VIA
Consulting & Development

Influence of the European Train Control System (ETCS)

ON THE CAPACITY OF NODES

May 2010

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Influence of the European Train Control System ETCS on the capacity of nodes

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ABBREVIATIONS

DMI	Driver machine interface
EBD	Emergency brake deceleration curve
EBI	Emergency brake indication curve
EOA	End of movement authority
ERTMS	European rail traffic management system
ETCS	European train control system
FLOI	First Line of Intervention
IP	Indication point
IM	Infrastructure manager
s	Space
SBD	Service brake deceleration curve
SBI	Service brake intervention curve
SRN	Serial Route Node
SRS	System Requirement Specification
SvL	Supervised location
t	Time
TOC	Train operating company
UIC	International Union of Railways

Influence of the European Train Control System ETCS on the capacity of nodes

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1 Foreword

The effect of train operations using ETCS on capacity consumption is an important aspect in the justification and planning of ETCS implementation with adequate migration strategies. In the March 2008 study dealing with the capacity of lines, professor Wendler's expert team from the Institute of Transport Science (VIA) of RWTH Aachen University examined the influence of the various ETCS configurations based on typical "synthetic" models covering track and timetable configurations for high-speed, conventional mixed traffic and regional train services.

Since then the VIA Consulting & Development GmbH team has been tasked by UIC with developing a similar study on the influence of ETCS on the capacity of nodes. In the preparatory phase, it became clear that the "synthetic" model approach could not be used. Instead, it was agreed to analyse typical real examples of nodes with the corresponding track-layouts and programmes for train operation: the node of Munich (DB) as an example of a dead-end station and the node of Bern (SBB) as an example of a transiting station. The calculation of these cases, analysing the influence of numerous ETCS configuration parameters onboard and trackside, proved to be very challenging for the railways involved and the VIA experts. Enormous volumes of geographical and operational data had to be gathered and structured in a suitable manner. Advanced IT-tools were used for modelling and calculations whereby some of those tools were further developed and refined "on the job".

After completion of the work, at end of January 2010, the authors presented and discussed the results at a workshop with interested experts from several networks and railway companies. The reactions were unanimously positive and since then, some of the railway representatives have expressed their interest in additional bilateral studies. This and the previous report help to improve the understanding of the influence of ETCS on the capacity of lines and nodes and thus contribute to the optimal application of this new technology.

Peter Winter, ERTMS advisor at UIC

2 Summary

For the new standardised signalling system ETCS, common understanding of its effect on the capacity of lines and nodes is needed. Thereby the influence of various application parameters, such as application level, operational mode or the parameterisation of braking curves is of prime interest.

Previous line study

In 2007 the UIC commissioned a study by the Institute of Transport Science (VIA) of the RWTH Aachen University, which had already been responsible for the development of UIC Leaflet 406 “Capacity”. The study covered the investigation of the effects of ETCS on typical line infrastructures and led to ETCS-specific improvements in the calculation methodology of UIC Leaflet 406.

Contents of this study

In the current study the previously gained insight into capacity and operation quality has been extended to the application of ETCS in the context of complex junctions, namely Munich Hbf (Germany) and Bern HB (Switzerland). To demonstrate the practical influence of ETCS, different application configurations are considered. They cover Level 1 in limited supervision mode, Level 1, Level 2 and Level 3. Furthermore, the impact of (long) infill loops, shifted speed restrictions and shortened block sections is evaluated.

In Figure 1 the mean occupation ratios of the different application configurations are shown.

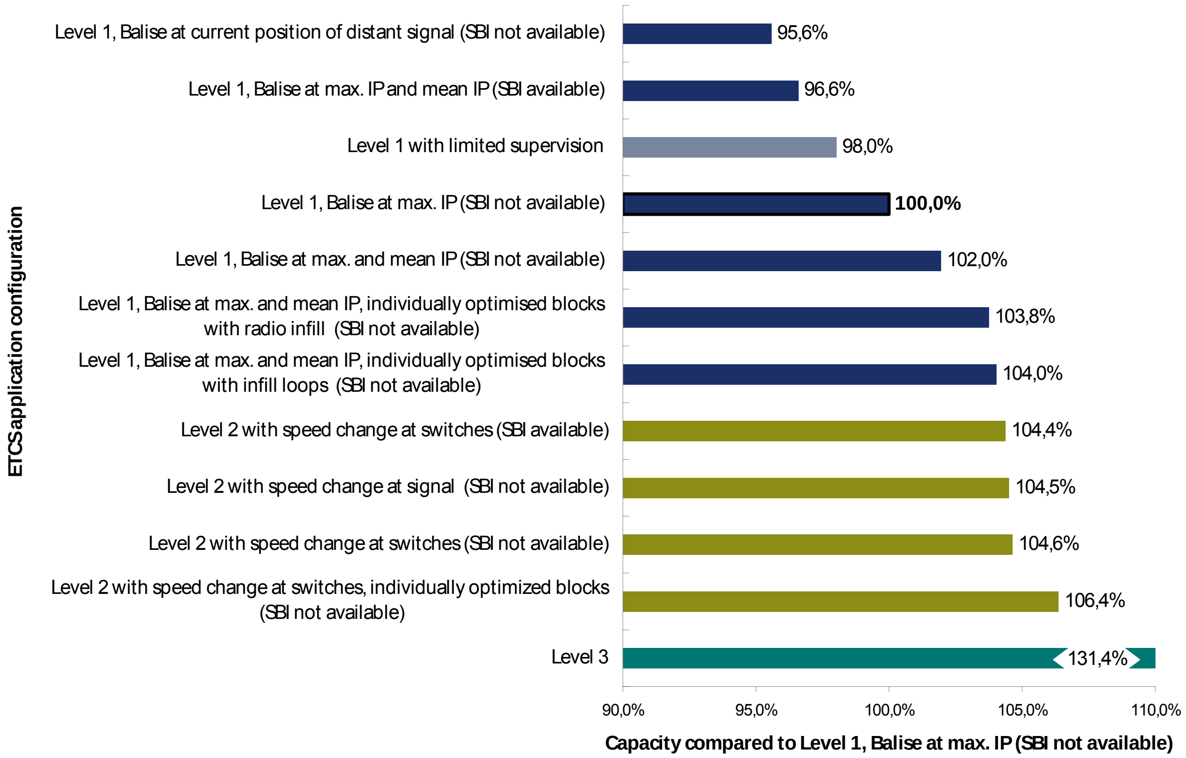


Figure 1 Overall occupation ratios (average values of both junctions)

When rating the impact on capacity of the different ETCS configurations it must be considered that the junctions examined only offer very small additional margins for further improvement. In general, optimisation has already been performed under current conditions.

ETCS Level 1

As already demonstrated in the previous analysis, the braking curve parameterisation affects capacity. The availability of service braking (SBI) in particular decreases the possible number of trains. If balise groups are located at the current distant signals, the “limited supervision” mode enables higher capacity than a pure ETCS Level 1 installation. The careful positioning of additional infill balises slightly reduces capacity consumption, because approaching times are reduced. In contrast, the capacitive effect of spot infill components enhancing movement authorities is negligible at the low speeds in junctions.

ETCS Level 2

The benefit to capacity of ETCS Level 2 relative to ETCS Level 1 in cases of similar and unchanged block sectioning is comparable to the effect on conventional lines, if Level 1 balise groups are located at distant signals and the distant signals may be separated from the main signals. In cases of strict combined signalling, the advantage of ETCS Level 2 might be more distinctive due to the longer approaching distance.

Moving speed changes

In both junctions the permitted speeds are lowered progressively when approaching the stopping position. Thus, moving the speed change to the switch does not significantly affect capacity in the junction area. Nonetheless, capacity is slightly increased on adjacent lines.

Shortening block sections

Exploiting the possibilities of shorter block sections by means of cab signalling, should however, be considered. Under certain conditions, locally restricted cab signalling provided by long loops within ETCS Level 1 can even exceed the effects of ETCS Level 2.

ETCS Level 3

ETCS Level 3 produces a notable increase in the possible number of trains, especially considering the extent of optimisation already in situ. On the other hand, the study reveals additional aspects in the constraints of the moving block approach in case of complex track layouts. The configuration is therefore less advantageous compared to pure lines but is still of interest.

Outlook: Transmission of optimised trajectories

To cover all aspects, it should be noted that one effect in terms of capacity and quality of ETCS Levels 2 and 3, which might be utilised in operations, has not yet been developed. The continuous communication channel offers an additional benefit, if it is used to transmit the results of semi-automatic conflict detection and solution to the trains (e.g. in terms of conflict-free running trajectories optimised for energy). The first results, based on a prototype transmission outside the ETCS system, look promising.

Outlook: Revision of UIC Leaflet 406

In UIC Leaflet 406 the occupation time is described for conventional signalling systems only. UIC Leaflet 406 does not yet deal with different ETCS configurations. For ETCS, the indication point determines the approaching time and affects capacity consumption. By performing the study, additional knowledge of the system's impact on capacity in junction areas was achieved. It is therefore recommended that the indication point be included along with the junction-specific particularities in a revised version of UIC Leaflet 406.

3 Assessing railway capacity

As railway capacity as such does not exist, it is not possible to find a general definition. The capacity of a given infrastructure is based on several interdependencies, e.g. between number of trains relative to the time interval, average speed, delays and traffic heterogeneity.

Theoretical capacity

In the case of absolute train path harmony, the shortest possible spacing of all trains is possible and enables the calculation of the maximum number of trains as a "theoretical capacity". But as the necessary assumptions are not accurate under real circumstances, this information is worthless for capacity assessment.

UIC Leaflet 406

In UIC Leaflet 406 "Capacity" therefore proposes a different "soft definition" of railway capacity: "Railway capacity is the total number of possible paths in a defined time window, considering the actual path mix or known developments respectively and the IM's own assumptions; in nodes, individual lines or part of the network; with market-oriented quality."

This "definition" of capacity is also applicable in terms of capacity comparisons. However, as it is quite informal, there remains a lot of flexibility in the details of capacity assessment. Therefore it is not possible to derive a concrete algorithm for capacity assessment directly from the "soft definition".

The method enables the consideration of the following attributes and their impact on capacity:

- Traffic mix,
- Interoperability,
- Different signalling and train protection systems, e.g. ETCS,
- Trade offs between track capacity ("trains per hour") and train capacity ("tonnes per train"),
- Impact of new technologies on track capacity (heavy haul, double stack etc.),
- Quality measures.

An adequate model of capacity consumption is a mandatory requirement for a serious capacity assessment method. This model should establish a relationship between track occupation and operational quality. As a first step, the capacity consumption of an individual train path, which is shown in Chapter 3.1.1 (page 6), needs to be modelled.

On the basis of this capacity consumption model UIC Leaflet 406 "Capacity" establishes an international standard method for the assessment of capacity on lines equipped with a conventional signalling system. This method is described in Chapter 3.1.3 (page 14).

The UIC standardised method provides no explicit report on operating quality. Tried and tested methods are outlined in Chapter 3.1.4 and additionally applied in this study.

Additional consideration of operating quality

3.1 Modelling railway capacity consumption

As shown above, a simple measurement of railway capacity is not possible, as capacity is affected by a number of complex parameters and issues.

With reference to the parameters of the "soft" capacity definition in the introduction to this chapter we will later calculate the level of capacity consumption of an example section of railway infrastructure (see Chapter 3.1.3).

Introduction of a general harmonised model

In preparation for this, a general harmonised model for capacity consumption shall be introduced in this chapter. The model shall be able to deal with the influence of important operational attributes within general scenarios on capacity consumption, such as traffic mix, interoperability, different signalling and train protection systems, especially ETCS levels, as well as interference between track capacity ("trains per hour") and train capacity ("tonnes per train").

3.1.1 Blocking time and blocking time sequences

The central question that needs to be answered in the context of capacity consumption concerns describing and quantifying the capacity consumption of a single train movement ("train path"). By taking the interactions between the individual train paths, it is possible to calculate the efficiency of the infrastructure element under consideration.

For the past few decades the blocking time model defined by HAPPEL in Aachen in 1959 [2] has been the standard method of modelling capacity consumption in Germany. With the introduction of a software tool for computer-aided train-path management, this model has also been employed to compile timetables in Germany since 1998. The International Union of Railways, moreover, recommends the model for use in capacity studies (cf. Chapter 3).

Operational occupation of a block section lasts longer than physical occupation

The basic idea underlying the blocking time sequence is that the operational occupation resulting from a train movement of a block section demarcated by two main signals lasts longer than the actual physical act of occupation (Figure 2). Switching time (set-up time), sighting time and approaching time for the movement between the distant/warning and main signals before the front of the train reaches block signal A must be taken into account. Once block signal B has been passed, it is necessary to add the clearance time to the blocking time (end of train at rear integrity proving point) and any further switching time (cancelling time) that passes before the section is released. The sum of these blocking time segments is referred to as blocking time (Figure 3) and denotes the capacity consumption of a train movement.

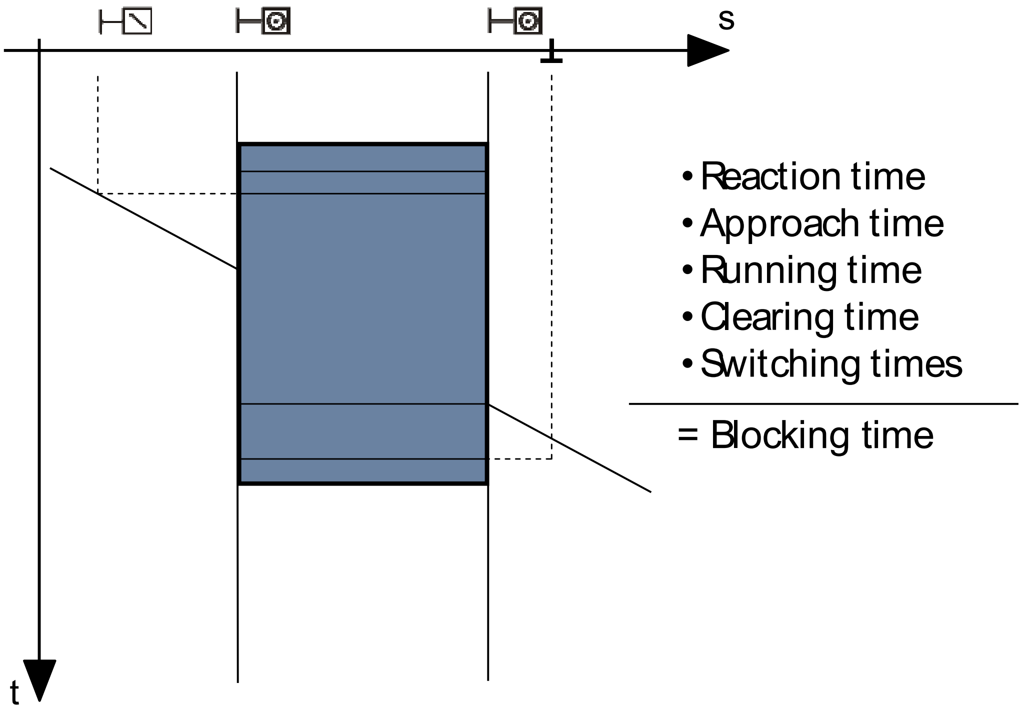


Figure 2 Components of the blocking time in a time-space-diagram

Blocking time begins at sighting point

The point which determines the start of the blocking time is the moment when the train driver has to be notified of the main signal changing from stop to proceed. For conventional distant/main signalling systems, this is the “sighting point” ahead of the distant signal, which is not necessarily identical to the point at which braking is initiated. The sighting point is generally a considerable distance ahead of the “initiate braking” point. If the train driver has not yet been notified about a “proceed” aspect of the related main signal upon reaching the sighting point, then he is required to assume that the main signal is at “danger” and he has to initiate the appropriate action. In most cases this leads to a deviation from the scheduled (hindrance-free) driving curve.

Assumption of running without hindrance

It is always assumed with blocking time sequences that the driving curve upon which they are based (s-t-function in the train diagram) can be performed without hindrance, since running on distant signals at “caution” is assumed when planning for either train-path management or efficiency calculations. The assumption of hindrance-free running is based on the situation that receiving restrictive information at the distant signal in most cases leads to higher capacity consumption, since deceleration and reacceleration are necessary (Nonetheless, to examine the effect of infill equipment, secondary delays must be considered. This is undertaken in a separate approach, see Chapter 3.1.6).

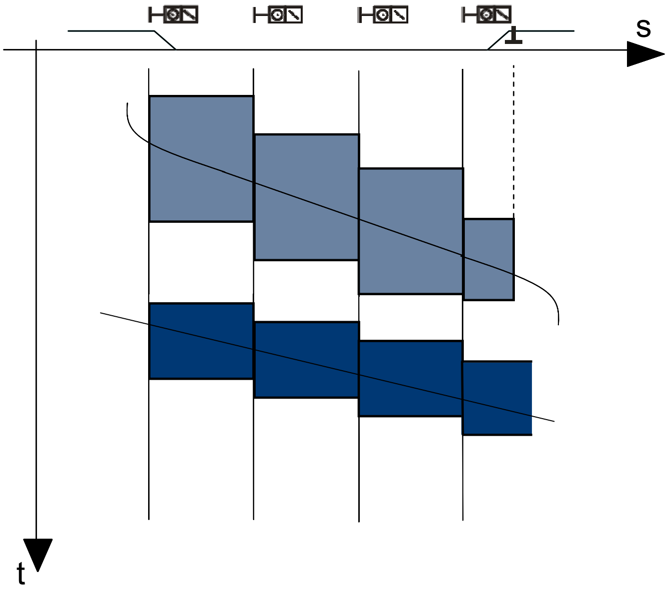


Figure 3 Blocking time sequences

By moving the blocking time sequences of two trains on an overtaking section as close together as possible, the minimum headway can be derived from the first element of the common section (see Chapter 3.1.3).

