A new offer concept for increasing capacity with smartrail 4.0

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Summary

The aim of the technology behind smartrail 4.0 is to improve blocking sections and reduce the gap between consecutive trains by using moving blocks and precisely identifying the locations of these trains. An initial capacity assessment of a locally isolated route and a nodal point has identified and outlined the first effects of smartrail 4.0. The service concept was grounded by the system limitations of the observation perimeter, which meant that a quantum leap in the form of capacity gains could not be achieved. The next step comprised the development of a network-wide service concept, which would enable conclusions about capacity effectiveness to be drawn. This paper presents the technical assumptions, the findings achieved thus far and the next steps towards achieving a network-wide service structure and its impact on capacity.

Keywords: smartrail 4.0, increase in capacity, ETCS Level 3, service concept

1 Introduction

smartrail 4.0 is an innovation programme from the Swiss railway industry. The Swiss railway industry aims to use this programme to harness digitalisation and the potential of new technologies in order to further increase capacity and safety, make more efficient use of railway infrastructure, save costs and thus maintain the railway's competitiveness in the longer term.

The focus of this specialist article is the increase in capacity that this programme could trigger and its implementation in a specific service concept on the Swiss normal-gauge network.

In Section 2, we will outline the technical parameters and the most important changes to be expected from smartrail 4.0 in terms of capacity. We will then go on to take a look at which other factors besides technology have an influence on capacity in Section 3. Section 4 and 5 will illustrate the outcomes of local capacity assessments with two different methods and Section 6 will conclude the paper by presenting methodology for a network-wide capacity assessment.

In Switzerland, the timetable information for conducting a capacity study of this kind are very detailed. In December 2004, Switzerland introduced an integral regular-interval timetable as part of the Rail 2000 project. This also led to an extensive change in the way in which major network expansion projects are identified, planned and concluded in the medium (+8 years) and long term (+20 years). The regular-interval timetable in Switzerland has enabled minute-by-minute timetables to be produced for use in the long term. Knowledge of a long-term timetable structure and the underlying service volumes lead to the following particular approach to capacity assessments.

2 Effects of smartrail 4.0 on capacity

2.1 Background

Before the capacity assessment got under way, the technical parameters that would change with smartrail 4.0 were identified. In Switzerland, blocking sections are not yet widely deployed. Instead, the concept of headway times is applied, whereby the journeys of two consecutive trains are observed at each signal. Using these headway times as guidance, the concept of blocking sections was introduced with the aim of drawing a comparison between the signalling systems.

2.2 Headway times model

The technical headway time (tZfZ) for trains travelling at a constant speed can be calculated very easily using a closed formula. According to Figure 88, the distance between two trains following each other at a speed of v can be calculated on the basis of train length sZug, overlap sDW, signal section length sSA, braking distance sB and system times (response time tE and resolution time tA). The response time tE includes all times from the start of the route to the time at which the movement authority applies to the vehicle, i.e. in particular the times of the signal box, the Radio Block Centre (RBC) and the transmission via GSM-R. The resolution time tA, on the other hand, comprises the times from when the train leaves the section to the time the route is terminated.

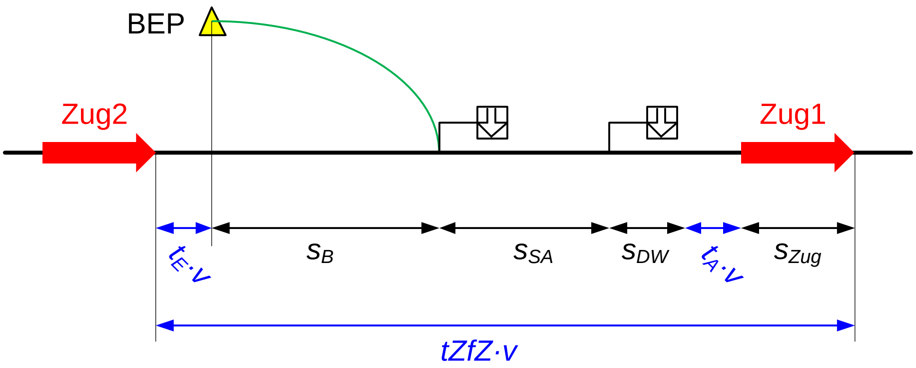

Figure 88: Representation of technical headway time tZfZ

The technical headway time can be calculated as follows:

$$tZfZ = \frac{s_B + s_{SA} + s_{DW} + s_{Zug}}{v} + t_E + t_A$$

Formula 1: Calculation of headway time

The train length has been specified. The system times can be influenced within tight margins and according to the choice of technical implementation. The braking distance (at the given speed) is determined by the braking capacity and the required safety margin. The overlap is also taken from the safety specifications. The signal section length is the only variable.

Table 14 presents the resulting tZfZ for different scenarios. The calculations are based on the ETCS braking curves in accordance with SRS Baseline 3, without using the service brake and by applying the safety margins specified for L2 facilities in Switzerland. The values tE=10 s and tA=2 s were adopted for the service times; the gradient was taken as zero.

