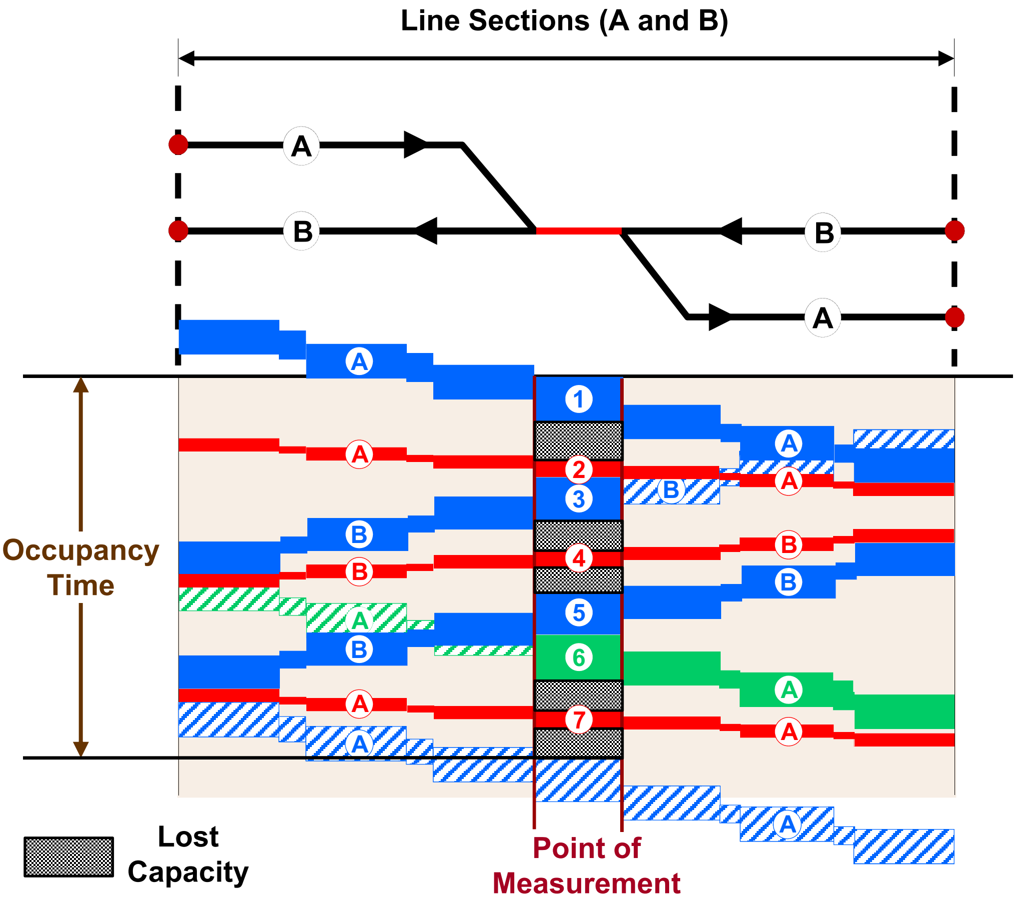

Fig. 54 - Timetable compression of a bottleneck area

Fig. 54: Timetable compression of a bottleneck area illustrates a representative example of a bottleneck between two defined train paths (A and B) with the compression of both corresponding line sections in the bottleneck area over during the defined time period. The point of measurement is at the entry and exit points of the bottleneck area occupied by trains from both train paths. Seven train paths are compressed in chronological order of their times entering the bottleneck area. The eighth train path is the repetition of the first as recommended in *UIC Leaflet 406*.

The above compression methodology is specific to bottlenecks and illustrates the disadvantages of heterogeneous timetables with variable travelling speeds by applying the definition of both train paths according to their points of passing. Fig. 54 also illustrates the results of such timetables by taking gaps between trains travelling at different speeds into consideration. These results are lost capacities that CANNOT be compensated for by any other related activities.