Application to various signalling systems

The model of blocking times, as explained above for conventional main/distant signalling, can be adapted to suit any signalling and automatic train control system, especially all the ETCS Levels (see following chapter).

3.1.2 Special aspects of ETCS

Summary of ETCS Level 1

ETCS Level 1 is a spot transmission-based train control system, which can be used as an overlay on an underlying signalling system. Movement authorities (MA) are generated trackside and transmitted to the train via Eurobalises. Additional Eurobalises can be positioned to transmit infill information. Semi-continuous infill can be provided using Euroloop or radio infill. In this case, the onboard system can provide the driver with new information as soon as it is available and even when stationary. Finally, the application of infill equipment enables the benefits of continuous train supervision to be incorporated locally (e.g. by additional block sections only available with ETCS supervision).

Summary of ETCS Level 2 and 3

ETCS Level 2 and ETCS Level 3 are radio-based train control systems. Movement authorities are generated trackside and transmitted via the Radio Block Centre (RBC) to the train via Euroradio. Both levels are based on Euroradio for track to train communication and on Eurobalises as spot transmission devices mainly for location (re-)referencing. The system of radio-based transmission enables continuous train supervision.

In ETCS Level 2 train detection and train integrity supervision are carried out by the trackside equipment of the underlying signalling system (axle counters, track circuits etc.). In contrast, in ETCS Level 3 train location and train integrity supervision are carried out by the trackside RBC in cooperation with the train itself (which sends position reports and train integrity information). For further details, reference is made to [11].

The capacity consumption of a train running with ETCS can be described by means of the blocking time model as in the conventional case, but ETCS braking curves are the most capacity-relevant elements.

While the approaching time is determined by the position of the distant signal in conventional signalling systems (see Chapter 3.1.1), the location of the Indication Point (IP) is decisive for the approaching time when using ETCS. Passing the IP results in the colour of the driver machine interface (DMI) changing from grey to yellow. At this point the driver is required to initiate braking. Assuming a hindrance-free run of the train, an extended movement authority (reaching beyond the upcoming EOA) needs to be transmitted before passing the IP.

The location of the IP is calculated onboard based on the relevant braking curve plus an additional brake build-up and optional driver reaction time (details are presented in Chapter 4.3.6). The underlying sophisticated calculation algorithm is specified by the ERTMS braking model EEIG: 97E881. In general, braking curves depend upon the braking capability of the train (braking percentages λ), the position of the supervised location (SvL), i.e. the overlap behind the main signal, and a set of national correction factors. By means of these national values, the safety of braking curves is controlled and adapted to individual circumstances. Figure 4 illustrates the calculation of the IP position.

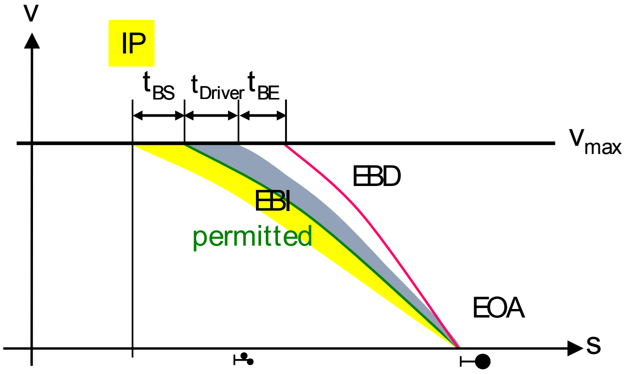


Figure 4 Indication Point equals End of Authority (simplified)

To ease understanding, the v-s-diagram has been simplified:

- In this case, the position of the SvL equals the position of the EOA (no overlap).
- Operation mode “SBI not available” is illustrated.
- The additional supervision curve SBI1 is not shown.
- Preindication is not relevant for capacity consumption and left out.

In the following chapters, the three different ETCS levels are described from the point of view of the blocking time model.

ETCS Level 1

The approaching time is determined by the first relevant group of balises, which needs to be passed before the IP is reached (cf. Figure 5). In most cases, the approaching time is longer than that of the current situation due to the longer braking curves.

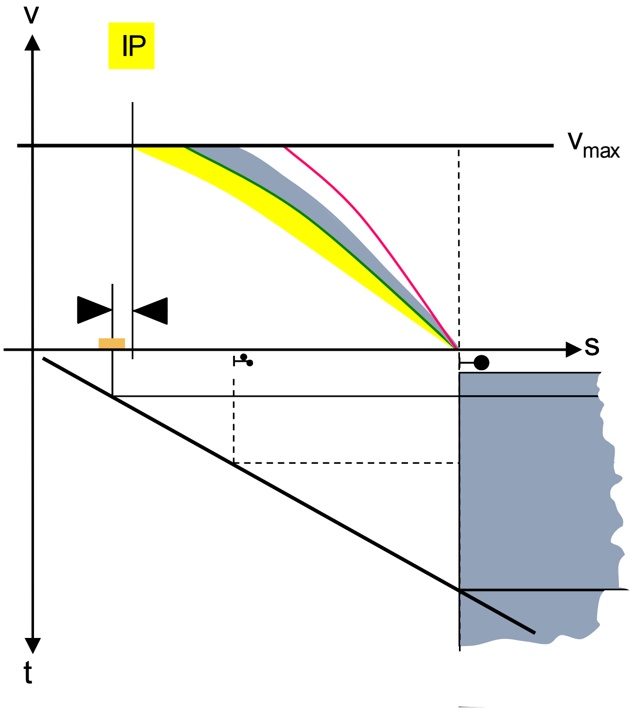


Figure 5 ETCS Level 1, position of infill balise determines the approaching time

It should be noted that the balise group related to the start of blocking time may be different from one train to another (as a function of the train braking parameters). Therefore, for some trains the blocking time reference balise group may be far behind the beginning of the deceleration curve. This has an important impact on the headway. If, instead, there is a harmonised speed profile (all trains running at nearly the same speed), the optimal position of this infill balise can be determined as close as possible to the IP.

Incorporated driver's reaction time

Since driver reaction time is incorporated into the braking model, it is not necessary to consider a separate reaction time as a component of the blocking time. Instead, the blocking time has to be extended by a short constant element to cover the information transmission via the air gap between Eurobalise and train.

ETCS Level 2

Being a fixed block signalling system, the modelling of infrastructure occupation in the context of ETCS Level 2 is based on the same principles. In contrast to ETCS Level 1 the approaching time depends directly on the IP, as shown in Figure 6.

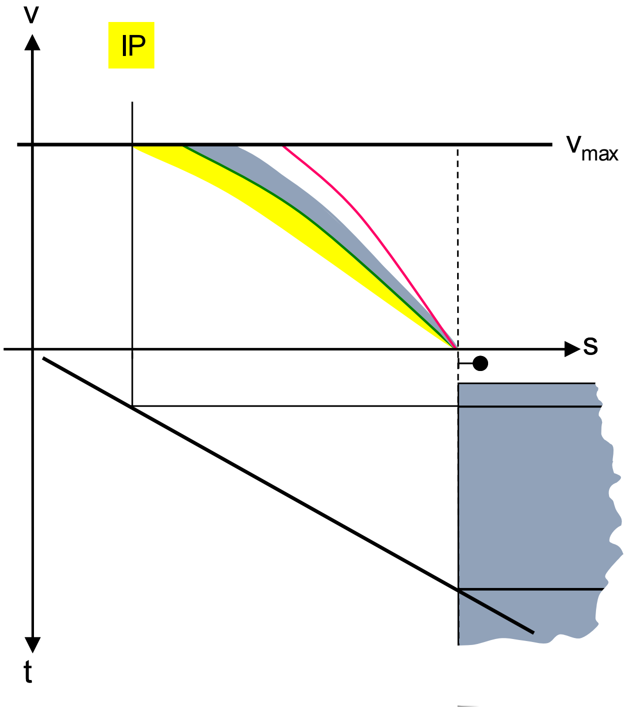


Figure 6 ETCS Level 2, Indication point determines the approaching time

Advantages in case of inhomogeneous train mix

ETCS Level 2 can provide benefits in capacity in cases of inhomogeneous traffic mixes due to the absence of fixed “distant” balise groups. Instead, the latest possible start of the approaching time can be considered.

Comparatively high transmission times

Compared to ETCS Level 1 longer transmission times between interlocking - RBC - train need to be taken into account as part of the blocking time. Under certain conditions they may reverse the benefit arising from shorter approaching times.

ETCS Level 3

As a moving block-signalling system, ETCS Level 3 always provides the shortest minimum headway for all train order scenarios. As the train ensures integrity, fixed track sectioning is given up. The functions of the interlocking and the RBC are merged.

Nevertheless several restrictions lead to discrete blocking time segments within the continuous blocking time band. The principal restrictions are caused by catenary section separators and sets of switch points, because a point has to be considered as a block if the preceding train has passed the point on its other leg. An example of a blocking time band is illustrated in Figure 7.

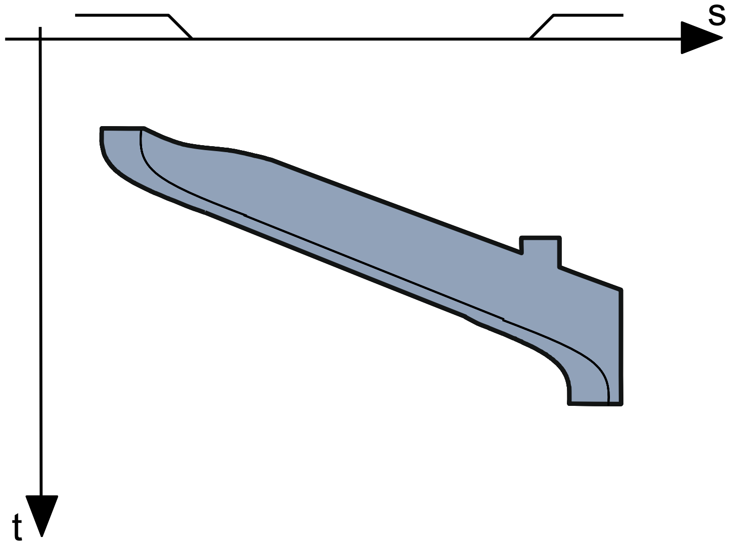


Figure 7 Blocking time band of ETCS Level 3

Boundary function of an infinitely dense block sectioning

The occupation curve of the blocking time band is determined by the train's braking distance (distance between IP and EOA), by its cancellation curve, by the train's length, by safety margins, by route setup times and reset times as well as by transmission times via Euroradio. The blocking time band thus constitutes the boundary function for the blocking time sequence assuming a theoretical, infinitely dense block arrangement.

Because changes in the speed limits are supervised by the same braking curves as the EOA, further discontinuities arise in the blocking time band at positions where the train has reached the lower speed. An example is given in Figure 8.

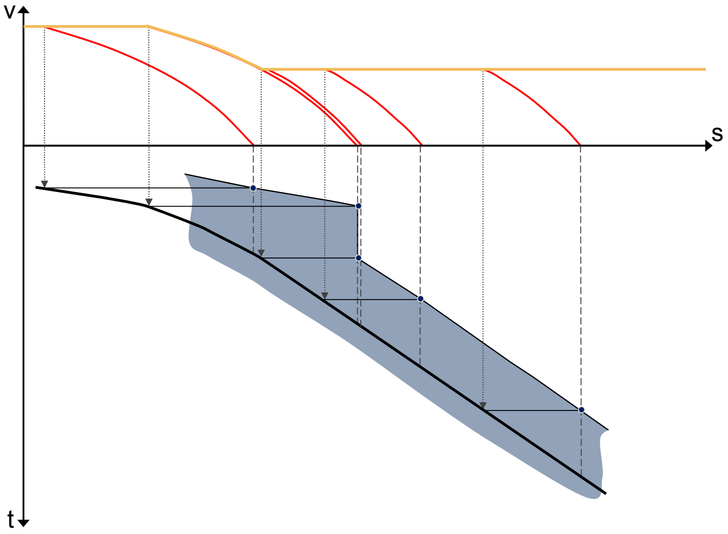


Figure 8 Blocking time band and speed limit drop

For the purpose of practicable calculations it is efficient to describe the blocking time band using a polygon traverse with nodes on all known trackside elements (such as change in gradient, points, change in speed limit). Details on the underlying data model are given in Chapter 3.2.1.

Modelling by polygon traverse

Since no exact definition of the previously mentioned safety margins behind the EOA is available yet, they are assumed to be comparable to fixed signalling. In particular this means that if the EOA's position equals a fixed block sign or a signal, its SvL is taken into account.

Fictive overlaps

Particularities of ETCS in junctions

In comparison to previous studies, which mainly covered capacity aspects of lines, various extensions of the model are required to cope with a junction's situation, for example:

- Transitions between either different ETCS levels or between existing systems and ETCS (cf. Chapter 4.1) need to be considered in the blocking time calculation.
- The interaction between ETCS speed supervision curves and scheduled braking to stop.
- The consideration of release speeds. If the scheduled stop is entered while the movement authority ends at the exit signal, or conversely, if the MA already targets beyond the exit signal before entering the platform section, then the occupation of the subsequent line section has to be modelled.

3.1.3 Calculation of capacity consumption in UIC Leaflet 406

The capacity consumption calculation method suggested in UIC Leaflet 406 “Capacity” is based on blocking time sequences (cf. Chapter 3.1.1) as the underlying capacity consumption model [3]. Therefore, the focus must be on the interaction between different train paths and their influence on the capacity of railway infrastructure.

Minimum headway time represents “touching” paths

Obviously there cannot be a capacity problem for the first “constructed” train path on a section of railway infrastructure. A second train movement can only take place without hindrance, i.e. to the speed profile requested by the railway undertaking, if there is no overlapping of blocking time sequences. Any overlapping of blocking time sequences constitutes a timetabling error. The minimum distance between two trains with specified speed profiles is referred to as minimum headway h_{ij} (Figure 9). In cases where the blocking time sequences of any two trains just touch in the graphical representation, the minimum headway can be gauged from the blocking time elements comprising the first block section jointly negotiated.

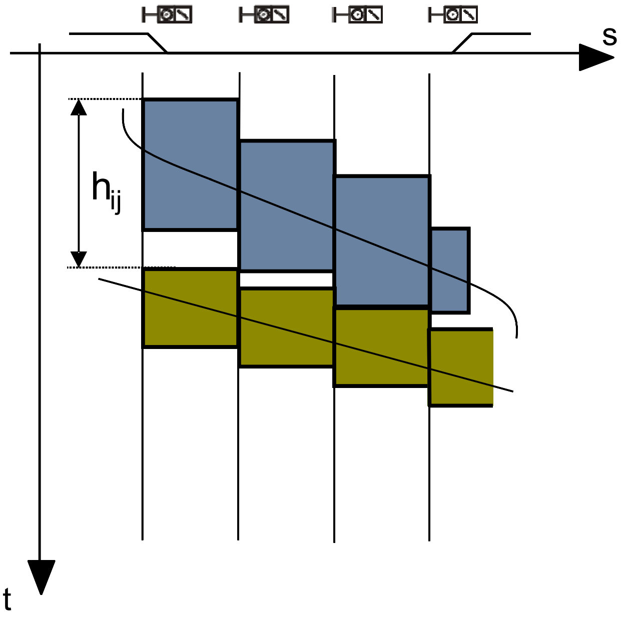


Figure 9 Minimum headway time

Determination of minimum headway times for each overtaking section

Minimum headway times h_{ij} refer to the common route of trains i and j and must be determined for each overtaking section separately. An overtaking section is limited by stations, in which a sequence change between trains i and j is possible. The possibility of the sequence change is not only influenced by technical parameters (e.g. track length), but also by commercial constraints.

Generally both the approach based on UIC Leaflet 406 and that based on waiting times (cf. Chapter 3.1.4) permit an assessment independent of the timetable of infrastructure variants, because each train sequence is weighted by its probability. In this way, questions in the mid to long term can also be answered.

In practical timetabling, buffer times between blocking time sequences are introduced to make it less likely that delays are passed on from one train movement to the next.

Buffer times lessen delay propagation

There are various factors which influence the capacity of a railway network. In general, for capacity analysis and the comparison of scenarios, different operational requirements, dispatching strategies, priority rules, speeds, block distances, train control systems or signalling equipment have to be considered. Furthermore the traffic mix, the degree of interoperability and the interferences between track capacity and train capacity change when new technologies are implemented. By using the minimum headway time all of these factors are considered precisely (no estimation necessary), because each single impact is taken into account in the calculation of the minimum headway times.

Minimum headway times embrace various aspects

The proposed method for the determination of line capacity consumption in UIC Leaflet 406 is the compression method: all blocking time sequences of a line section within the investigation period are pushed together up to the (theoretical) minimum headway. This approach can also be used if, instead of a concrete timetable, only the operating programme (train-mix) is known.