Train	sZug	Braking percentage	v	sB	sSA	sDW	tZfZ	sB1	sB2	sB3
IC	400 m	135%	100 km/h	1009 m	500 m	50 m	82.5 s	111 m	347 m	552 m
IC	400 m	135%	160 km/h	2094 m	500 m	50 m	80.5 s	178 m	555 m	1361 m
IC	400 m	135%	200 km/h	3118 m	500 m	200 m	87.9 s	222 m	693 m	2202 m
GZ	750 m	65%	100 km/h	2087 m	500 m	50 m	133.9 s	111 m	639 m	1336 m

Table 14: Comparison of distances for headway times

The braking distance sB is crucial in terms of headway time, which is why it is worth taking a closer look at this. The braking distance is essentially composed of:

- sB1: Engine driver ergonomics time (time within which the engine driver can react and apply the brakes; the time is determined in accordance with SRS 4 s and is converted to distance)
- sB2: Technical reaction time of the braking system (from the time the brakes are applied by the engine driver to when the brakes begin to take effect; converted to distance)
- sB3: Safe monitoring of the braking distance (braking curve, which, when exceeded, triggers emergency braking, resulting in a safe stop before a danger point; in ETCS, this corresponds to the emergency brake intervention curve EBI)

The sB2+sB3 ratio is crucial. The term comprises the technical condition of a train's braking system and, in particular, its monitoring with regard to safety. The required level of safety has direct major impact on the headway time, but for its part is not, however, dependent on the technical implementation of the monitoring. With the same safety requirements, sB2+sB3 therefore does not ultimately depend on whether the automatic train protection is ETCS L1, L2, L3 (with or without a moving block) or another system. It also becomes clear here that the scope for reducing headway time is fairly limited.

In contrast to the calculations above using a constant speed, the headway times with a variable speed (or even variable gradients) are much more complex. Particularly relevant here is the effect of speed thresholds going from higher to lower speeds, which cause headway times to increase. In this case, the rise in the headway time directly depends on the extent of the speed threshold. This behaviour occurs regardless of the signalling system selected.

2.3 Using the blocking section model to calculate headway times

In order to compare the capacity of smartrail 4.0 with existing systems, the blocking sections for different types of signalling were compared – visual signalling (ZUB/SIGNUM/ETCS L1 LS), cab-signalling ETCS L2 and smartrail 4.0. As part of this task, various aspects of smartrail 4.0 with moving blocks were identified (also see [1]). In the case of moving blocks (L3), the signal section length is zero in theory. In real terms, the signal section length corresponds to the distance covered by the train during a TPR (train position report) cycle, plus twice the localisation inaccuracy (at the rear of train 1 and the front of train 2). For the purposes of comparison with visual signalling, the following blocking section model with a distance-time representation was used:

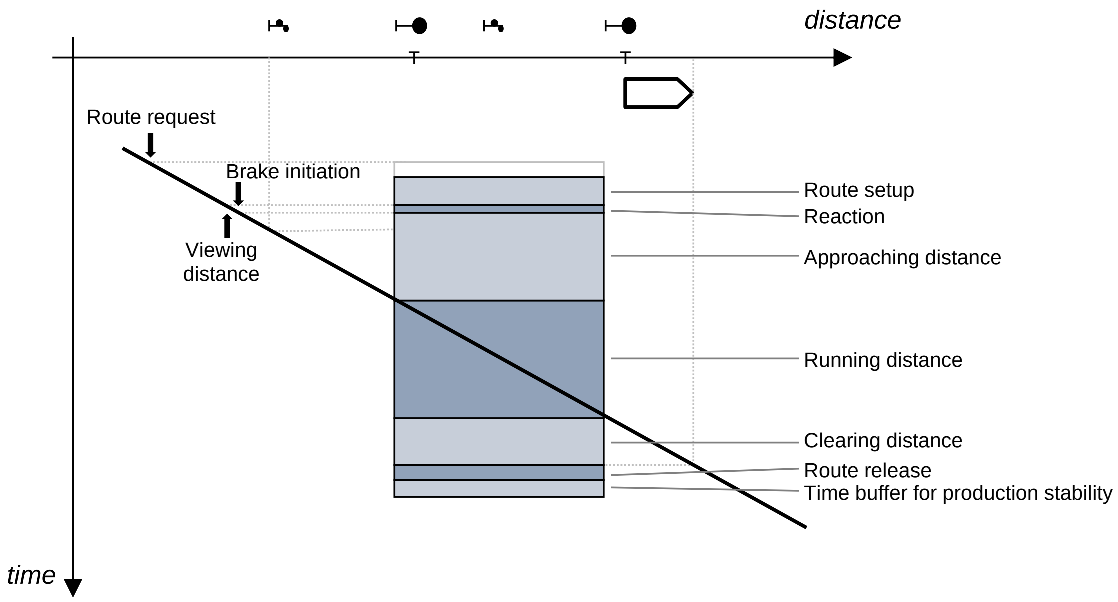

Figure 89: Generic blocking section model

Explanation of terms used in the blocking section model:

Time element	**Description**
Route setup	The *route request* has to start early enough so that the signal will be open before the start of the reaction time. This corresponds to tE in Figure Figure 88.
Reaction	The reaction time is granted to the train driver in order to interpret the information and react in consequence. This is included in sB in Figure Figure 88.
Approaching distance	Time needed for the head of the train to reach the position of the considered start signal. This is sB2+sB3 in Figure Figure 88.
Running distance	Time needed for the head of the train to reach the position of the considered end signal. This corresponds to sSA in Figure Figure 88.
Clearing distance	Time needed for the head of the train to reach the position where the end of the train gets out of the considered block or movement authority. This corresponds to sDW+sZug in Figure Figure 88.
Route release	Time needed for the system to release the occupation of the considered block. This corresponds to tA in Figure Figure 88.

Time buffer for production stability	Time needed to ensure a higher stability of the train traffic. This is not included in Figure Figure 88.

Table 15: Overview of the time elements in the blocking section model

The ergonomics time (reaction) covers slightly different aspects depending on the signalling and safety system. In Switzerland, a visual signal must be displayed for at least 10 seconds before it is passed. The brakes actually need to be applied before the signal is passed. These 10 seconds therefore only represent an actual ergonomics time sB1 to an extent, as they also account for the technical reaction time of the braking system sB2.

For each train, blocking times are calculated for each signal section length. By grouping the blocking section times of one section together, you can calculate the headway time for this section.

2.4 Influence of smartrail 4.0

Adopting smartrail 4.0 in the blocking times model

The foundation for smartrail 4.0 is ATO GoA 2 [2] with an absolute braking distance and a localisation accuracy of +/-10 metres, a localisation frequency of 1 second (TPR cycle) and the removal of all local track-release signalling equipment. The signalling installation calculates the extension of the movement authority and sends it directly to the vehicle without waiting for a request from the vehicle. The calculations are based on the ETCS Baseline 3.6.0 braking curve model with no service brake in target speed monitoring. The safety margins of the braking curves correspond to the provisions for Level 2 routes applicable in Switzerland. It is also assumed that the trains are travelling along the $V_{Permitted}$ [3].

The ergonomics time of 4s in sB1 included in the current headway times model is not sufficient for the narrow blocking sections in smartrail 4.0. It is hardly reasonable for an engine driver to constantly be on the verge of applying the brakes when driving. Instead, an additional reserve is to be brought in, which is currently believed to be 15 seconds. With ATO, this time is not a factor.

smartrail 4.0 allows for very short signal sections, which theoretically head in the direction of zero with moving blocks. As a result, the blocking sections become significantly narrower. This can be seen in Figure 90, in which the blocking sections with smartrail 4.0 (bands) are compared with the blocking sections of conventional external signalling (empty) squares. The free time between the blocking sections of the individual trains, made possible by smartrail 4.0, is clearly visible. By way of comparison, the figure also shows the blocking sections of conventional external signalling in the form of.

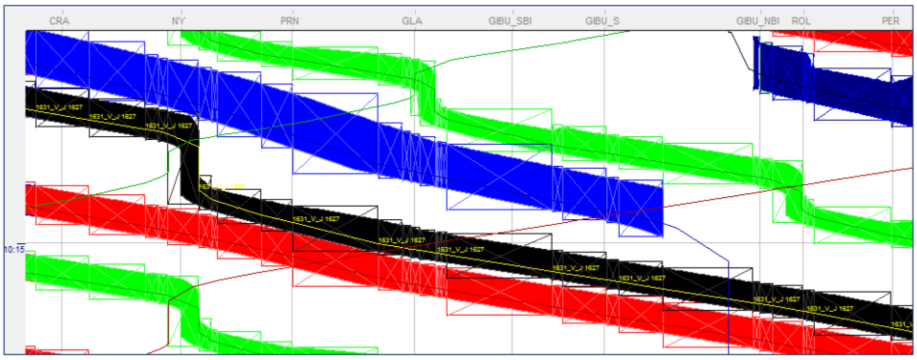

Figure 90: Change to the blocking time sections on the Lausanne–Geneva route

The default value is calculated according to $\boldsymbol{T_{Indication\_ATO} = max(0.8 \cdot T_{bs}, 5s)}$, i.e. with ATO, the time T_{Driver} is not considered.

Impact of smartrail 4.0 on blocking times, headway times and travel times

The relationship between advance signal distances and permitted speeds is eliminated with cab-signalling. Each train receives its own (individual) time to apply the brakes at any given location (in contrast to the fixed-location advance signal used with external signalling). This means that any train can travel at the maximum speed permitted by rolling stock and topology without any additional signalling restrictions. On routes with mixed traffic, on which today the blocking distances are mostly designed to meet the needs of passenger traffic, freight trains can better deliver their permitted speeds thanks to cab-signalling.