Appendix B - Defining sections for evaluation

B.1 - Passing on a double track line section

Fig. 55 illustrates a case example of a double track corridor planned for marketable train paths and includes the following critical points for potential passing:

- *Interlocking C*
  Potential passing between commuter & regional and long distance passenger trains

- *Interlocking G*
  Passing between long distance passenger & freight trains

- *Interlocking I*
  Potential passing between regional & long distance passenger trains

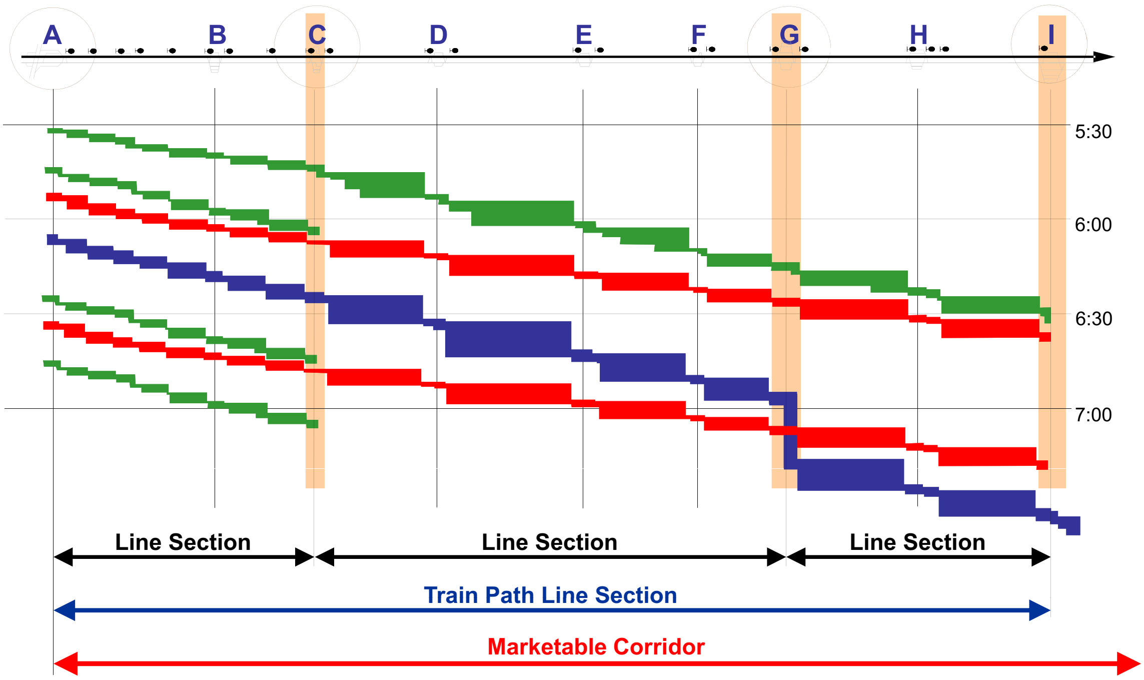

Fig. 55 - Train path line section divided by points of potential passing

In this case the train path line section starts at the beginning of the "marketable corridor" (Interlocking "A") with the option of choosing Interlocking "C", "G", or "I". Even though the section between interlocking A and C is most heavily travelled with additional commuter trains, the section between interlockings C and I has different infrastructure and operating characteristics, thus resulting in regional and freight trains travelling at much slower speeds than intercity passenger trains. Furthermore, intercity passenger trains include long distance international services, and its potential passing with freight and regional trains needs to be taken into consideration.

For the purposes of this leaflet, the train path line section is defined between interlockings "A" and "I". The resulting capacity consumption represents the most critical of both scenarios - higher traffic volumes between interlockings "A" and "C" and speed differences between interlockings "C" and "I".

Appendix C - Evaluating available Capacities

C.1 - Double track corridor section

Marketable train path corridors that reflect long-distance services may likely overlap when evaluating all train path line sections in a railway network. Fig. 56 illustrates overlapping train path line sections along two corridors.