Compression of minimum headway times

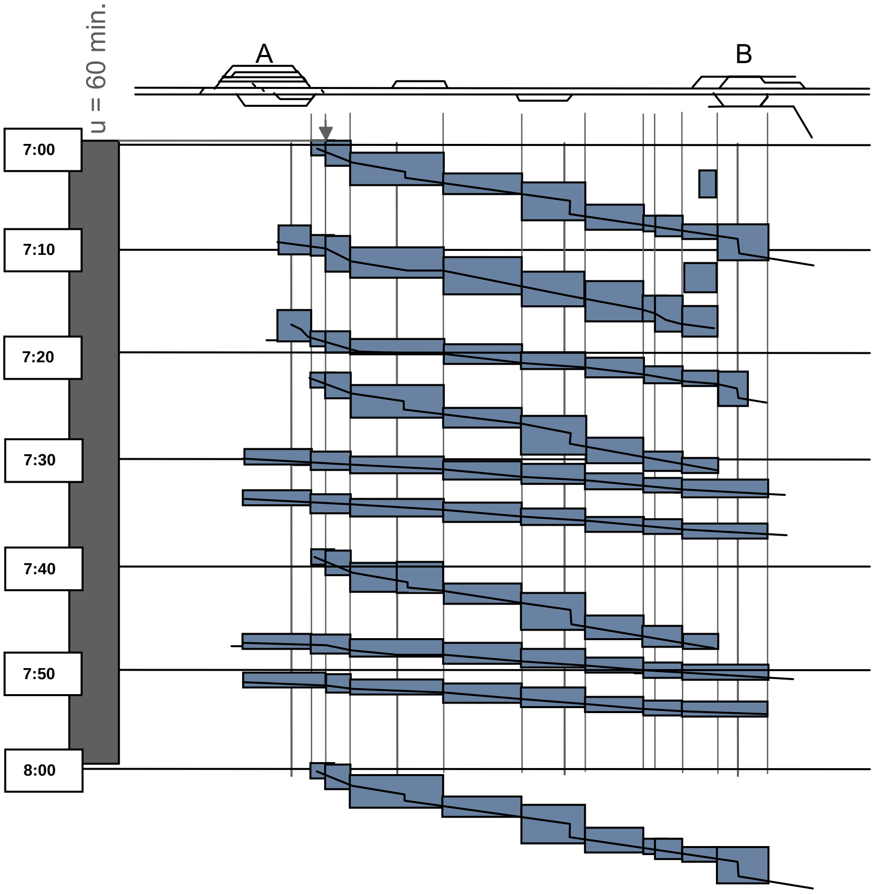


Figure 10 Original timetable (example)

Figure 10 and Figure 11 outline the compression method for an investigation period of 60 minutes. In the first one the original timetable is represented, while the second one shows the compressed timetable with the condensed blocking time sequences. In this example the occupation time begins at 7:00 and ends at 7:33. Thus here the minimum occupation time within the investigation period amounts to 33 minutes. This corresponds to an occupation ratio of 33:60 = 55%.

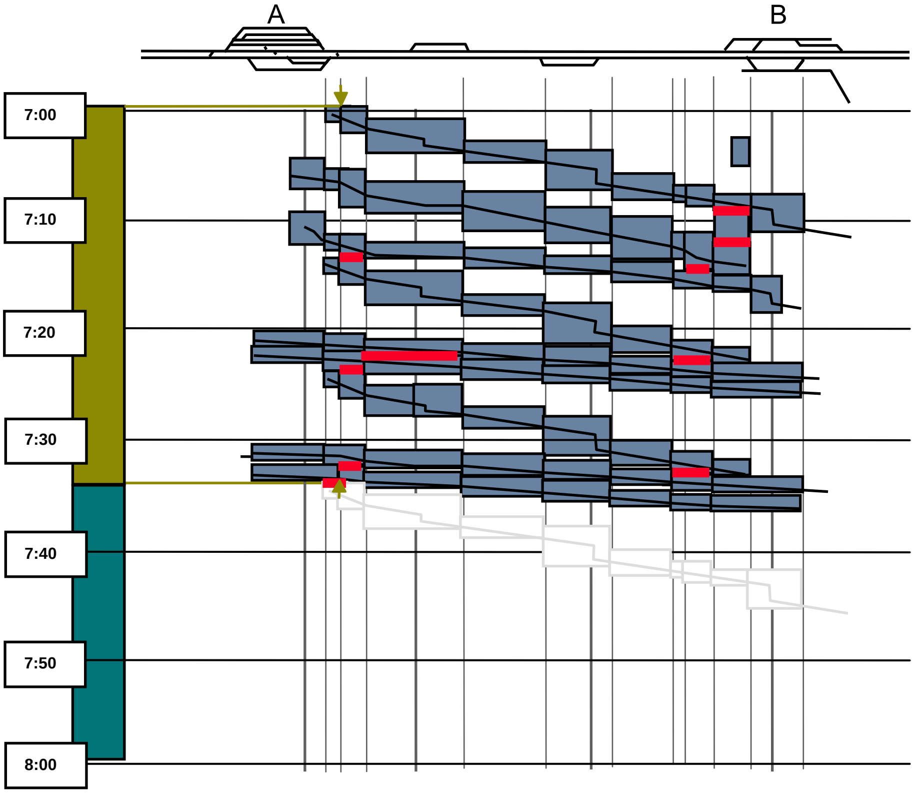


Figure 11 Compressed timetable (example)

Capacity remains unused

For the calculation of capacity consumption it is necessary to add time reserves for timetable stabilisation (buffer times) and for maintenance requirements in addition to the minimum occupation time. The remaining time slice is the unused capacity. Owing to market requirements a part of this unused capacity cannot be used, and no further train paths can be inserted into this time window. The second part of the unused capacity represents still available capacity, which could be marketed as additional train paths. Figure 12 shows the different times slices, from which capacity consumption and the unused capacity of a railway line can be determined.

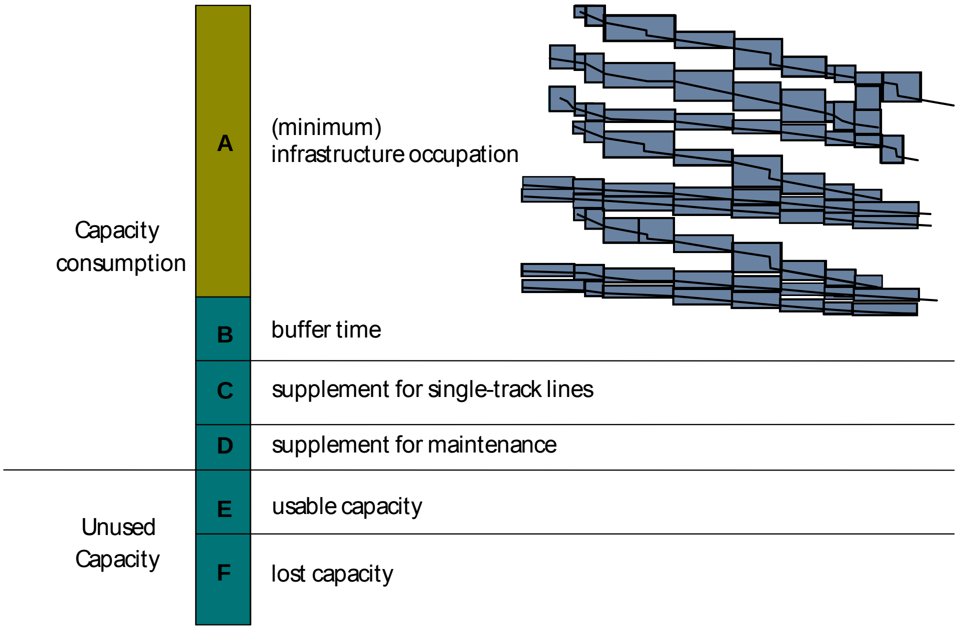


Figure 12 Determination of capacity consumption

The total consumption time (k) consists of the time components A, B, C and D:

$k = A + B + C + D$ with

k: total consumption time [min]

A: infrastructure occupation [min]

B: buffer time [min]

C: supplement for single-track lines (if applicable) [min]

D: supplements for maintenance [min]

Capacity consumption K is defined as

$K = 100 \cdot k / U$

K: capacity consumption [%]

U: chosen time window [min]

Guidelines for infrastructure occupation time

In UIC Leaflet 406 standard values for the ratio of infrastructure occupation time A and the chosen time window for a satisfying operating quality are given. These values are indicated as a function of the type of line and the infrastructure use.[1] The ratio used is defined as occupation ratio.

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

Table 1 UIC's recommended values for infrastructure occupation

It is possible to calculate an optimal line utilisation with help of the recommended values. This is demonstrated below in an example for a local passenger line in a chosen time window of U=720 minutes:

$A / U = 70\%$ with

$$A = n_{opt} \cdot h$$

n_{opt}: optimal number of trains with satisfying quality of operation

h: average minimum headway time [min]

This results in an optimal number of trains of

$$n_{opt} = 70 \cdot u / 100 / h = 504 / h$$

With help of the trains' capacity utilisation rate it is generally possible to express the infrastructure capacity by means of capabilities of traffic flows in dimensions passengers/time unit or tonnes/time unit.

The optimal number of trains depends solely on the minimum headway times

With this method of calculating the capacity consumption the optimal number of trains only depends on the average minimum headway times h_{ij}. Buffer times are merely implicitly respected.

Additionally, there is no explicit interrelation between capacity and quality, as this method is independent of delays or train priorities. One can use the method for the calculation of a rough benchmark of capacity consumption. For a more comprehensive capacity analysis, a more sophisticated method is available, which is outlined in the following chapter.

---

[1] The recommended values for infrastructure occupation were validated in a research study by RWTH Aachen University [8].

3.1.4 Capacity assessment with reference to operating quality

When queuing theory is applied a direct interrelation between operating quality and capacity of a section of railway infrastructure can be assessed.

The (theoretical) capacity n_{max} of a section of railway infrastructure is the number of trains that can be processed with an unlimited storage capacity in front of the infrastructure section.

Introduction of an optimal capacity

Waiting times and delays grow to infinity in an n_{max}-scenario, so that operation on a railway line is only possible with a considerably reduced number of trains. The optimal capacity n_{opt} is the number of train paths that allows the infrastructure manager to achieve the maximum profit. When a line is used by the optimal number of trains, the average waiting times are reduced to an expected value in accordance with the market expectation (EW_{los}, level of service, cf. Figure 14).

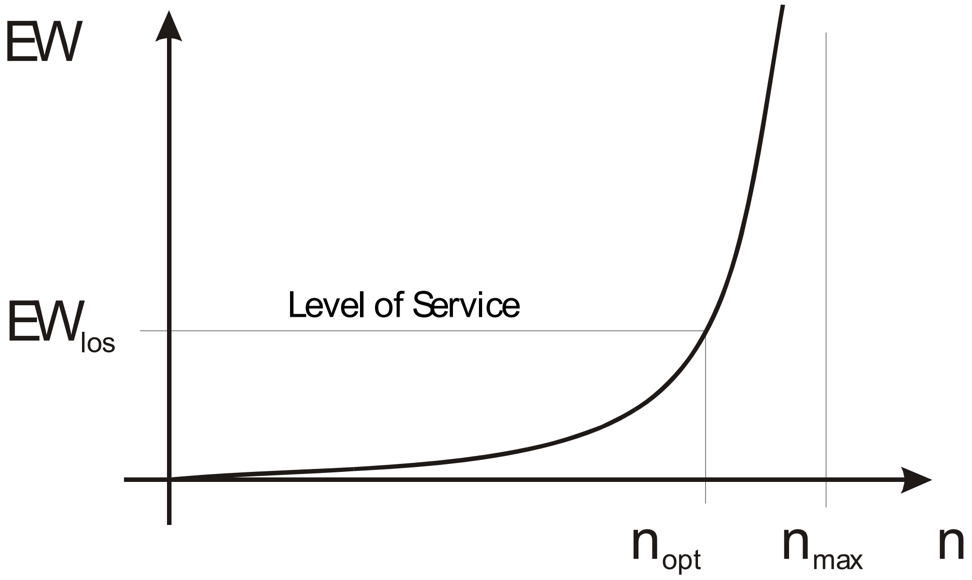


Figure 13 Average waiting times and level of service

Average waiting times as a quality measure

Average waiting times are used as a measure of quality when assessing the capacity of a railway line, which can be defined for timetable construction process and for operational process. Models and formulas of queuing theory allow a connection to be established between the characteristic performance quantity (trains per time unit) and the quality measure (waiting time).

The timetabling capacity $n_{max,tt}$ [trains/unit of time] of railway infrastructure is the maximum number of train paths that can be scheduled without conflicts within a reference period U. Normally, capacity is lost between two train paths, because of the constraints in the timetable construction process (for example regular-interval traffic).

Scheduled waiting times

Timetabling capacity corresponds with scheduled waiting times as a suitable quality measure. Scheduled waiting times arise during timetabling if it proves necessary to remove train paths from the slot desired by the train operating company (TOC) owing to conflicting paths [7].

Unscheduled waiting times

The optimal capacity $n_{max,op}$ [trains/unit of time] on the other hand is the number of trains that can be operated on a section of railway infrastructure within a reference period U as commercial services. This value when linked with secondary delays (or unscheduled waiting times) acts as a suitable quality measure. Secondary delays are likewise a capacity-dependent quality indicator [5].

In addition to the pure occupation ratio, optimal capacities can be applied to compare different infrastructure scenarios. While an evaluation of the occupation ratio alone permits an indirect reference to the level of service (cf. Table 1), the arrangement by an optimal number of trains directly incorporates operation quality.

3.1.5 Capacity of route nodes and junctions

Route nodes strictly speaking are the switch zones in the front end of railway nodes (stations). A junction is also a route node. In the broader sense even a sub-network can be understood as a route node.

Decoupling of sub-networks into single-channel components

From the perspective of queuing theory, the railway node represents a multiplicity of sequentially-parallel concatenated service systems. This sub-network must be divided into suitable components for the purpose of efficiency capacity assessment. Single-channel components are known as serial route nodes (SRN). In each case a SRN represents a larger connected track area, within which all train runs are mutually exclusive (Figure 14).

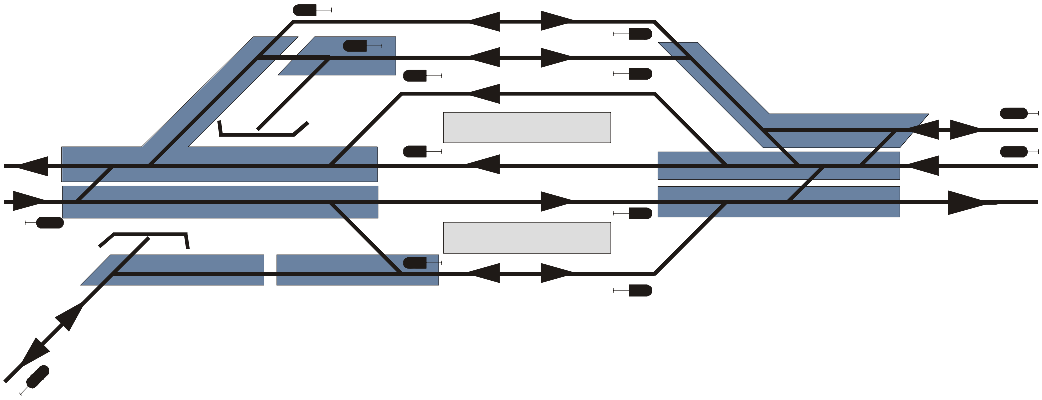


Figure 14 Serial route nodes

Determination of the system’s bottleneck

Dividing a station or sub-network into SRNs has an important practical aspect: for questions of dimension it is often interesting to identify the system bottleneck. This division is a basic condition which enables bottlenecks to be precisely located.

Waiting areas do not belong to the SRN. These are overtaking tracks and track clusters, in which trains can wait for a section to become available. Although there is a finite number of waiting positions in a real station, in railway operation research the existence of an infinite waiting area is assumed. If a finite waiting area were to be assumed, losses could arise in the system. As trains cannot get lost in a railway network, a model with an infinite waiting area is appropriate. If there is no waiting place for a train in a given waiting group, it is accepted that it can wait in another waiting group in a preliminary station.

A further substantial reason for the assumption of an infinite waiting area is the necessity of initially testing each SRN with no connection to other SRNs in order to determine its own waiting period behaviour. Stations are decoupled by the acceptance of an infinite waiting area.

Application of similar methods as for overtaking sections

In the same way that the capacity of line sections is assessed, scheduled and unscheduled waiting times can be determined with the help of the queuing theory for SRNs too.

3.1.6 Assessing the impact of infill on quality and capacity

The methods outlined above assume a train will have a hindrance-free driving curve. The time between the distant and the main signal is the approaching time. The model assumes that the train does not brake during this time. That means the following block section is duly cleared by the previous train and the following train run is not affected.

Influence of infill should be taken into account for the evaluation of operation.

For scheduling, a hindrance-free driving curve makes sense. For operation, the influence of automatic train control with infill functionality (balise, loop, GSM-R) dictates different treatment. If the train is slowed down due to a slower leading train, infill has an impact on capacity. If the following block section is occupied the train has to brake between the distant and the main signal. With infill, if the next block section is cleared, the train can get the information to accelerate before the release speed or standstill has even been reached.

Qualitative impact of infill

The influence of infill has to be evaluated from the point of view of quality and capacity. In general the removal of secondary delays thanks to earlier transmission of the new movement authority is evidence for the improvement of operation quality. Figure 15 outlines the relationships between the first train’s delay and the second train’s knock-on delay both for a system without any infill components and for a system with complete infill. It is obvious that infill offers no benefit at either very low disturbances (no delays occur with or without infill) or very high disturbances (the second train has to stop anyway – with or without infill).

Impact of infill on capacity

For any non-continuous ATP/ATC system the amount of additional buffer time required to reach the same operation quality as a system with total infill can be numerically calculated. In this way, an equivalent buffer time can be used to assess the impact of infill on capacity. Information on the infrastructure elements and the train characteristics apart, input data on the distribution of the train's initial delay is also necessary to apply the model.

Optimisation of balise positioning

By using characteristics as goal functions, the model enables the positioning of infill elements (as well balises as loops) to be optimised. For a detailed discussion reference is made to [9].