Speed thresholds increase headway times. This effect can be reduced by distributing thresholds with large speed differences to several thresholds with small speed differences. However, trains must then brake earlier, i.e. to slow down for shifted speed thresholds. The lower headway times thus result in an increase in the travel time. This optimisation option between travel and headway time must be taken into account by the Traffic Management System on a case-by-case basis.

With cab-signalling, speed thresholds can be freely configured independently of fixed signal locations (e.g. exactly at the start of a set of points travelled over in the diverging position). One would expect that the later brake application point would reduce the minimum travel time. With ETCS, however, $V_{Permitted}$ and thus the assumed travel curve of the train reaches the lower speed before the actual speed threshold. This behaviour, combined with the braking curves which are flatter than those of external signalling, prevents savings in travel time.

3 Relevant factors for capacity

For the purposes of this observation, the number of train paths that can be operated effectively in relation to a given service and quality objective (punctuality) is of interest. This capacity effectively adds value for rail customers. As described in Section 2, the signal sections are reduced to zero with smartrail 4.0 and enable headway time to be reduced. However, the capacity not only depends on the signal section length, but is also a result of the interaction of various factors: timetable structure (service), rolling stock (dynamics and stopping procedure), technical possibilities of the signalling installations (blocking sections), regulatory framework, railway network topology and operational precision when travelling and stopping. In order to make a statement about capacity, assumptions must be made about all these aspects. Unless otherwise stated, the following assumption applies: “It generally remains at least as good as it is.”

Timetable structure (service)

An increase in capacity means that additional train paths are planned which can be used by more trains while still maintaining their quality. This will only be possible if there is a service request and the network-wide timetable structure is expanded accordingly without causing any conflicts.

The network-wide timetable structure determines which “time slots” [13] are occupied by which trains in which order, where and when. The resulting capacity utilisation (in number of trains) is higher or lower, depending on the timetable structure.

Which train can be where and when is particularly important. All newly created “time slots” must also be used accordingly by a train that fulfils a service request.

Rolling stock (dynamics and stopping procedure)

When and where a train can be, depends on the service, the railway topology (tracks) in use, its driving dynamics and the time required for each stop. In terms of capacity, it is important that a train can always accelerate and brake equally, reliably and strongly in all weather conditions. The time required for the doors to open, for the exchange of passengers, to change direction, join together, disconnect and start up (restart) must be kept as short as possible.

Technical possibilities of signalling installations

The signalling installations ensure the required safety of rail traffic. Visual signals, ETCS L2 and the new smartrail 4.0 technology are various ways of making train journeys safe and secure. They have different effects on the blocking sections.

[13] The density of the entry possibilities is to be understood here based on air traffic.

Regulatory framework

Railway operations in Switzerland are governed by many regulations and implementing provisions. These documents regulate the activities related to how train journeys and shunting manoeuvres are carried out. They are revised regularly or as a result of an incident and can also affect capacity – usually in a restrictive sense. For example, following an accident in Rafz on 20 February 2015, a maximum speed of 40 km/h was set for all starting or turning trains until they reached the first balise.

Railway network topology

The topology of the railway network determines which stations are connected, which maximum speeds and train loads are possible, how many train journeys are possible at the same time (e.g. single/double track), how many tracks and platforms are available in nodal points (including their useful length and equipment such as water or power supply) and which switch connections are available (track).

Operational precision (travelling and stopping)

A train path also defines travel and stopping times. The train journey must then adopt these times. Parameters for operational precision are the deviation between realised and planned travel time and between realised and planned stopping time. The shorter the blocking section duration, the more severe the impact of a deviation is. For example, a deviation of 30 seconds with a blocking section duration of 90 seconds is considerably more severe than with a blocking section duration of 5 minutes. Any deviation – whether during stop in station or run on the line – leads to an alternating blocking section, which is then potentially no longer conflict-free with the others.

4 Reducing blocking times with effectively the same service

4.1 Effect on timetable quality

Reducing blocking times leads to more “air” between trains, which reduces the propagation of delays and increases stability and punctuality. As the following study has shown, this effect is very interesting for punctuality alone. Punctuality in the Swiss normal-gauge network would already improve by one percentage point (measured at 180 seconds) if all headway times were reduced by 12 seconds. Based on a real annual service and primary delays measured on the entire Swiss rail network [4], all minimum headway times were gradually increased or reduced on the basis of actual headway times. Figure 91 shows the graphical determination of Swiss punctuality and its connection achievement level with OnTime:

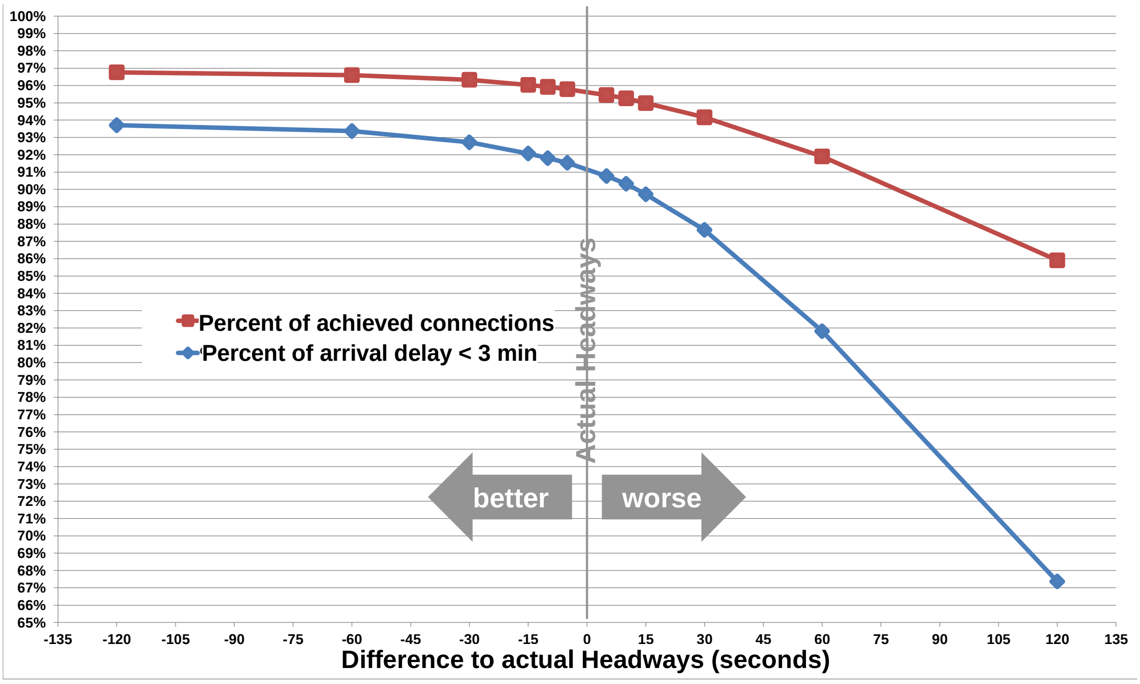

Figure 91: Influence of reduced headway time on punctuality

The figure shows the development of network-wide punctuality (blue line) and connection achievement level (red line) in Switzerland in association with a reduction in the area of restricted blocking sections for train sequences. The technical headway times have been gradually reduced (-X) or increased (+X) by X seconds throughout Switzerland to a minimum of 90 seconds compared with today's headway times.

4.2 Increasing local capacity

After the technical aspects had been clarified, their effects on the capacity of a route and in a nodal point were examined at local level. It is often methods such as the UIC 406 or the STRELE procedure that are used to draw conclusions about capacity. Since the UIC 406 only takes network-wide effects into account to a certain extent and the detailed timetable structure is hidden as standard in STRELE, we opted for an iterative procedure using microsimulation – the planning is simulated, then manually adjusted where necessary and simulated again. This process of using iterative adjustments requires a lot of manual work. However, it does make it possible to become familiar with the new effects (with their opportunities and limitations) very precisely.

Constructive capacity analysis

In order to determine the first effects of smartrail 4.0 on services and infrastructure, a capacity assessment was carried out using a constructive method. The purpose of the study was to find out whether and to what extent additional service objectives could be achieved on an underlying infrastructure. It was also examined whether and to what extent infrastructure measures set for implementation could be abandoned. The aim was to formulate conclusions demonstrating the influence and limits of the new smartrail 4.0 technology using the current service and dimensioning premises.

Test plans

Two laboratory environments with the following different features were defined:

1) Geneva–Lausanne. Very busy route with mixed traffic (long-distance traffic, freight services, two S-Bahn systems).
   The Geneva–Lausanne route needs to be upgraded to achieve the capacity set out in the 2035 outlook. That is why the Swiss Confederation's strategic railway structure development programme (STEP) 2035, among other projects, plans to expand capacity on the La Plaine–Geneva–Lausanne–Biel/Bienne corridor. In addition to various headway time reductions, the three-track expansion of the Allaman–Morges and Gilly-Bursinel–Rolle section is also planned. The route is well suited for simulating the new technical possibilities of smartrail 4.0 and working out their impact on service and infrastructure planning.
2) Lucerne nodal point: terminus operated at its capacity limits with a total of six feeder lines (incl. narrow-gauge line).
   The Lucerne nodal point is currently operating at the limits of its capacity. Only an extension with an underground through-station is currently envisaged as a possible measure to sustainably expand the service in the long term. The project planning for this is in progress. This makes the nodal point very suitable for testing the new technological possibilities of smartrail 4.0 at a terminus operating at the limits of its capacity.

The variants to be examined were first deduced at macroscopic level in the Viriato planning tool. They were then examined with LUKS at microscopic level. Wherever possible, conflicts were resolved using an iterative approach. In order to obtain as valid results as possible, the topology data had to be entered into LUKS.

The table below shows the individual objects of investigation and their results.