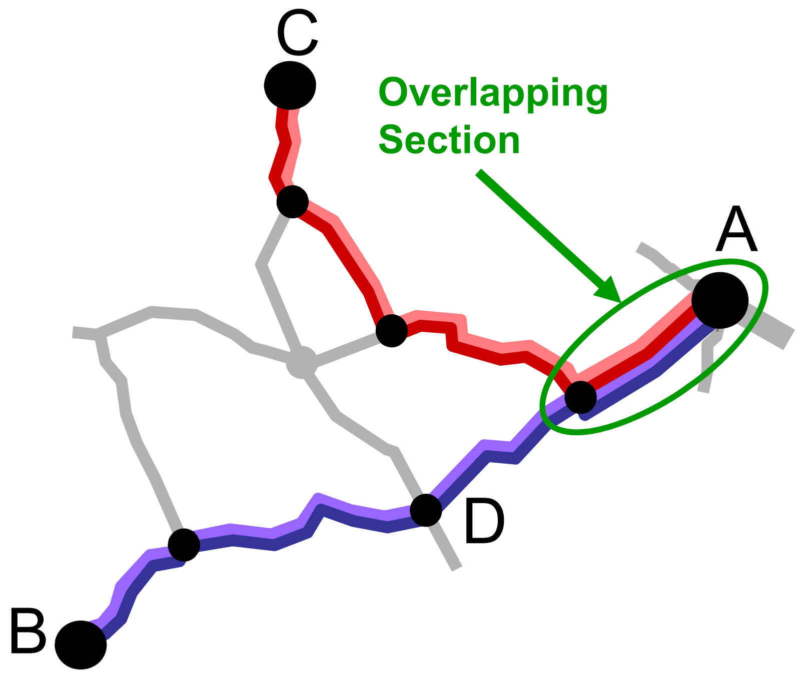

Fig. 56 - Overlapping train path line sections

In this case it is necessary to determine the proportion of additional train paths for each corridor. Additional train paths should be inserted alternating respectively regarding their proportion on the overlapping section.

C.2 - Evaluating capacity consumption values

Fig. 57 represents a train path line section over a double track section between interlockings A and B. The representative train path sections with the highest capacity consumptions vary by direction. From A to B the representative train path section is between interlockings A and W, and from B to A between interlockings B and W. Their respective capacity consumption values are 125 % and 102 %, thus presenting deteriorating levels of service with no room for additional train services. As a result, these sections are subject to timetable or infrastructure improvement measures.