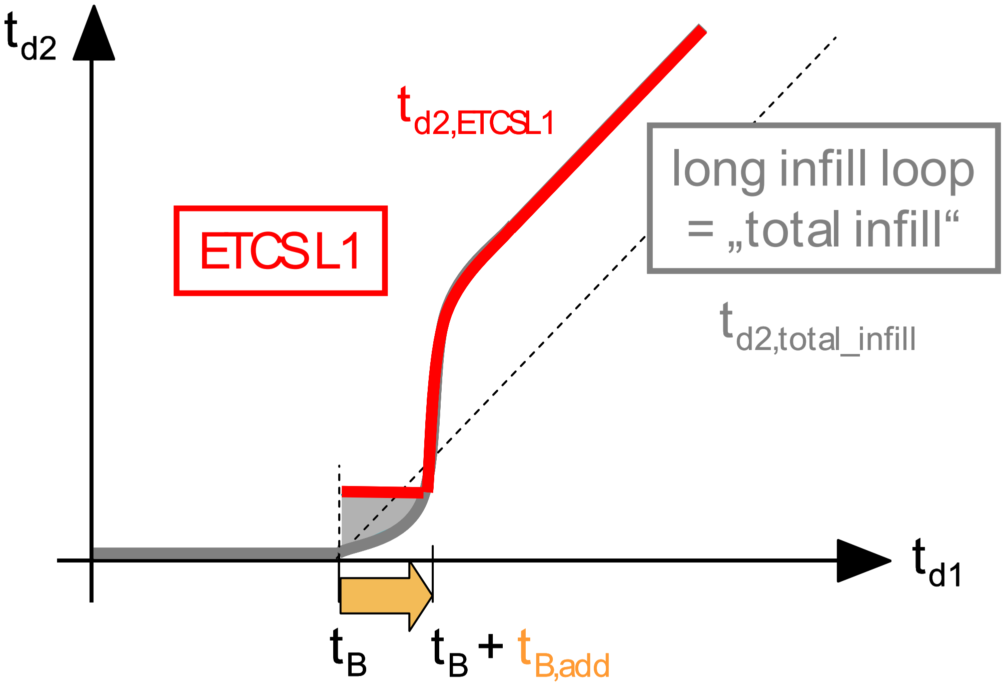


Figure 15 Knock-on delay as a function of infill and buffer time

3.2 LUKS® tool

To analyse capacity consumption, the software suite LUKS® ("Leistungsuntersuchung Knoten und Strecken") is applied. Within LUKS® several former applications (SPURPLAN, FAKTUS, ANKE and BABSI), which have been developed at the Institute of Transport Science (VIA) at RWTH Aachen University [1], have been merged. Furthermore, LUKS® is the standard tool for capacity assessment and simulation used by DB Netz AG.

3.2.1 Infrastructure

In LUKS® all infrastructure data is represented by a node-rated “digraph”. This is a directed graph, in which nodes contain the track attributes and links represent the track. The infrastructure model includes, among others, the following elements:

- Switches/Points, crossings,
- Signals: distant and main signals, rear-integrity proving points,
- Speeds,
- Stopping places for passenger and freight trains,
- Stations: beginning, middle and end,
- Gradients,
- Other infrastructure elements: braking distance, etc.

Each infrastructure element is characterised by its type, name, position, value and the corresponding station. In addition they have a single direction.

3.2.2 Interlocking routes

In addition to the infrastructure elements, interlocking routes are mandatory to model train runs. An interlocking route is defined as running from a station border to either the stopping place or another station border.

3.2.3 Modelling of ETCS

The sophisticated braking model as described in EEIG: 97E881 is fully implemented in LUKS® to enable the impact of ETCS on capacity to be evaluated. At present, versions 6K and 7A can both be considered, but this study is based on the latter.

To calculate the supervision curves, about four dozen parameters have to be fed into the braking model in addition to the infrastructure graph and the train-based information. Besides the basic description of the supervised braking curves, other parameters which have an impact on capacity consumption have to be taken into account:

- Transmission time by air gap (ETCS Level 1),
- Transmission time by GSM-R (ETCS Level 2 and Level 3),
- Separate values for route setup reset without fixed block sections (ETCS Level 3),
- Transmission time of radio infill (ETCS Level 1)

Details on the values used are given in Chapter 4.3.6. The figure below shows how the supervision curves can be illustrated individually by End of Authority and train to check the assumptions. (In this example the shortest distance between the FLOI and the End of Authority (EOA) was achieved by optimising the overlap.)

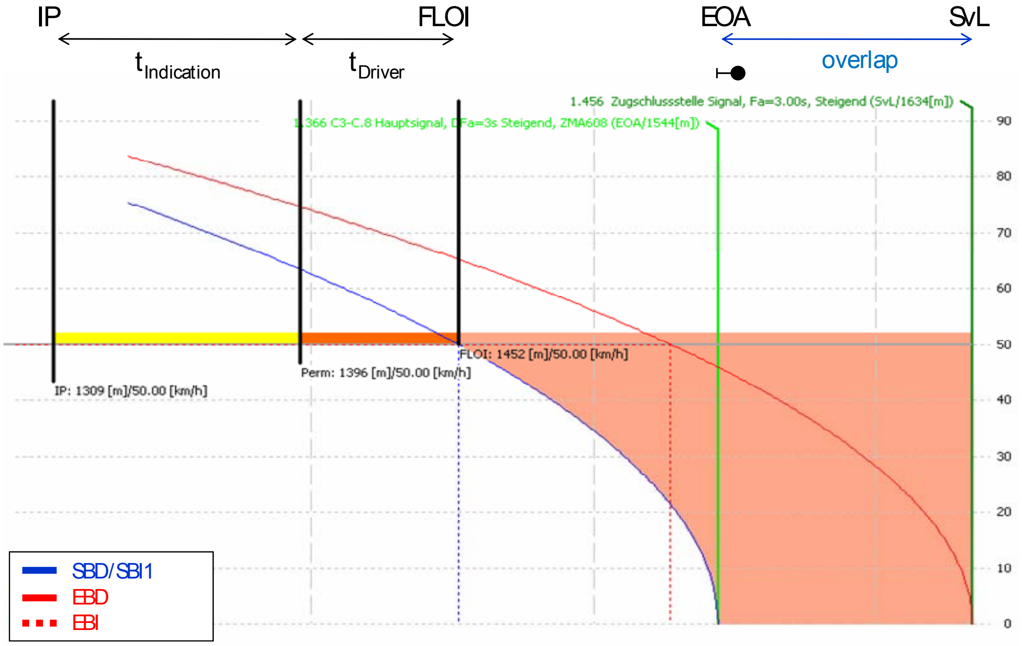


Figure 16 Tool-based application of the braking model

3.2.4 Positioning of balises

The analysis of the different strategies to choose the positioning of the balise groups which “refresh” the movement authority is supported by a semi-automatic approach.

For each EOA in the network under consideration the indication point (IP) of each passing train in the train-mix is determined. As described in Chapter 3.1.2, these IPs represent the optimal balise position from the view of capacity. To combine the optimal train-related positions, a weighting with regard to the operating programme can be performed. The resulting balises can be spread into the infrastructure graph individually per EOA or for all block sections automatically. The following strategies are currently covered:

One balise group at maximum optimal distance from EOA (a)

All trains can receive a new movement authority “early” enough (i.e. before the FLOI is passed). However, capacity is wasted if a train offers high deceleration rates.

One balise group at the weighted optimal distance from EOA (b)

A share of (badly braking) trains has passed its FLOI before a new movement authority can be transmitted. Their capacity consumption is increased, because the last balise group (e.g. at the previous EOA) determines their approaching time. Nonetheless the overall capacity consumption may be reduced compared to (a) if there is a high share of good braking trains.

Two balise groups at the maximum and weighted optimal distance (c)

When combining both approaches, the overall capacity consumption may drop further but a second balise group is required. (In case of a badly braking train, this second balise group may serve infill purposes.)

Positioning of balise groups at all optimal distances (d)

From a rather theoretical point of view, balise groups may be placed at the optimal position of each train in the train-mix. Balise groups which are too closely located may be combined to make one group at the maximum distance.

Infill loop or radio-infill between maximum and weighted optimal distance (e)

To cover a larger share of trains, either a long infill loop or radio-infill can be introduced between the derived positions of the balise groups. In this way, the approaching time is minimal for all those trains, whose IPs are located in between the balise positions.

3.2.5 Analytic module LUKS®-A

The module LUKS®-A is used for the calculation of waiting times [6]. The infrastructure has to be divided up into single-channel service systems (SRN, cf. Chapter 0). These are automatically separated on the basis of the infrastructure graph. For the calculation of the minimum headway time, alternative routes are automatically analysed to establish overtaking and crossing sections. Afterwards the scheduled and unscheduled waiting times can be ascertained.

The scheduled waiting time is generated during the timetable construction process, where train paths have to be moved to solve conflicts. The unscheduled waiting time arises during operation because of delayed trains. For the quantification of the scheduled waiting time queuing, a queuing model is used, whilst for the calculation of the unscheduled waiting time during operation (secondary delays) stochastic theoretical models are applied. Without an existing schedule only the train mix and the probability of train sequences can be considered. If the train mix is derived from a concrete timetable, similar train paths are aggregated to train types, which are attributed by their frequency (number of runs per time).

4 The nodes of Munich and Bern

Two large and heavily used European nodes have been chosen to assess the impact of ETCS on their capacity. On the one hand, Munich (Germany) represents a dead-end station, on the other hand, Bern (Switzerland), serves traffic as a through-station.

In this chapter, the geographical scopes of evaluation, the source of data and various modelling assumptions are outlined.

4.1 Geographical scopes of the analysis

In addition to the track layout in the centre of the nodes, all adjacent lines have to be considered to the extent that the correct calculation of minimum headway times can be ensured. Thus, all high priority adjacent scheduled passenger train stops have to be taken into account. Details on the network areas under consideration are given below.

4.1.1 Munich junction

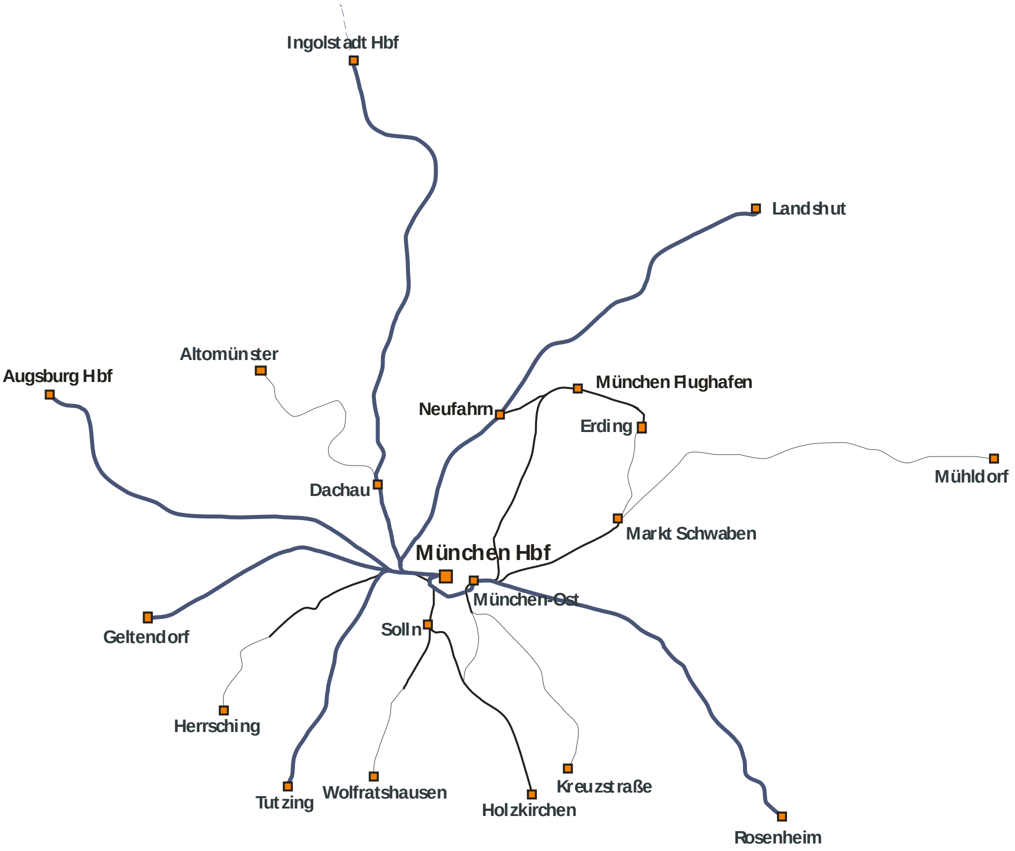


Figure 17 Evaluated network area of Munich Hbf (high-speed line to Nuremburg not entirely shown)

The network evaluated to assess the impact of ETCS at Munich junction is illustrated by Figure 17. Since it is mostly operated separately, the "S-Bahn" main line (Munich Hbf – Munich Ostbahnhof) is excluded from the study.

Mixed operation with LZB

In each of the considered scenarios, it is assumed that the network is completely equipped with the individual ETCS configuration. Only line sections which are already equipped with continuous train control by means of LZB (parts of Augsburg – Munich and Nuremburg – Munich) are left unchanged. This means that a transition between ETCS and LZB has to take place at the interfaces.

4.1.2 Bern junction

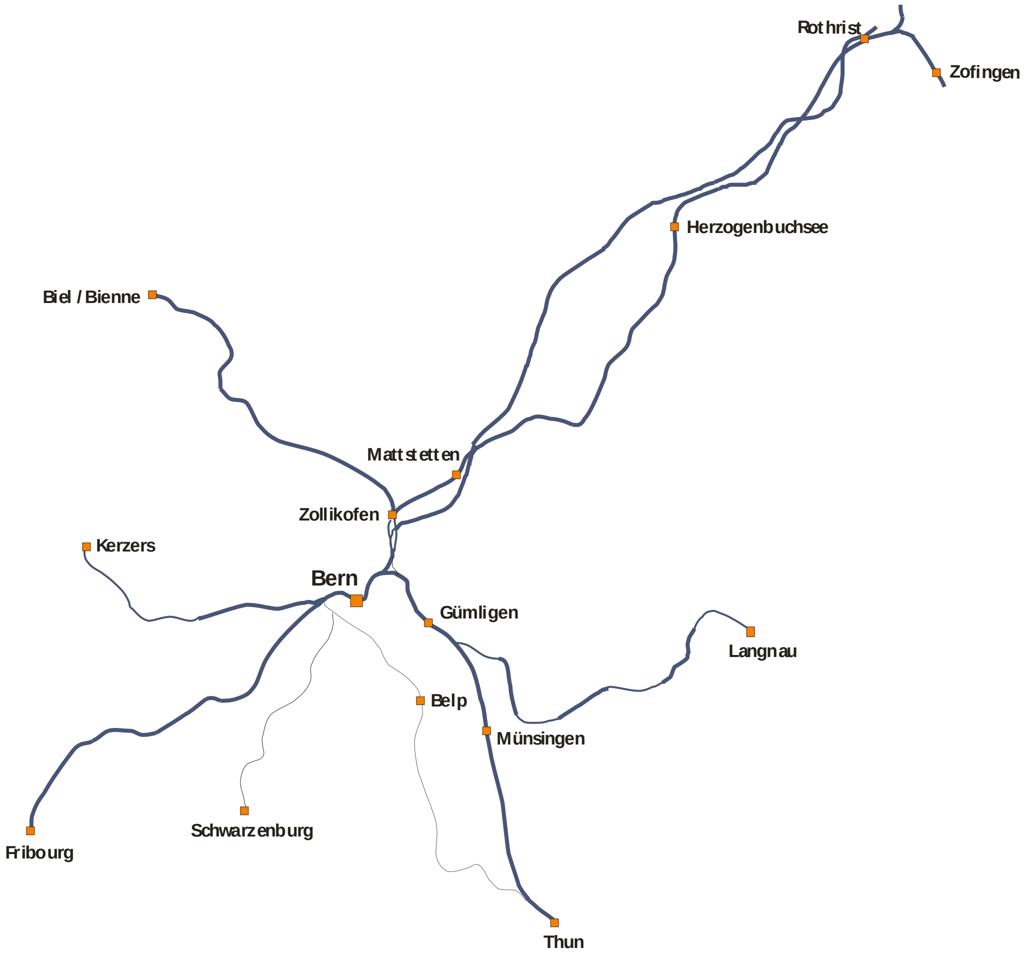


Figure 18 Evaluated network area of Bern HB

Figure 18 depicts the SBB network section which was used to analyse the impact on capacity at Bern junction. To ensure that data can be compared, an unchanged installation of ETCS Level 2 on the high-speed line Mattstetten – Rothrist has been assumed in all scenarios.

4.2 Source of data

Usage of XML-ISS and XML-KSS data

For an analysis of capacity, both infrastructure data and an operating programme are needed. For Munich junction the obligatory data was provided by DB Netz AG. A representative operating date for the capacity analysis – 20 February 2008 – was chosen. Timetable and infrastructure data in terms of xml files were imported via the standardised xml interfaces, whereas train runs were already aggregated to train types in the xml-file (Paula-Z).

After the import, infrastructure and train runs were validated and crosschecked in LUKS®. Trains bypassing the junction of Munich were deleted. As a result, 175 train types were used for capacity assessment.

Infrastructure data transferred from OpenTrack

The obligatory infrastructure data for Bern junction was provided by Swiss Federal Railways (SBB), division “Infrastruktur”, section “Fahrplan und Netzentwicklung”. Infrastructure data was firstly exported from Open Track to RailML and afterwards re-imported to LUKS®. Comprehensive manual customisation was necessary, because several infrastructure elements were not covered by the RailML graph.

Manual entry of timetable

The timetable data was based on Netgraph “Timetable Switzerland 2009”, whereby only regular-interval passenger trains calling at Bern HB were considered. Any peak-hour trains were left out, since they were not covered by the Netgraph. Thus 48 train types were used for capacity assessment. The low number of train types in comparison to Munich junction can be partly explained by the timetable structure. Indeed, one train type describes several local passenger trains per hour (e.g. “S-Bahn”).

For both junctions, the operating programmes cover the timetabled hours 6am to 11pm. A detailed list of the train types covered is presented in the appendix.

4.3 Modelling assumptions

To work out the minimum headway times by means of the tool described in Chapter 3.2 (page 23) the various assumptions described in the following chapters have to be made.

4.3.1 Dwell times

Dwell times in large stations might vary strongly depending on connections or synchronisation times, for example. For capacity analysis the minimum dwell times only are relevant. Stochastic variations of the stopping times are not considered in this study.