Station, route, product	*Expected optimisation*	*Result*
Lucerne nodal point additional LD-train path	Conflict-free planning of an additional train path.	
Coppet, additional connection	RE connection → Create RER to Geneva.	
Lausanne-Triage–Geneva La Praille, quick freight services train path	15-minute reduction in the stopping time at an overtaking station.	
Geneva, quick repopulation of platforms	Quick repopulation of track 3 with RE trains from/to Annemasse.	
Biel/Bienne–Geneva Airport, additional LD-train path	Introduction of an additional bypass train.	
Lausanne–Allaman, reschedule RER by 15 minutes	Dispense with third track for Morges–Allaman.	
Biel/Bienne–Geneva Airport, additional LD-train path	Introduction of a bypass train with rescheduling of the RER Lausanne–Allaman.	

Table 16: Overview of objects of investigation

Below are some of the selected objects of investigation from the test plan.

Lucerne nodal point

The example shows how LUKS was used to investigate a problem relating to the gap in time between a departing freight train and an incoming passenger train. In Figure 92, you can see how close all the journeys are one after the other on a LUKS train graph. Orange is the train's advance reservation, red is the train's occupancy rate and the green triangle is the position of the train's front end with train number information:

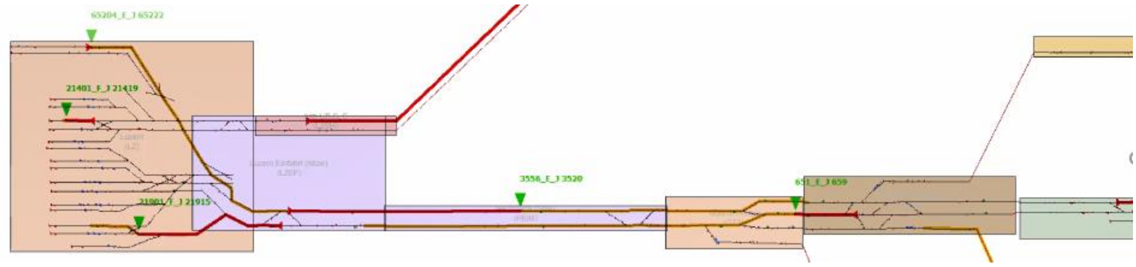

Figure 92: Lucerne nodal point crossing

A freight train (65204) leaves the top left, immediately after passenger train (21041) enters the top left and passenger train (3556) exits. The animation impressively illustrated the feasibility but also the presupposed increase in driving precision.

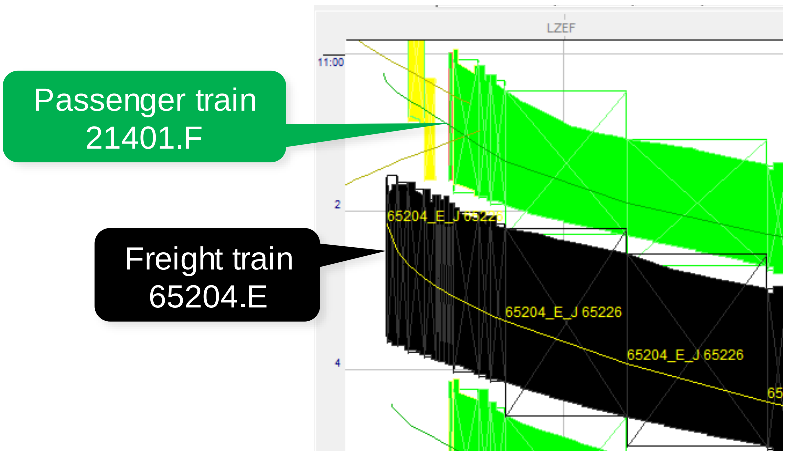

Figure 93: Blocking sections in the Lucerne nodal point

The blocking sections shown in Figure 93 for the two departures illustrate the technical feasibility thanks to the moving blocks of smartrail 4.0. The thin square frames represent the visual blocking sections that would clearly not make it possible.

<u>Coppet, creating a new connection</u>

This example shows how an original variant was converted into an additional connection relationship to a single-track system with narrow crossings. Although the purely technical travel times are identical, an additional connection relationship can be offered in Coppet thanks to the new technological possibilities as well as a percentage reduction in the travel time reserve and a reduction in the stopping time reserve. For passengers travelling from Lausanne, the new short connection time translated into an enormous gain in travel time when changing to the S-Bahn to Geneva at Coppet. Figure 94 compares the original timetable locations of the trains in black with the new timetable locations thanks to smartrail 4.0 in orange:

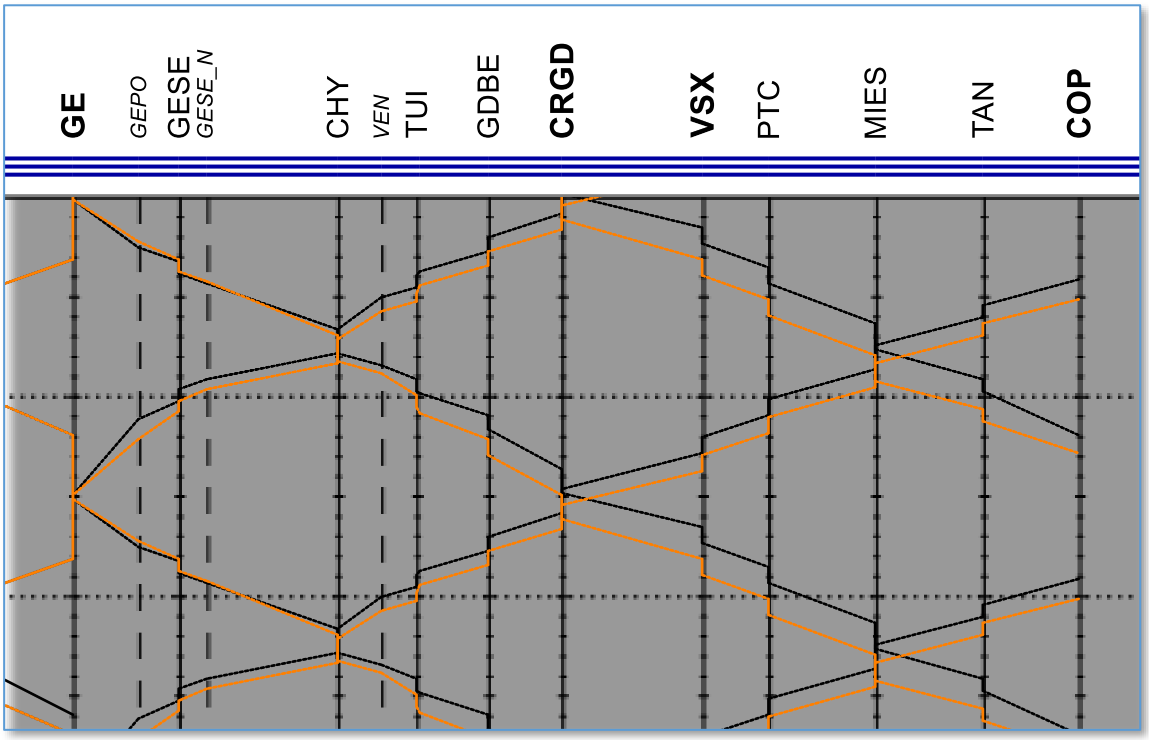

Figure 94: Consolidating rail traffic with smartrail 4.0

A connection can be created from Lausanne thanks to the later departure time at Coppet (COP) station.

4.3 Findings

With LUKS, it was possible to identify essential system connections of the new technical possibilities of smartrail 4.0 and construct them in detail in numerous situations.

The closely interlinked timetable configuration in Lucerne meant that the additional route could be introduced, albeit in conflict with several connections (not enough time). Some other situations were similar in the nature of their problem; the timetable structure of the regular-interval timetable with its predefined connection relationships and services premises set at the system boundaries of the observation perimeter considerably reduced the range of possible solutions. In order to be able to exploit the full spectrum of solutions, thus also demonstrating the overall benefit for public transport customers, an overall concept was developed following this initial test planning stage. See Section 6.

The interactions between traffic density and operational quality were not considered in detail here. For the additional train path in Lucerne, for example, the increase in capacity was represented, but the impact on the operational quality and thus on performance was ignored. To this end, an analytical performance analysis of the selected routes was carried out parallel to the development of the overall concept. See Section 5.

5 Analytical determination of the nominal performance

At the same time, the local study of the Lausanne–Geneva route was supplemented by a study of an isolated route using the STRELE method. The findings aim to challenge, validate and supplement the capacity estimation of the manual planning.

5.1 Performance analysis

With the constructive methods explained in Sections 4.2 and 6, capacity increases were able to be investigated. The operational quality, however, was not specifically considered. In order to draw conclusions about the performance of the new technical capabilities of smartrail 4.0, an analytical study was carried out in LUKS for selected routes and nodal points. Using the STRELE and Potthoff methods based on queueing models, the routes and nodal points were modelled and the nominal performance determined. This was intended on the one hand to provide a comparison basis for the overall concept and, on the other hand, to estimate the reduction in delays that had to be obtained by the achieved capacity while maintaining the current operational quality.

5.2 Object of investigation

In a first iteration, the routes in the Geneva–Lausanne/–Yverdon-Les-Bains triangle were examined. As a premise, it was assumed that the capacity planned for the 2020 timetable represents the accepted level of service with the underlying infrastructure and delay data. The delay data of two whole years (Mon-Fri, 1.1.2017–31.12.2018) was used for the calibration. The capacity increase for smartrail 4.0 was determined on the basis of this. Conclusions were also drawn about the reduction in delays required by a capacity increase of 20-30% with smartrail 4.0 while maintaining the current level of service.