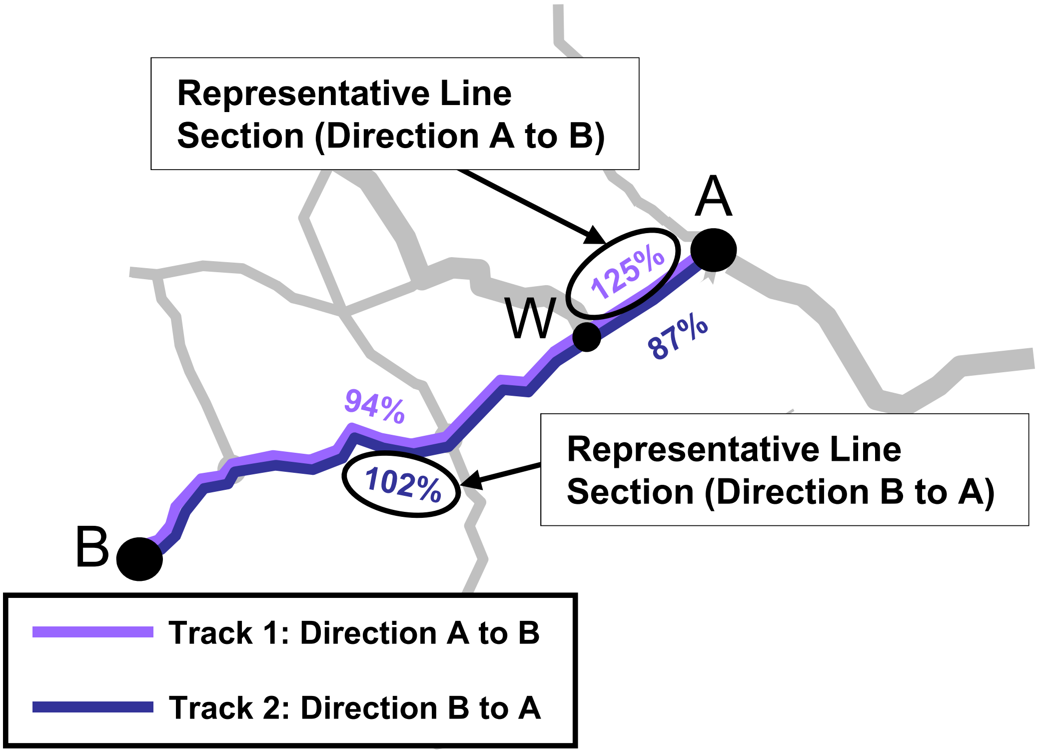

Fig. 57 - Different representative line sections on a double track line

C.3 - Classification of capacity consumption values

Capacity consumption values can illustrate the conditions of a railway network and respective available capacities. Fig. 58 shows the capacity consumption values of a representative day from a railway network's annual timetable. The capacity consumption values highlighted in red are over 100 % and represent a deteriorating level of service with no room for available capacities along defined marketable train path corridors. Values between 80 % and 100 % highlighted in yellow represent corridors with high capacity utilisations and little available capacity. The values less than 80 % are highlighted in green and represent corridors with lower capacity utilisation rates and sufficient amounts of capacity.

These three classifications of capacity utilisations can be used as a basis for decision making as follows:

Over 100 %	*- Timetable or infrastructure improvement measures required*
Between “X” and 100 %	*- Strategic planning to fulfil future market demands/ optimal utilisation of infrastructure*
Less than "X"	*- Planning of possible infrastructure service reductions*

For some reasons such maps can be interesting showing capacity consumption values for peak- or off-peak-hours since evaluation of a 24 hours period not always serves the market demand. Available train paths during the night hours may be interesting for long distance freight trains, but are not satisfying for commuter trains at all.

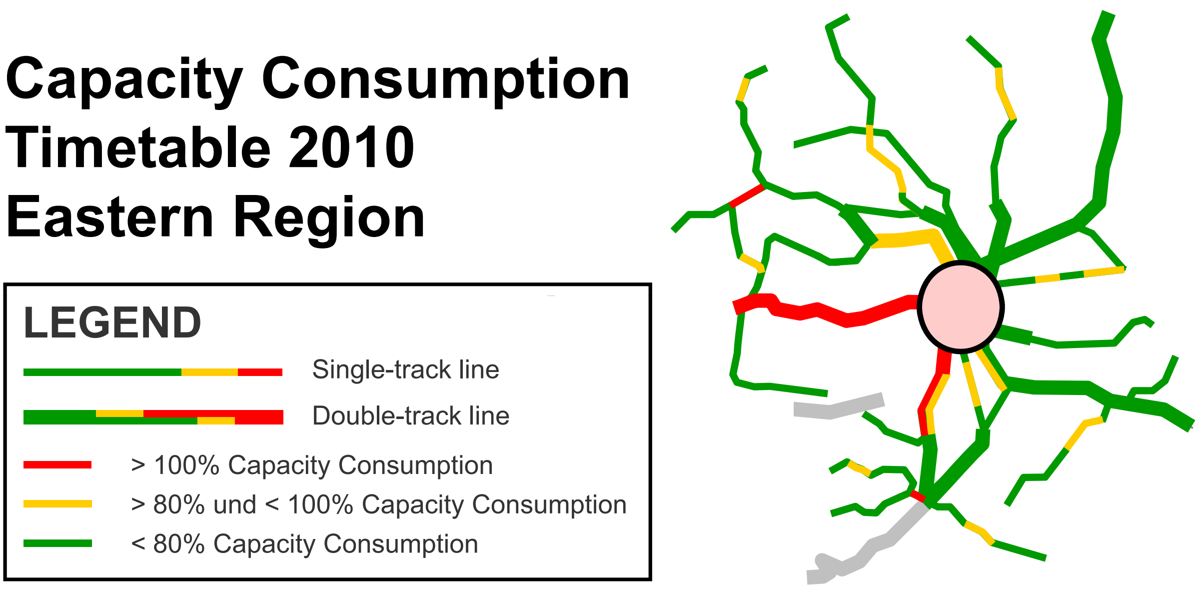

Fig. 58 - Network map classified by capacity consumption percentage values[1]

1. Capacity Calculations 2010 (OEBB Infrastruktur AG, Track & Operations Planning).

Warning

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