4.3.2 Speed profiles

Speed profiles for Munich junction and the adjacent lines were already incorporated in the xml-data source. The provided speed profiles for Bern junction and the adjacent lines in RailML were partially disputable. For this reason a manual compensation with RADN route data [4] was required.

4.3.3 Clearance of sections

Infrastructure sections are cleared when a train passes the trackside signalling equipment (e.g. axle counters). For Munich the position of the relevant signalling equipment was covered by the xml-input data. In contrast clearing points are not embraced by RailML. For this reason an additional manual input of signal and route clearing points was required.

Position of the Supervised Location

For modelling the different ETCS levels, the End of Authority (EOA) is equal to the main signal and the Supervised Location (SvL) is located at the end of the overlaps.

4.3.4 Constant components of blocking times

Route setting up and liquidation

Setting up a route is assumed to take 9 seconds, however cancelling a route or a clearing section is assumed to take 3 seconds. These parameters are valid for conventional signalling and ETCS supervision (also within ETCS Level 3).

Reaction time of six seconds in conventional signalling

Within ETCS Level 1 with limited supervision a driver's reaction time of 12 seconds is applied in the calculation of minimum headway times. During this time he notices the distant signal and initiates braking. When deriving the blocking times corresponding to supervision by ETCS, the offset *T_Driver* is individually calculated according to the braking model.

4.3.5 Unlimited capacity of GSM-R

An infinite capacity of GSM-R is assumed in this paper. It is as yet uncertain whether the number of channels will be sufficient for application in the junctions.

4.3.6 Input parameters to the ETCS braking model

The ETCS braking model as described in EEIG: 97E881 version 7A is applied, whereby all input parameters are assumed to be globally defined as national values. The possibility of setting up individual onboard parameters, which was introduced by the upgrade from version 6K to 7A, is not considered.

Baseline 3.0.0

At this point it shall be noted that version 7A of the braking model (as well as ETCS Level 1 Limited supervision) is intended to become part of the future ETCS baseline 3.0.0.

The table below illustrates the chosen speed dependent correction factors *kv*. The separate consideration of high-speed factors was not carried out due to a lack of input data. *A_P12* equals 1.15 m/s² and *A_P23* equals 1.40 m/s².

Freight		Passenger		Passenger		Passenger	
		maxEBD ≤ A_P12		*A_P12 < maxEBD ≤ A_P23*		*A_P23 < maxEBD*	
v ≤ ... [km/h]	*kv [-]*	*v ≤ ...* [km/h]	*kv [-]*	*v ≤ ...* [km/h]	*kv [-]*	*v ≤ ...* [km/h]	*kv [-]*
160	1	160	0.92	160	0.90	160	0.88
		200	0.80	200	0.78	200	0.76
						250	0.72
						300	0.64

Table 2 Speed dependent correction factors

Correction factors

The train length dependent correction factor *kr* is set at 1. The correction parameter applied to the brake build up times *kt* is fixed at 1.11.

Transmission times

Within ETCS Level 1 a transmission time between the change of the signal aspect and the balise of 1 second is assumed. Within ETCS Level 2 and Level 3 a transmission time from the Interlocking via the Radio Block Control Centre (RBC) to the train of 3 seconds is taken into account. These values have been calculated during previous research.

4.3.7 Timetable independent train types

As described in Chapter 3.1.3, the method of UIC Leaflet 406 can be applied independent of a concrete timetable. Instead, the minimum headway times are worked out for a mix of generalised train types. These headway times are also input for the additional calculation of capacity consumption with reference to operating quality according to Chapter 3.1.4.

5 Capacity assessment

In this chapter the different scenarios investigated are described. Finally the results of the capacity analysis for both junctions are presented.

5.1 Preparation of different ETCS scenarios

12 different scenarios were set up for each junction. The scenarios varied in the ETCS installation of the infrastructure and the ETCS equipment of the train types. The operating programme was always left unchanged.

5.1.1 ETCS Level 1, Balise at maximum IP (SBI not available)

In this scenario one balise is installed at the Indication Point (IP) of the worst braking train type. This balise is relevant for the approaching time of all train types. Details of the positioning can be found in Chapter 3.2.4. The service brake intervention (SBI) is not available.

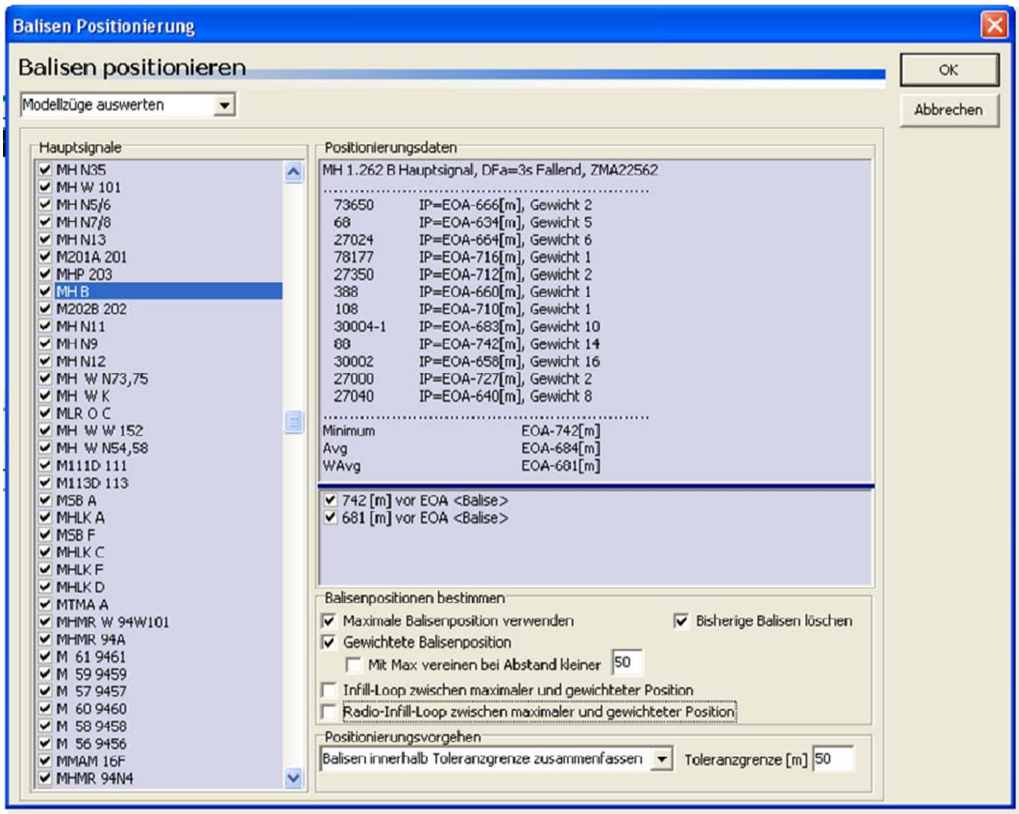
Reference scenario

To help better rank the different ETCS scenarios, this scenario is considered the “base” scenario. The impact on capacity of the other scenarios is compared to this base scenario.

5.1.2 ETCS Level 1, Balise at maximum IP and mean IP (SBI not available)

As an addition to the scenario described above, one more balise is installed at the weighted mean of all Indication Points. Depending on the parameters of the train type, either the balise at the maximum IP or the balise at the mean IP was relevant for the calculation of the approaching time.

Figure 19 shows the calculation of the mean and weighted IP for the signals and the different options for the location of the balises.



Modellzüge auswerten

☑ MH N35
☑ MH W 101
☑ MH N5/6
☑ MH N7/8
☑ MH N13
☑ M201A 201
☑ MHP 203
☑ MH B
☑ M202B 202
☑ MH N11
☑ MH N9
☑ MH N12
☑ MH W N73,75
☑ MH W K
☑ MLR O C
☑ MH W W 152
☑ MH W N54,58
☑ M111D 111
☑ M113D 113
☑ MSB A
☑ MHLK A
☑ MSB F
☑ MHLK C
☑ MHLK F
☑ MHLK D
☑ MTMA A
☑ MHMR W 94W101
☑ MHMR 94A
☑ M 61 9461
☑ M 59 9459
☑ M 57 9457
☑ M 60 9460
☑ M 58 9458
☑ M 56 9456
☑ MMAM 16F
☑ MHMR 94N4

```
MH 1.262 B Hauptsignal, DFa=3s Fallend, ZMA22562
..............................................................
  73650        IP=EOA-666[m], Gewicht 2
  68           IP=EOA-634[m], Gewicht 5
  27024        IP=EOA-664[m], Gewicht 6
  78177        IP=EOA-716[m], Gewicht 1
  27350        IP=EOA-712[m], Gewicht 2
  388          IP=EOA-660[m], Gewicht 1
  108          IP=EOA-710[m], Gewicht 1
  30004-1      IP=EOA-683[m], Gewicht 10
  88           IP=EOA-742[m], Gewicht 14
  30002        IP=EOA-658[m], Gewicht 16
  27000        IP=EOA-727[m], Gewicht 2
  27040        IP=EOA-640[m], Gewicht 8
..............................................................
Minimum                      EOA-742[m]
Avg                          EOA-684[m]
WAvg                         EOA-681[m]
```

☑ 742 [m] vor EOA <Balise>
☑ 681 [m] vor EOA <Balise>

☑ Maximale Balisenposition verwenden ☑ Bisherige Balisen löschen
☑ Gewichtete Balisenposition
☐ Mit Max vereinen bei Abstand kleiner 50
☐ Infill-Loop zwischen maximaler und gewichteter Position
☐ Radio-Infill-Loop zwischen maximaler und gewichteter Position

Balisen innerhalb Toleranzgrenze zusammenfassen Toleranzgrenze [m] 50

Figure 19 Positioning of balises according to different strategies

5.1.3 ETCS Level 1, Balise at maximum IP and mean IP (SBI available)

The same as the last scenario except that service braking is available. This can lead to longer breaking distances and – as a consequence – to longer approaching times.

5.1.4 ETCS Level 1, Balise at current position of distant signal (SBI not available)

In this scenario one balise is located at the current position of the distant signal. In some cases not all Indication Points of the different train types may be covered because the ETCS braking curves are flatter compared to their conventional counterparts. If this is the case the balise of the last block section becomes relevant and the approaching time increases considerably.

5.1.5 ETCS Level 1 with limited supervision

In ETCS Level 1 limited supervision mode the supervision curve is invisibly running in the background beneath the current signal system. The train driver reacts to the signal aspects. To calculate the approaching time, the location of the distant signal is relevant. If the ETCS supervision curve starts before the driver can act on the signal aspects the train's line speed has to be reduced (as in conventional signalling).

5.1.6 ETCS Level 1, Balise at maximum IP and mean IP, individually optimised blocks with infill loops (SBI not available)

In a large station the disadvantages of conventional signalling (e.g. minimum distance between signals, aspects of visibility) are accumulated. Thus the actual block sections are often much longer than necessary. Cab signalling allows the introduction of additional sections, which shorten the minimum headway times. This advantage can also be drawn on by ETCS Level 1 (especially combined with long loops or partial radio infill). Figure 20 provides an example of block optimisation with ETCS sections in a station.

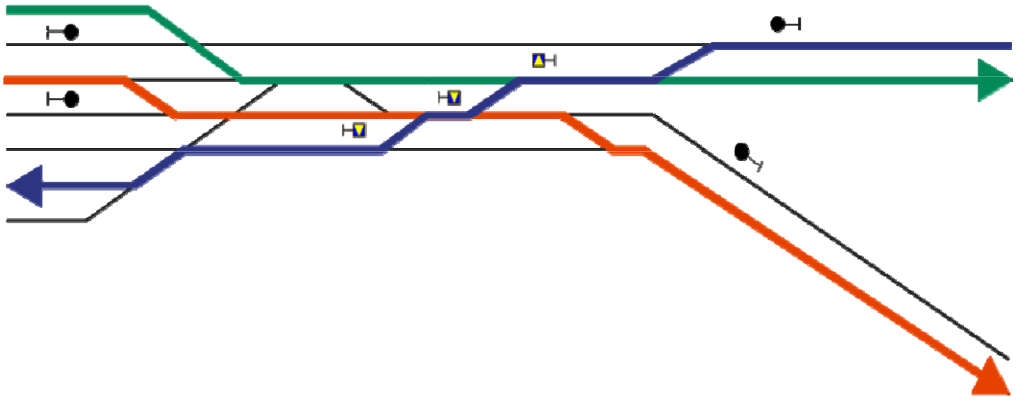


Figure 20 Block optimisation with additional ETCS block sections in stations

Application of pure ETCS block sectioning

In this scenario relevant sections at the entry and exit of the station (Munich or Bern) are investigated. Additional block sections divided by ETCS block signs are introduced if they enable a reduction in minimum headway times. If necessary, the position of the entry signal can also be changed.

Long infill loops

To take the most of block optimisation all sections with new ETCS block signs are equipped with infill loops. The long loop starts about two kilometres ahead of the station. Thus, all indication points are covered by continuous communication – this configuration is equivalent to an ETCS Level 2 installation for the corresponding infrastructure areas.

For the remaining part of the infrastructure the ETCS equipment as described in the base scenario is assumed.

5.1.7 ETCS Level 1, Balise at maximum IP and mean IP, individually optimised blocks with radio infill (SBI not available)

Instead of infill loops – as described in the last chapter – radio infill is applied for the optimised block sections in this scenario. As a result the ETCS transmission time increases from 1 second to 3 seconds.

5.1.8 ETCS Level 2 with speed changes at signals (SBI not available)

Within ETCS Level 2 trains can continuously receive Movement Authorities via GSM-R, thus the different strategies of balise group placement are not evaluated for ETCS Level 2 (and Level 3).

In this scenario the speed changes are located at the signal ahead (see below). Service braking is not considered.

5.1.9 ETCS Level 2 with speed changes at switches (SBI not available)

Within conventional signalling on the networks considered the speed change is located at the (entry) signal. This scenario takes advantage of cab signalling to allow the location of the speed change to be defined elsewhere. By choosing the roots of the switches instead of the corresponding signal, capacity consumption is decreased.

Figure 21 gives an example of shifting the speed changes from the signal to the roots of the points.

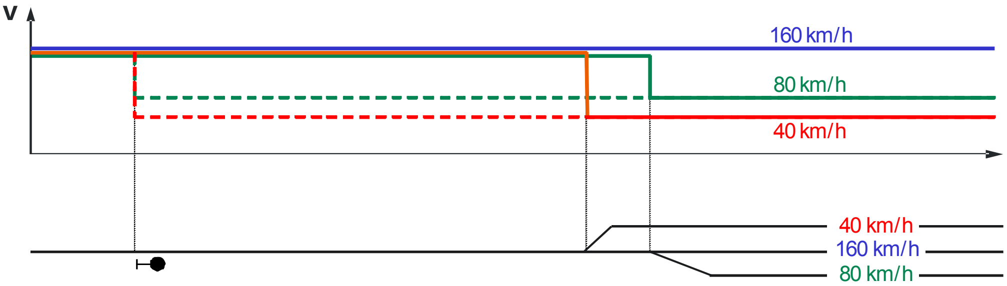


Figure 21 Changing the speed changes

5.1.10 ETCS Level 2 with speed changes at switches (SBI available)

In contrast to the scenario described above the service brake is available here.

5.1.11 ETCS Level 2 with speed changes at switches, individually optimised blocks (SBI not available)

This scenario is based on the same procedure described in Chapter 5.1.9. In addition block optimisation is carried out.

5.1.12 ETCS Level 3

In this scenario all train movements are covered by ETCS Level 3. Block sections are no longer relevant.

5.2 Capacity assessment of Munich junction

Figure 22 shows the network area of Munich junction and adjacent lines which are modelled in the capacity calculating tool LUKS®. In the lower section a detailed view of Munich main station in LUKS® is shown.

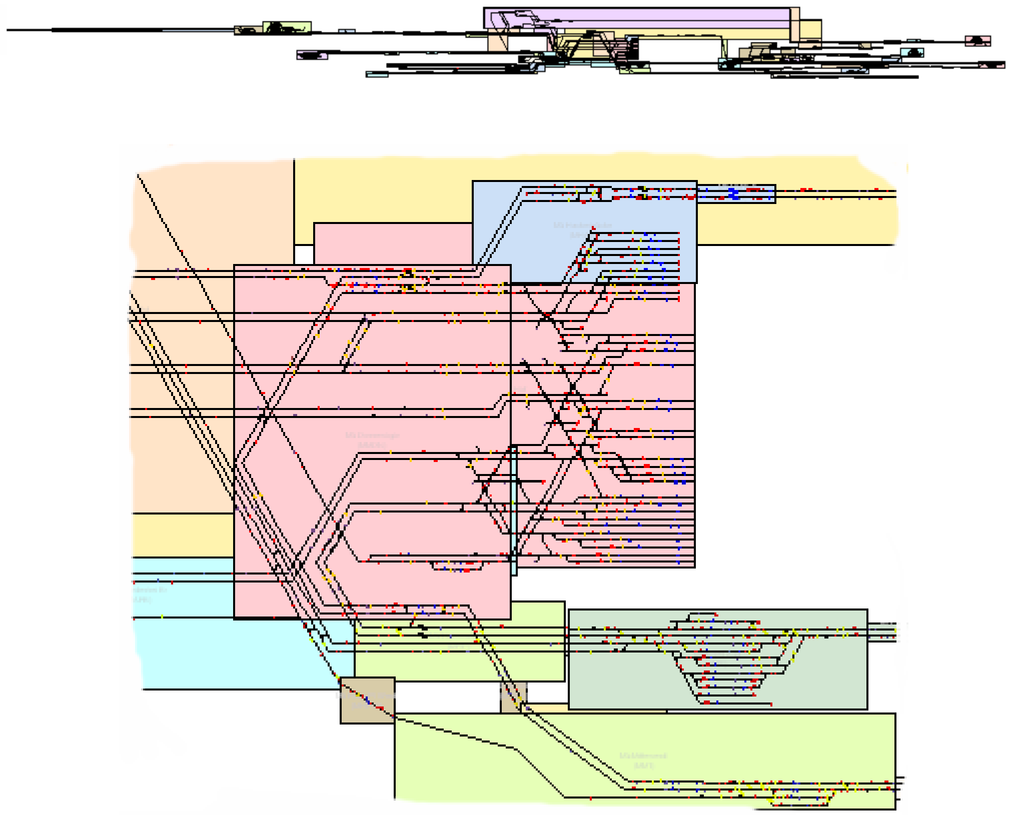


Figure 22 Evaluated network areas of Munich junction and Munich main station in LUKS ®

For capacity analysis not all serial route nodes (SRN) are evaluated. Ten route nodes are chosen, which cover the relevant parts of the station. In Figure 23 the selected serial route nodes are illustrated.

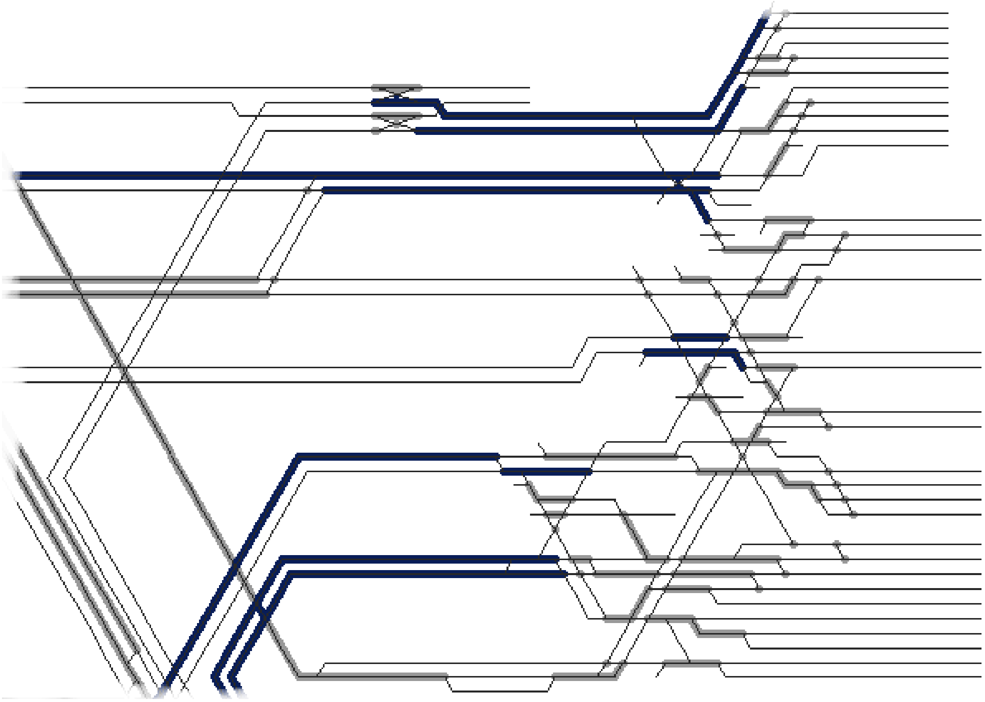


Figure 23 Serial route nodes in Munich Hbf

5.2.1 Influence of ETCS on the capacity

For the scenarios described in Chapter 5.1 analytic capacity calculation is performed. As a result, the occupation ratios of the serial route nodes are derived. These figures correspond to capacity consumption according to UIC Leaflet 406 (for details on UIC Leaflet 406 see Chapter 3.1.3). The results of the different scenarios are listed below.

In Chapter 5.2.6 the results of the ten serial route nodes are merged to give an overall result for each scenario. Finally, the methods outlined in Chapter 3.1.4, which explicitly covers operating quality, are also evaluated.

5.2.2 ETCS Level 1 scenarios

In Table 3 the results of the “base” scenario with one balise at the maximum IP are presented. Serial route node A is the most occupied.

Serial route node	A	B	C	D	E	F	G	H	I	J
Occupation ratio	0,5070	0,3799	0,1655	0,3271	0,3033	0,3316	0,3083	0,2819	0,3415	0,3035

Table 3 Occupation ratio: Level 1, Balise at max. IP (SBI not available)

By introducing a second balise at the weighted mean of all IPs the occupation ratio of the SRNs drops and capacity is increased. For SRN H the results remain the same. Here only local trains (e.g. S-Bahn) with almost the same train characteristics use the infrastructure. Therefore one balise for covering all relevant IPs is sufficient at this position.

Serial route node	A	B	C	D	E	F	G	H	I	J
Occupation ratio	0,4928	0,3664	0,1647	0,3248	0,2995	0,3291	0,2985	0,2819	0,3399	0,2975

Table 4 Occupation ratio: Level 1, Balise at max. and mean IP (SBI not available)

If the service brake is available (Table 5), the occupation ratio for some SRNs increases, but for other SRNs it is reduced. This strongly depends on the trains' sequence. Generally, capacity decreases in this scenario.

Serial route node	A	B	C	D	E	F	G	H	I	J
Occupation ratio	0,4932	0,3821	0,1630	0,3268	0,2977	0,3424	0,3087	0,2819	0,3385	0,2828

Table 5 Occupation ratio: Level 1, Balise at max. IP and mean IP (SBI available)

By installing a balise at the current position of the distant signal instead of the maximum IP the occupation ratio is increased in most cases.

Serial route node	A	B	C	D	E	F	G	H	I	J
Occupation ratio	0,5119	0,3868	0,1663	0,3189	0,3043	0,3331	0,3048	0,2777	0,3549	0,3214

Table 6 Occupation ratio: Level 1, Balise at current position of distant signal (SBI not available))

For the highly occupied SRNs A and B a block optimisation is performed in combination with long infill. For details see Chapter 5.1.6. Figure 24 shows the new ETCS block signs and the starting position of the long infill for SRN B. In addition the entry signal is relocated.

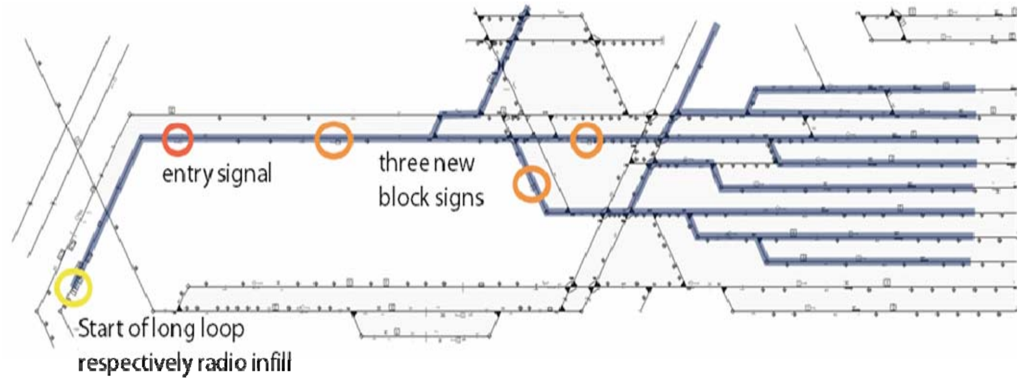


Figure 24 Block optimisation at Munich junction

The occupation ratio of the SRNs A and B decreases, the other SRNs are unchanged compared to the scenario without block optimisation.

Serial route node	A	B	C	D	E	F	G	H	I	J
Occupation ratio	0,4681	0,3598	0,1647	0,3248	0,2995	0,3290	0,2985	0,2819	0,3399	0,2975

Table 7 Occupation ratio: Level 1, Balise at max. and mean IP, individually optimised blocks with infill loops (SBI not available)

When using radio infill instead of infill loops the ETCS transmission time increases to 3 seconds and the occupation ratio of the two relevant SRNs increases as shown in Table 8.

Serial route node	A	B	C	D	E	F	G	H	I	J
Occupation ratio	0,4691	0,3623	0,1649	0,3248	0,2995	0,3290	0,2985	0,2819	0,3399	0,2975

Table 8 Occupation ratio: Level 1, Balise at max. and mean IP, individually optimised blocks with radio infill (SBI not available)

5.2.3 ETCS Level 1 with limited supervision

The differences of the ETCS limited supervision mode are described in Chapter 5.1.5. In comparison with the base scenario the capacity of the SRNs shifts up for some SRNs and moves down for the other ones. Altogether capacity remains almost the same in this scenario.

Serial route node	A	B	C	D	E	F	G	H	I	J
Occupation ratio	0,4808	0,4011	0,1679	0,3180	0,3063	0,3326	0,3107	0,2763	0,3445	0,3163

Table 9 Occupation ratio: Level 1 with limited supervision

5.2.4 ETCS Level 2 scenarios

The results of the ETCS Level 2 scenario with speed change at the signal are shown in the table below. The occupation ratio of all SRNs decreases compared to the base scenario.

Serial route node	A	B	C	D	E	F	G	H	I	J
Occupation ratio	0,4691	0,3623	0,1629	0,3125	0,2919	0,3259	0,2806	0,2775	0,3362	0,2780

Table 10 Occupation ratio: Level 2 with speed change at signal (SBI not available)

By moving the speed change to the root of the switches for some SRNs the occupation ratio falls. Generally a slight increase in capacity can be observed.

Serial route node	A	B	C	D	E	F	G	H	I	J
Occupation ratio	0,4691	0,3623	0,1629	0,3102	0,2917	0,3259	0,2797	0,2775	0,3360	0,2767

Table 11 Occupation ratio: Level 2 with speed change at switches (SBI not available)

If the service brake is available then capacity consumption rises. The occupation ratios illustrated in Table 12 are higher than those of the scenario above.

Serial route node	A	B	C	D	E	F	G	H	I	J
Occupation ratio	0,4701	0,3654	0,1629	0,3118	0,2924	0,3264	0,2799	0,2775	0,3360	0,2767

Table 12 Occupation ratio: Level 2 with speed change at switches (SBI available)

If block optimisation for SRNs A and B is introduced then the occupation ratios fall for both SRNs.

Serial route node	A	B	C	D	E	F	G	H	I	J
Occupation ratio	0,4296	0,3600	0,1629	0,3102	0,2917	0,3258	0,2797	0,2775	0,3360	0,2767

Table 13 Occupation ratio: Level 2 with speed change at switches, individually optimised blocks (SBI not available)

5.2.5 ETCS Level 3

In Table 14 the results of ETCS Level 3 are presented. All SRNs show the smallest occupation ratio values.

Serial route node	A	B	C	D	E	F	G	H	I	J
Occupation ratio	0,2667	0,2234	0,1356	0,2380	0,2397	0,2851	0,2330	0,2572	0,2827	0,2594

Table 14 Occupation ratio: Level 3

5.2.6 Overall results Munich

To compare the different ETCS scenarios the results of the ten SRNs are averaged. The base scenario ETCS Level 1 with one balise at the maximum IP (SBI not available) is scaled to 100% and the other scenarios are ranked according to their mean value. In Figure 25 the overall results for Munich junction are illustrated.

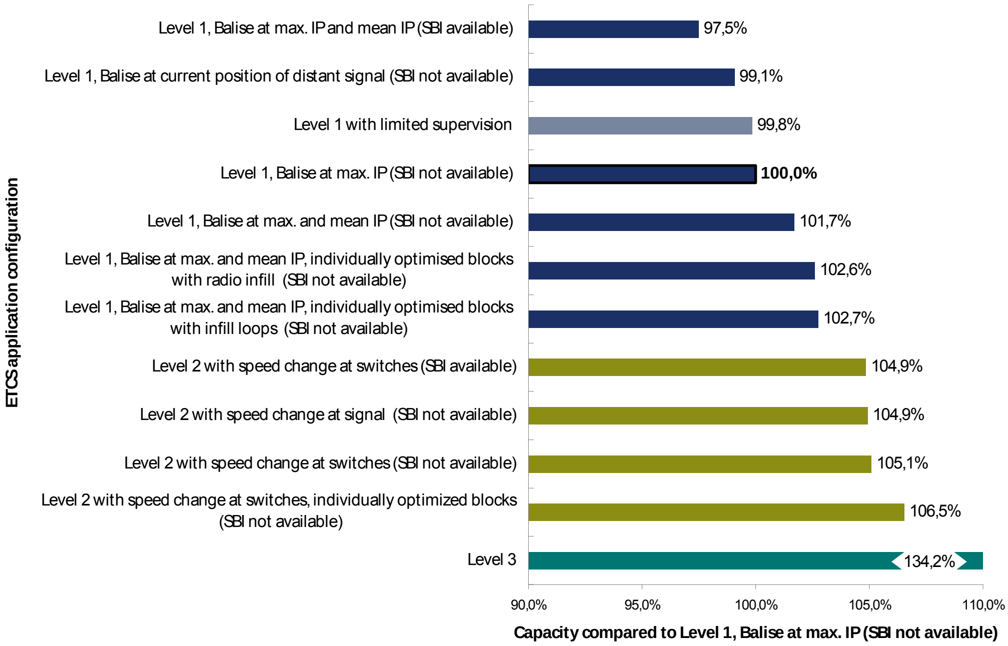


Figure 25 Overall occupation ratios in Munich junction

5.2.7 Evaluation of waiting times

Besides the evaluation of the occupation ratio it is also possible to analyse the impact on operating quality by means of the waiting times occasioned. For each scenario a different waiting time curve as a function of the number of trains can be calculated. When a standardised level of service is applied, an optimal number of trains is eventually obtained. For details on the methodology see Chapter 3.1.4.

In Table 15 the calculated optimal mean number of trains is shown and in the figure below the results are scaled to the base scenario. The overall results of the waiting times correspond to the results of the occupation ratio. There exist only some minor changes in the capacity utilisation (almost +/- 1%).

Scenario	Mean optimal number of trains per hour and SRN
Level 3	8,70
Level 2 with speed change at switches, individually optimised blocks (SBI not available)	6,89
Level 2 with speed change at switches (SBI not available)	6,81
Level 2 with speed change at signal (SBI not available)	6,80
Level 2 with speed change at switches (SBI available)	6,79
Level 1, Balise at max. and mean IP, individually optimised blocks with infill loops (SBI not available)	6,66
Level 1, Balise at max. and mean IP, individually optimised blocks with radio infill (SBI not available)	6,65
Level 1, Balise at max. and mean IP (SBI not available)	6,59
Level 1, Balise at max. IP (SBI not available)	6,54
Level 1 with limited supervision	6,52
Level 1, Balise at current position of distant signal (SBI not available)	6,51
Level 1, Balise at max. IP and mean IP (SBI available)	6,26

Table 15 Mean optimal number of trains per hour and SRN in Munich

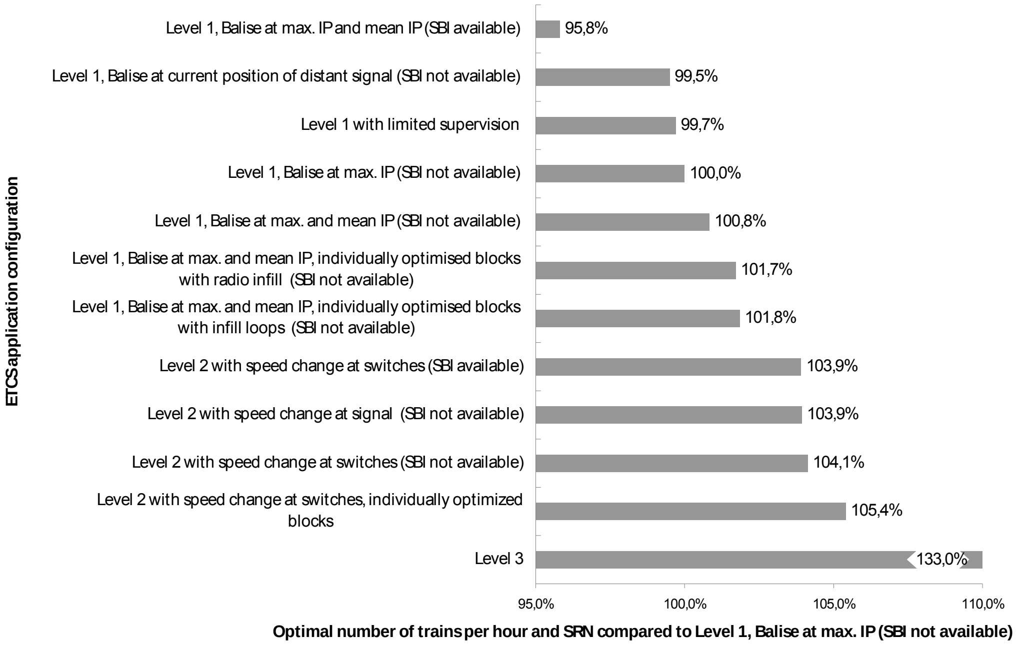


Figure 26 Average optimal number of trains depending on waiting times in Munich junction

5.2.8 Evaluation of infill

The impact on quality and capacity of infill equipment is evaluated by means of the buffer time equivalent as presented in Chapter 3.1.6. Various block sections in Munich junction as shown by Figure 19 are taken into account.

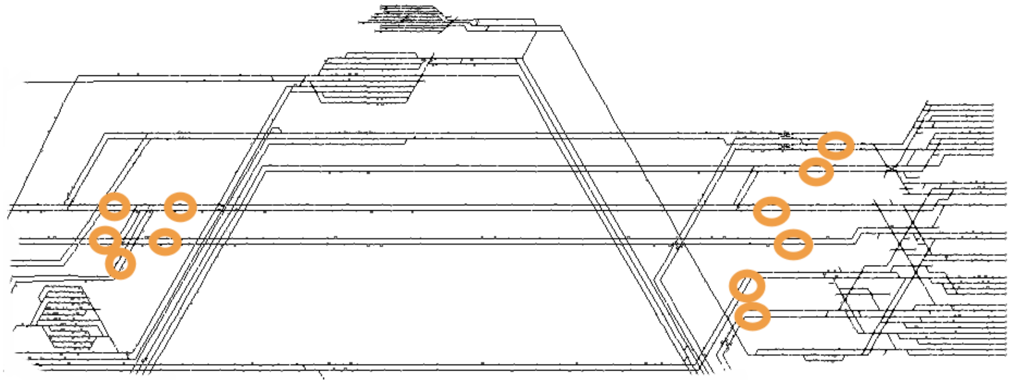


Figure 27 Block sections considered by the buffer time equivalent

In this way, two types of End of Authorities are covered:

- Very low speeds at the heavy occupied sections close to the terminus,
- Crossing section at intermediate speeds next to Munich-Pasing.

The necessary input parameters are derived from the infrastructure, the running time calculation and, regarding the delay distributions, from standard values of DB Netz AG. A release speed of 40 km/h is chosen.

Infill at entry signals

In the first case, the impact of infill can be estimated without further calculation, since the release speed reaches the permitted speed, which is valid either at the position of the entry signal or at least a couple of metres behind the entry signal. As a consequence, there is no improvement in either capacity or quality..

Infill at crossing movements

In contrast, next to Munich-Pasing infill offers a small improvement in case of particular train sequences, e.g. if a train departing towards Ingolstadt has to slow down from 120 km/h due to a crossing movement leaving the yard. Because of the small minimum headway time of h_{ij} = 114 seconds, an additional capacity of 4.1 seconds (in the case of a reduced speed ICE3 trainset) can be achieved in this situation, whilst the improvement in quality from the 0.13 seconds reduction in secondary delay may be totally neglected. However it should be noted that this train sequence seldom arises.

5.3 Capacity assessment of Bern junction

Figure 22 shows the network area of Bern junction and the adjacent lines which are modelled in the capacity calculating tool LUKS®. In the lower part a detailed view of Bern main station in LUKS® is shown.

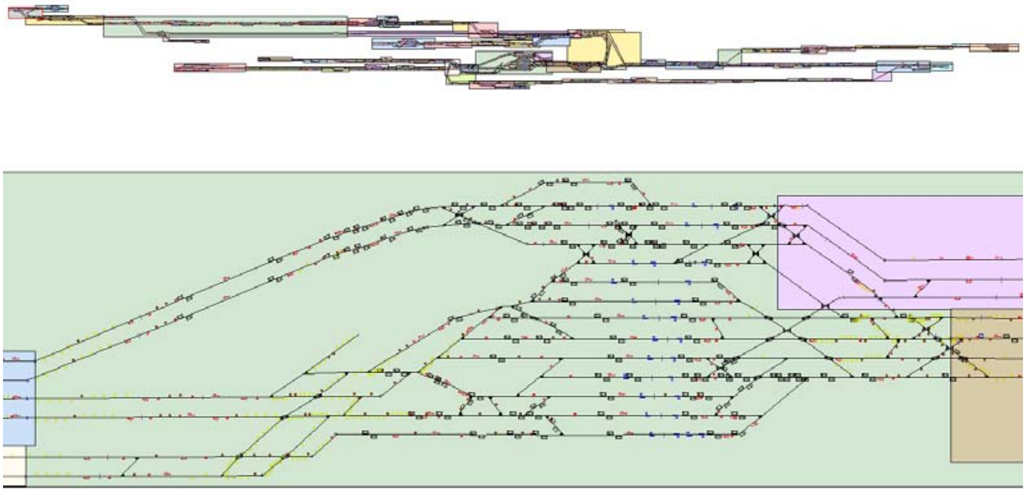


Figure 28 Evaluated network areas of Bern junction and Bern main station in LUKS®

Not all serial route nodes (SRN) are evaluated for capacity analysis. Eight route nodes are chosen, which cover the relevant parts of the station. In Figure 29 the chosen serial route nodes of Bern junction are highlighted.

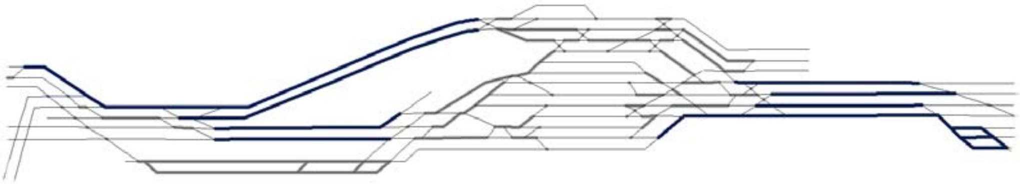


Figure 29 Serial route nodes in Bern HB

5.3.1 Influence of ETCS on capacity

For Bern junction analytic capacity calculation is performed in an analogous way. The results for the occupation ratios of the different scenarios are listed below.

In Chapter 5.3.6 the results of the ten serial route nodes are merged to give an overall result for each scenario.

5.3.2 ETCS Level 1 scenarios

In Table 16 the results of the “base” scenario with one balise at the maximum IP are listed. Serial route node E is the most occupied.

Serial route node	A	B	C	D	E	F	G	H
Occupation ratio	0,4547	0,5248	0,4663	0,4265	0,6480	0,3356	0,4497	0,5826

Table 16 Occupation ratio: Level 1, Balise at max. IP (SBI not available)

When a second balise at the weighted mean of all IPs is introduced, the occupation ratio of the SRNs decreases and capacity is raised.

Serial route node	A	B	C	D	E	F	G	H
Occupation ratio	0,4525	0,5175	0,4602	0,3970	0,6354	0,3266	0,4369	0,5802

Table 17 Occupation ratio: Level 1, Balise at max. and mean IP (SBI not available)

If the service brake is available (Table 18), the occupation ratio increases for some SRNs, but for other SRNs it is reduced. This strongly depends on the actual train sequence. Overall capacity decreases in this scenario.

serial route node	A	B	C	D	E	F	G	H
occupation ratio	0,4533	0,5416	0,4855	0,4252	0,6689	0,3836	0,4738	0,6291

Table 18 Occupation ratio: Level 1, Balise at max. IP and mean IP (SBI available)

When installing a balise at the current position of the distant signal instead of the position at the maximum IP the occupation ratio is increased in most cases.

Serial route node	A	B	C	D	E	F	G	H
Occupation ratio	0,4691	0,6344	0,5310	0,3967	0,7004	0,3509	0,4720	0,6670

Table 19 Occupation ratio: Level 1, Balise at current position of distant signal (SBI not available)

For the serial route nodes located at the northern head of Bern HB block optimisation is performed in combination with long infill. For details see Chapter 5.1.6. The occupation ratio of these SRNs decreases; the other SRNs are unchanged compared to the scenario without block optimisation.

Serial route node	A	B	C	D	E	F	G	H
Occupation ratio	0,4525	0,4896	0,4411	0,3970	0,6354	0,3163	0,4210	0,5393

Table 20 Occupation ratio: Level 1, Balise at max. and mean IP, individually optimised blocks with infill loops (SBI not available)

By using radio infill instead of infill loops the ETCS transmission time increases by up to 3 seconds and the occupation ratio of the two relevant SRNs increases as shown in Table 21.

Serial route node	A	B	C	D	E	F	G	H
Occupation ratio	0,4525	0,4930	0,4441	0,3970	0,6354	0,3171	0,4240	0,5432

Table 21 Occupation ratio: Level 1, Balise at max. and mean IP, individually optimised blocks with radio infill (SBI not available)

5.3.3 ETCS Level 1 with limited supervision

In comparison with the base scenario the capacity of the SRNs decreases in most cases.

Serial route node	A	B	C	D	E	F	G	H
Occupation ratio	0,4551	0,5534	0,4873	0,3957	0,6788	0,3662	0,4738	0,6309

Table 22 Occupation ratio: Level 1 with limited supervision

5.3.4 ETCS Level 2 scenarios

The results of the ETCS Level 2 scenario with speed change at the signal are shown in the table below. The occupation ratio over all SRNs decreases compared to the base scenario.

Serial route node	A	B	C	D	E	F	G	H
Occupation ratio	0,4553	0,5150	0,4293	0,3767	0,6297	0,3236	0,4235	0,5808

Table 23 Occupation ratio: Level 2 with speed change at signal (SBI not available)

Moving the speed change to the root of the switches leads to a lower occupation ratio in only two SRNs.

Serial route node	A	B	C	D	E	F	G	H
Occupation ratio	0,4553	0,5150	0,4279	0,3767	0,6297	0,3236	0,4235	0,5793

Table 24 Occupation ratio: Level 2 with speed change at switches (SBI not available)

If service braking is available then capacity consumption rises. The occupation ratios illustrated in Table 25 are higher than those of the scenario above.

Serial route node	A	B	C	D	E	F	G	H
Occupation ratio	0,4554	0,5165	0,4314	0,3773	0,6299	0,3247	0,4254	0,5822

Table 25 Occupation ratio: Level 2 with speed change at switches (SBI available)

After block optimisation between Bern HB and Bern-Wylerfeld is carried out, the occupation ratios fall, as expected.

Serial route node	A	B	C	D	E	F	G	H
Occupation ratio	0,4553	0,4957	0,4279	0,3767	0,6297	0,3144	0,4137	0,5463

Table 26 Occupation ratio: Level 2 with speed change at switches, individually optimised blocks (SBI not available)

5.3.5 ETCS Level 3

In Table 27 the results of ETCS Level 3 are presented. All SRNs show the smallest occupation ratio values.

Serial route node	A	B	C	D	E	F	G	H
Occupation ratio	0,3802	0,3869	0,3626	0,3136	0,5844	0,2674	0,3477	0,3817

Table 27 Occupation ratio: Level 3

5.3.6 Overall results Bern

To compare the different ETCS scenarios the results of the eight SRNs are averaged. The base scenario ETCS Level 1 with one balise at the maximum IP (SBI not available) is scaled to 100% and the other scenarios are ranked according to their mean value. In Figure 30 the overall results for Bern junction are illustrated.

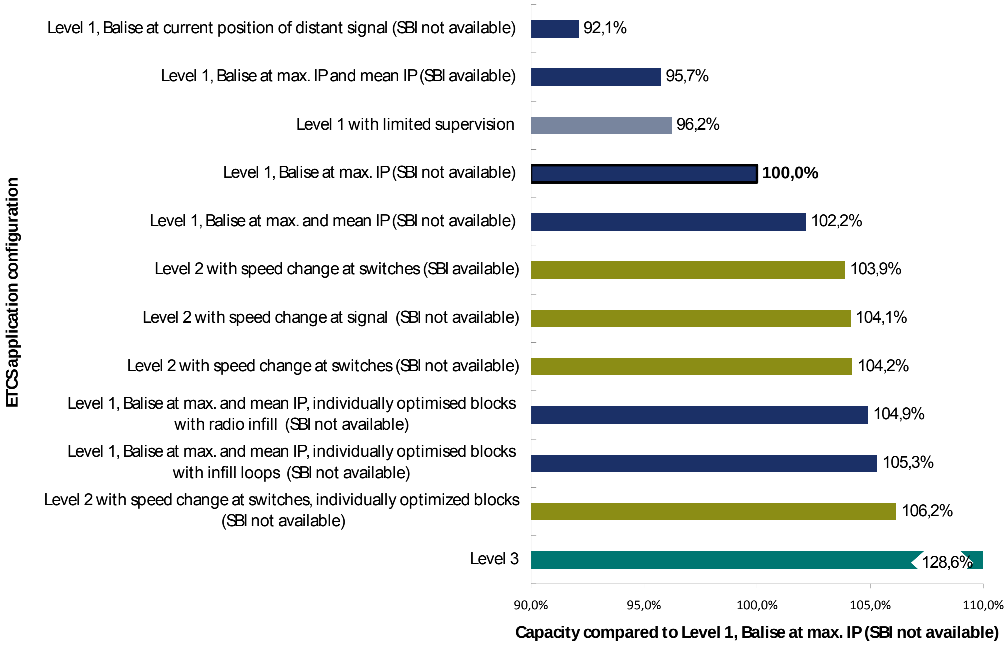


Figure 30 Overall occupation ratios in Bern junction

5.3.7 Evaluation of waiting times

Besides the evaluation of the occupation ratio the change in waiting times is once again taken into account. In Table 28 the calculated optimal mean number of trains is shown and in the figure below the results are scaled to the base scenario.

Scenario	Mean optimal number of trains per hour and SRN
Level 3	9,80
Level 2 with speed change at switches, individually optimised blocks (SBI not available)	8,34
Level 1, Balise at max. and mean IP, individually optimised blocks with infill loops (SBI not available)	8,23
Level 1, Balise at max. and mean IP, individually optimised blocks with radio infill (SBI not available)	8,20
Level 2 with speed change at switches (SBI not available)	8,20
Level 2 with speed change at signal (SBI not available)	8,19
Level 2 with speed change at switches (SBI available)	8,17
Level 1, Balise at max. and mean IP (SBI not available)	7,99
Level 1, Balise at max. IP (SBI not available)	7,81
Level 1 with limited supervision	7,71
Level 1, Balise at max. IP and mean IP (SBI available)	7,60
Level 1, Balise at current position of distant signal (SBI not available)	7,00

Table 28 Mean optimal number of trains per hour and SRN in Bern

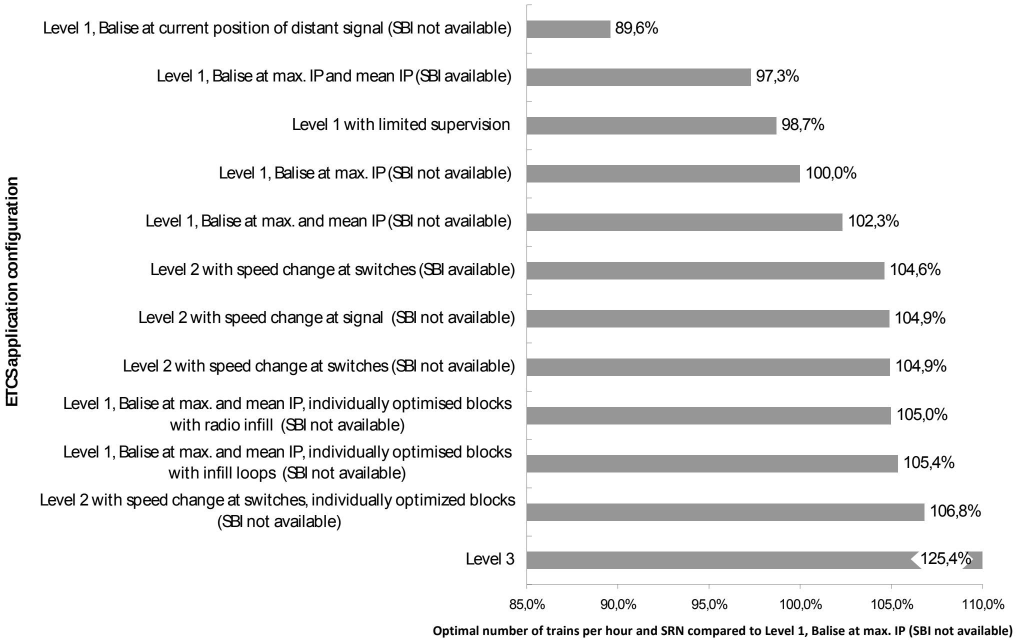


Figure 31 Average optimal number of trains depending on waiting times in Bern junction

5.3.8 Evaluation of infill

In addition to the considerations of Chapter 5.2.8 the effect of infill is taken into account in another situation. Entering Bern HB southbound, trains changing direction in the station may run the "last" couple of metres on the opposite line track after passing switches permitting a high speed of 100 km/h. The impact of infill in the case of an opposing train movement at Bern-Wylerfeld (train leaving Bern HB northbound on correct track, train entering Bern HB southbound on opposite track) is assessed. The release speed is set to 40 km/h again, and the acceleration values of the second train correspond to an SBB class Re 460 with ten passenger coaches.

Only small benefit from infill

Since the opposing movement leads to a minimum headway time of 181 seconds, infill merely shows a small effect in terms of 1.4 seconds additional buffer time or 0.16 seconds "saved" knock-on delay. Furthermore it must be remembered that this train sequence only occurs a couple of times per hour, if the second train reverses in Bern HB.

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Annexes

Train types at Munich junction

Train Type Number	Train Type Character	Train category	Train class	Origin	Destination
108	ICE-A	FRz	401-17.22	Rosenheim	München Hbf
109_1	ICE-A	FRz	401-17.22	München Hbf	Rosenheim
1201	TALGO	FRz	101-3.2	Augsburg Hbf	München Hbf
1503	ICE-T	FRz	411-2.2	Augsburg Hbf	München Hbf
1603	ICE-T	FRz	411-2.2	Reichswald	München Hbf
1710	ICE-T	FRz	411-2.2	München Hbf	Augsburg Hbf
191	EC	FRz	218-3.0	Geltendorf	München Hbf
196	EC	FRz	218-3.0	München Hbf	Geltendorf
2083	IC	FRz	1116-1.2	Augsburg Hbf	Rosenheim
2088	IC	FRz	1116-1.2	Rosenheim	Augsburg Hbf
2293	IC	FRz	101-3.2	Augsburg Hbf	München Hbf
2293_1	IC	FRz	101-3.2	München Hbf	Rosenheim
2296_1	IC	FRz	101-3.2	München Hbf	Augsburg Hbf
25473	S	S	628-4.0	Dachau Bahnhof	München Hbf
25480	S	S	628-4.0	München Hbf	Dachau Bahnhof
27000	RE-D	NRz	218-3.0	Mühldorf/Obb	München Hbf
27013	RE-D	NRz	218-3.0	München Hbf	Mühldorf/Obb
27024	RB-D	NRz	218-3.0	Mühldorf/Obb	München Hbf
27025	RB-D	NRz	218-3.0	München Hbf	Mühldorf/Obb
27040	RB-D	NRz	218-3.0	Mühldorf/Obb	München Hbf
27043	RB-D	NRz	218-3.0	München Hbf	Mühldorf/Obb
27350	RB	NRz	628-4.0	Grafing Bahnhof	München Hbf
30001	RB-D	NRz	111-1.2	München Hbf	Rosenheim
30002	RB	NRz	111-1.2	Rosenheim	München Hbf
30004	RE-D	NRz	111-1.2	Rosenheim	München Hbf
30009	RE-D	NRz	111-1.2	München Hbf	Rosenheim
30453	RB-D	NRz	111-1.2	Ingolstadt Nord	München Hbf
30454	RB-D	NRz	111-1.2	München Hbf	Ingolstadt Nord
30560	RB	NRz	425-3.2	Tutzing	München Hbf
30563	RB	NRz	425-3.2	München Hbf	Tutzing
30603	RB	NRz	111-1.2	München Hbf	Tutzing
30607	RB	NRz	111-1.2	München Hbf	Tutzing
30622	RB	NRz	111-1.2	Tutzing	München Hbf
318	CNL	FRz	101-3.2	München Hbf	Augsburg Hbf
32372	RB	NRz	143-6.2	München Hbf	Landshut/B Hbf
32377	RB	NRz	143-6.2	Landshut/B Hbf	München Hbf
32404	RB	NRz	143-6.2	München Hbf	Landshut/B Hbf
32568	RB	NRz	143-6.2	München Hbf	Landshut/B Hbf

Annexes

Train Type Number	Train Type Character	Train category	Train class	Origin	Destination
32668	RE	NRz	218-3.0	München Hbf	Geltendorf
32751	RE	NRz	218-3.0	Geltendorf	München Hbf
37026	RE-D	NRz	111-1.2	München Hbf	Augsburg Hbf
37027	RE-D	NRz	111-1.2	Augsburg Hbf	München Hbf
37035	RB	NRz	111-1.2	Augsburg Hbf	München Hbf
37068	RB-D	NRz	111-1.2	München Hbf	Augsburg Hbf
388	EN	FRz	1116-1.2	Rosenheim	München Hbf
389	EN	FRz	1116-1.2	München Hbf	Rosenheim
4002	RE	NRz	101-3.2	München Hbf	Reichswald
4003	RE	NRz	101-3.2	Reichswald	München Hbf
4032	RE	NRz	101-3.2	München Hbf	Ingolstadt Hbf
4035	RE	NRz	101-3.2	Ingolstadt Hbf	München Hbf
40554	TEC	FGz	155-1.2	München Ost Rbf	Augsburg Hbf
40580	DGS	FGz	185-2.2	Rosenheim	Mü-Laim Rbf
4171	RE-D	NRz	111-1.2	Augsburg Hbf	München Hbf
42126	TEC	FGz	182-1.2	Rosenheim	Mü-Laim Rbf
42149_1	TEC	FGz	1016-1.2	Mü Nord Rbf Mi	Rosenheim
42180_1	TEC	FGz	182-1.2	München Ost Rbf	Augsburg Hbf
4264	RE-D	NRz	111-1.2	München Hbf	Landshut/B Hbf
4271	RE-D	NRz	111-1.2	Landshut/B Hbf	München Hbf
4276	RE-D	NRz	111-1.2	München Hbf	Landshut/B Hbf
43101_1	DGS	FGz	185-2.2	Mü-Laim Rbf	Rosenheim
43108	DGS	FGz	185-2.2	Rosenheim	Mü-Pasing Gbf
43236	TEC	FGz	152-3.2	München Ost Rbf	Augsburg Hbf
43241	TEC	FGz	152-3.2	Augsburg Hbf	München Ost Rbf
43246	TEC	FGz	151-1.2	München Ost Rbf	Augsburg Hbf
43811_1	DGS	FGz	185-2.2	Mü-Laim Rbf	Rosenheim
43845	TEC	FGz	1044-1.2	Landshut/B Hbf	Rosenheim
43848	TEC	FGz	1044-1.2	Rosenheim	Landshut/B Hbf
43849	TEC	FGz	1044-1.2	Landshut/B Hbf	Rosenheim
47765	CS	FGz	185-2.2	Augsburg Hbf	München Ost Rbf
482	EN	FRz	101-3.2	München Hbf	Ingolstadt Nord
483	EN	FRz	101-3.2	Ingolstadt Nord	München Hbf
48833_1	DGS	FGz	1116-1.2	Mü-Feldmoching	Rosenheim
48842	DGS	FGz	182-2.2	Rosenheim	Mü Nord Rbf Mi
49825	CSQ	FGz	151-1.2	Ingolstadt Nord	München Ost Rbf
50000	PIC	FGz	182-1.2	München-Riem Ubf	Ingolstadt Nord
50001	PIC	FGz	182-1.2	Ingolstadt Nord	München-Riem Ubf
50072	IKE	FGz	151-1.2	München-Riem Ubf	Augsburg Hbf
50121	IKE	FGz	151-1.2	Augsburg Hbf	München-Riem Ubf
50122	IKE	FGz	151-1.2	München-Riem Ubf	Augsburg Hbf

Annexes

Train Type Number	Train Type Character	Train category	Train class	Origin	Destination
50216	IKE	FGz	152-3.2	München-Riem Ubf	Augsburg Hbf
50246	IKE	FGz	152-3.2	Augsburg Hbf	München-Riem Ubf
511	ICE-W	FRz	403-2.1	Augsburg Hbf	München Hbf
521	ICE-W	FRz	403-2.1	Reichswald	München Hbf
52684	FR	NGz	217-2.0	Mühldorf/Obb	Mü Nord Rbf Mi
52686	FR	NGz	233-2.0	Mühldorf/Obb	Mü Nord Rbf For
52694	FR	NGz	217-2.0	Mühldorf/Obb	Mü Nord Rbf Mi
52741	FR	NGz	217-2.0	Mü Nord Rbf Mi	Mühldorf/Obb
56355	FZT	NGz	294-1.0	München Süd	Mü-Laim Rbf
56356	FZT	NGz	294-1.0	Mü-Mittersendl	Mü-Laim Rbf
56357	FZT	NGz	294-1.0	München Süd	Mü Nord Rbf Mi
56361	FZT	NGz	294-1.0	Wolfratshausen	Mü Nord Rbf Mi
56362	FZT	NGz	365-1.0	München Süd	Mü-Pasing Bbf
56364	FZ	NGz	365-1.0	München Süd	Mü-Pasing Bbf
56366	FZT	NGz	365-1.0	München Süd	München-Freiham
56367	FZT	NGz	365-1.0	München-Freiham	München Süd
56368	FZT	NGz	365-1.0	Mü Nord Rbf Ri S	München Süd
56369	FZT	NGz	365-1.0	München Süd	Mü Nord Rbf Mi
56370	FZT	NGz	294-1.0	Mü Nord Rbf Ri S	München Ost Rbf
56382	FZT	NGz	365-1.0	Mü Nord Rbf Mi	München Süd
56384	FZ	NGz	365-1.0	Mü Nord Rbf Mi	München Süd
56481	FZ	NGz	1044-1.2	Mü Nord Rbf Mi	Holzkirchen
56691	FZT	NGz	294-1.0	Feldkirchen b Mü	Mü Nord Rbf Mi
56692	FZT	NGz	1044-1.2	Mü Nord Rbf Mi	Feldkirchen b Mü
56716	FZ	NGz	294-1.0	Mü Nord Rbf Mi	München-Riem Ubf
56723	FZ	NGz	294-1.0	München-Riem Ubf	Mü Nord Rbf Mi
56725	FZ	NGz	140-1.2	München-Riem Ubf	Mü Nord Rbf Mi
56728	FZ	NGz	139-1.2	Mü Nord Rbf Mi	München-Riem Ubf
58422	Tfzf (RaR)	Lz	294-1.0	Mü Nord Rbf Mi	München Süd
58423	Tfzf (RaR)	Lz	294-1.0	Mü Nord Rbf For	München Süd
58428	Tfzf (RaR)	Lz	365-1.0	München Süd	Mü-Laim Rbf
58429	Tfzf (RaR)	Lz	365-1.0	Mü-Laim Rbf	München Süd
59078	DGS	FGz	182-2.2	München-Riem Ubf	Augsburg Hbf
59097	DGS	FGz	182-1.2	Augsburg Hbf	München-Riem Ubf
59116	DGS	FGz	182-1.2	München-Riem Ubf	Mü-Laim Rbf
60870	CS	FGz	233-2.0	Mühldorf/Obb	Augsburg Hbf
60882	CS	FGz	233-2.0	Mühldorf/Obb	Augsburg Hbf
60909	CS	FGz	155-1.2	Ingolstadt Nord	München Süd
616	ICE-W	FRz	403-2.1	München Hbf	Augsburg Hbf
63	EC	FRz	101-3.2	München Hbf	Rosenheim
68	EC	FRz	1116-1.2	Rosenheim	München Hbf

Train Type Number	Train Type Character	Train category	Train class	Origin	Destination
684	ICE-A	FRz	401-17.22	München Hbf	Reichswald
68963	Tfzf (RaS)	Lz	101-1.2	Mü-Laim Rbf	München-Riem Ubf
68978	Tfzf (RaS)	Lz	120-1.2	München-Riem Ubf	Mü-Laim Rbf
68995	Tfzf (RaS)	Lz	151-1.2	Mü Nord Rbf Mi	München Ost Rbf
69062	Tfzf (RaS)	Lz	1016-1.2	München Ost Rbf	Mü Nord Rbf For
69152	Tfzf (RaS)	Lz	1016-1.2	München Ost Rbf	Mü Nord Rbf Mi
726	ICE-W	FRz	403-2.1	München Hbf	Reichswald
73650	Lr-D	Rz	218-3.0	München Ost Pbf	München Hbf
73651	Lr-D	Rz	218-3.0	München Hbf	München Ost Pbf
73661	Lr	Rz	628-4.0	München Hbf	München Ost Pbf
75604	Fak	Rz	111-1.2	München Hbf	Mü-Pasing Bbf
75752	Lr	Rz	218-3.0	München Hbf	Geltendorf
75756	Lr	NRz	218-3.0	München Hbf	Geltendorf
75757	Lr	NRz	218-3.0	Geltendorf	München Hbf
75801	Lr	NRz	425-3.2	München Hbf	Tutzing
75954	Lr-D	NRz	111-1.2	Mü-Pasing Bbf	München Hbf
75961	Lr-L	NRz	218-3.0	München Hbf	Mü-Pasing Bbf
75962	Lr	NRz	110-1.2	Mü-Pasing Bbf	München Hbf
75971	Lr-D	NRz	111-1.2	München Hbf	Mü-Pasing Bbf
75972	Lr	Lz	111-1.2	Mü-Pasing Bbf	Mü Hbf Vorst.Süd
77166	Lr-D	Rz	111-1.2	München Hbf	Landshut/B Hbf
77168	Lr-D	Rz	111-1.2	München Hbf	Augsburg Hbf
78110	Lr	Lz	403-2.1	Mü Hbf Vorst.Süd	Mü-Laim ICE WuA
78118	Lr	Lz	403-1.2	Mü-Laim ICE WuA	Mü Hbf Vorst.Süd
78163	Lr	Lz	401-17.22	Mü-Laim Rbf	Mü Hbf Vorst.Süd
78169	Lr	NRz	110-1.2	München Hbf	Mü-Pasing Bbf
78175	Lr	NRz	101-3.2	München Hbf	Mü-Pasing Bbf
78177	FbZ	Rz	110-1.2	München Ost Pbf	München Hbf
78177_1	Lr	Lz	110-1.2	Mü Hbf Vorst.Süd	Mü-Pasing Bbf
78179	AS	Lz	110-1.2	Mü Hbf Vorst.Süd	Mü-Pasing Bbf
78188	Lr	Lz	110-1.2	Mü-Pasing Bbf	Mü Hbf Vorst.Süd
78193	Lr	NRz	110-1.2	München Hbf	Mü-Pasing Bbf
78195	Lr	Lz	110-1.2	Mü Hbf Vorst.Süd	Mü-Pasing Bbf
78256	LICE-A	Rz	401-17.22	München Hbf	Ingolstadt Nord
78258	LICE-A	FRz	401-17.22	München Hbf	Landshut/B Hbf
78265	Lr	NRz	403-2.1	München Hbf	Reichswald
78268	Lr	NRz	402-1.22	München Hbf	Geltendorf
78270	LICE-T	Rz	411-2.2	München Hbf	Ingolstadt Nord
79618	Lr	NRz	115-1.2	München Hbf	München Ost Pbf
79627	Tfzf (F)	Lz	115-1.2	Mü-Laim Rbf	München Ost Pbf
79634	Tfzf (F)	Lz	115-1.2	München Ost Pbf	Mü-Laim Rbf

Annexes

Train Type Number	Train Type Character	Train category	Train class	Origin	Destination
8006	S	S	423-5.2	Deisenhofen	München Hbf
8007	S	S	423-5.2	München Hbf	Deisenhofen
820	ICE-W	FRz	403-2.1	München Hbf	Ingolstadt Hbf
86002	DPN	NRz	182-2.2	München Hbf	Landshut/B Hbf
86003	DPN	NRz	182-2.2	Landshut/B Hbf	München Hbf
86205	DPN	NRz	ER 20D-2.0	Geltendorf	München Hbf
86208	DPN	NRz	ER 20D-2.0	München Hbf	Geltendorf
86720	DPN	NRz	INTEGR-2.0	Holzkirchen	München Hbf
86725	DPN	NRz	INTEGR-2.0	München Hbf	Holzkirchen
88	IC	FRz	101-3.2	Rosenheim	München Hbf
8857	S	S	423-5.2	Grafrath	München Hbf
8922	S	S	423-5.2	München Hbf	Wolfratshausen
8923	S	S	423-5.2	Wolfratshausen	München Hbf
985	ICE-A	FRz	401-17.22	Reichswald	München Hbf

Annexes

Train types at Bern junction

Train Type Number	Train Type Character	Train category	Train class	Origin	Destination
IC BR BN RH	IC	FRz	Re 460-1.2	Bern	Rothrist
IC BR BN RH	IC	FRz	Re 460-1.2	Thun	Bern
IC BS BN IO	IC	FRz	Re 460-1.2	Bern	Thun
IC BS BN IO	IC	FRz	Re 460-1.2	Rothrist	Bern
IC BS BN IO/BR	IC	FRz	Re 460-1.2	Bern	Thun
IC BS BN IO/BR	IC	FRz	Re 460-1.2	Rothrist	Bern
IC GEAP BN SG	IC	FRz	Re 460-1.2	Fribourg	Rothrist
IC IO BN BS	IC	FRz	Re 460-1.2	Bern	Rothrist
IC IO BN BS	IC	FRz	Re 460-1.2	Thun	Bern
IC IO/BR BN BS	IC	FRz	Re 460-1.2	Bern	Rothrist
IC IO/BR BN BS	IC	FRz	Re 460-1.2	Thun	Bern
IC RH BN BR	IC	FRz	Re 460-1.2	Bern	Thun
IC RH BN BR	IC	FRz	Re 460-1.2	Rothrist	Bern
IC SG BN GEAP	IC	FRz	Re 460-1.2	Rothrist	Fribourg
IR BN OL	IR	FRz	Re 460-1.2	Bern	Zofingen
IR BN ZH 1	IR	FRz	Re 460-1.2	Bern	Rothrist
IR BN ZH 2	IR	FRz	Re 460-1.2	Bern	Zofingen
IR GEAP BN LZ	IR	FRz	Re 460-1.2	Fribourg	Rothrist
IR LZ BN GEAP	IR	FRz	Re 460-1.2	Rothrist	Fribourg
IR OL BN	IR	FRz	Re 460-1.2	Aarburg-Oftringen	Bern
IR ZH BN 1	IR	FRz	Re 460-1.2	Rothrist	Bern
IR ZH BN 2	IR	FRz	Re 460-1.2	Aarburg-Oftringen	Bern
RE BI BN	RE	NRz	Re 460-1.2	Lyss	Bern
RE BN BI	RE	NRz	Re 460-1.2	Bern	Lyss
RE BN BR	RE	NRz	Re 460-1.2	Bern	Thun
RE BN LZ	RE	NRz	Re 460-1.2	Bern	Langnau
RE BN NE	RE	NRz	Re 460-1.2	Bern	Kerzers
RE BR BN	RE	NRz	Re 460-1.2	Thun	Bern
RE LZ BN	RE	NRz	Re 460-1.2	Langnau	Bern
RE NE BN	RE	NRz	Re 460-1.2	Kerzers	Bern
S1 FRI BN TH	S	S	Re 420-1.2	Fribourg	Thun
S1 TH BN FRI	S	S	Re 420-1.2	Thun	Fribourg
S2 LN BN LPN	S	S	Re 420-1.2	Langnau	Flamatt
S2 LPN BN LN	S	S	Re 420-1.2	Flamatt	Langnau
S3 BI BN BP	S	S	Re 420-1.2	Lyss	Belp
S3 BP BN BI	S	S	Re 420-1.2	Belp	Lyss
S44 SWG BN TH	S	S	Re 420-1.2	Burgdorf	Thun
S44 TH BN SWG/WR	S	S	Re 420-1.2	Thun	Burgdorf

Annexes

Train Type Number	Train Type Character	Train category	Train class	Origin	Destination
S5 BN NE	S	S	Re 420-1.2	Bern	Kerzers
S5 NE BN	S	S	Re 420-1.2	Kerzers	Bern
S51 BN BNB	S	S	Re 420-1.2	Bern	Bern Brünnen
S51 BNB BN	S	S	Re 420-1.2	Bern Brünnen	Bern
S52 BN KZ	S	S	Re 420-1.2	Bern	Kerzers
S52 KZ BN	S	S	Re 420-1.2	Kerzers	Bern
S6 BN SCBG	S	S	Re 420-1.2	Bern	Köniz
S6 SCBG BN	S	S	Re 420-1.2	Köniz	Bern
TGV BN Paris	TGV	FRz	Re 460-1.2	Bern	Kerzers
TGV Paris BN	TGV	FRz	Re 460-1.2	Kerzers	Bern

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