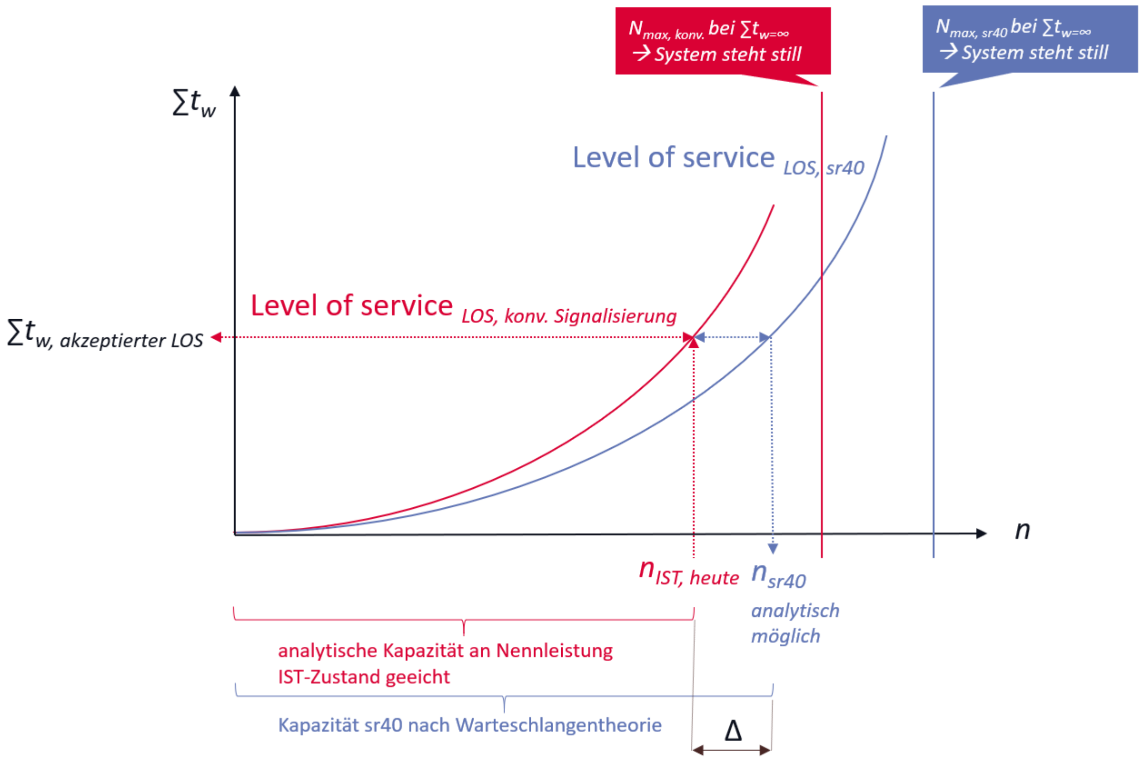

Figure 95: Relationship between quality and capacity

Key

$\sum t_w$	Sum of the average waiting time
LOS	Level of Service
n	Number of trains
n_{opt}	Ideal number of trains for a given *LOS*
n_{max}	Maximum number of trains

5.3 Findings

The study showed that the new technical possibilities of smartrail 4.0 can increase the nominal performance. Depending on the train sequence, the minimum headway times can be reduced by 15-25%. With otherwise unchanged overarching conditions, this increases the nominal performance by 10-20% compared to visual signalling. The capacity increase depends on the infrastructure characteristics and the stored operating program. Thanks to this study, we were able to conclude that an increase in capacity of 30% (nominal performance) with constant quality (level of service) must inevitably be accompanied by a reduction in delays of approximately 50%. Without an improvement in operational quality (delays), the new technical possibilities will not be exhausted and an increase in the number of train paths will not be feasible.

6 Implementation in an overall concept

After the local investigations, it became clear that the potential of smartrail 4.0 could only be demonstrated by an overall concept. This section addresses the creation of this overall concept.

6.1 Background

The development of new overall concepts is particularly suitable when framework conditions change:

1) Changes to infrastructure (e.g. new and expanded routes, etc.)
2) Changes in the mobility market (e.g. self-driving vehicles) and associated changes (e.g. number of stops and service points).
3) Technological changes (e.g. digitalisation, moving blocks, ATO, etc.)

The changes in technological capabilities described in Section 2 are the driving force behind the overall concept of smartrail 4.0. As described in Section 4.2, the significance of the results was limited by the fixation at the system boundaries. This, too, is another driving force behind the development of an overall concept.

6.2 Methodology

An overall concept is a network-wide planned timetable featuring all types of trains, routes and connection relationships. Among other things, it is used to determine the infrastructure requirements for an expansion phase [5]. The methodology is also suitable for constructive capacity determination (cf. analytical capacity determination in Section 5).

6.3 Planning procedures and philosophy

As for every overall concept, the planning foundations had to be determined in this case as well. The planning foundations of the expansion phase for the 2035 outlook (abbreviated STEP AS 2035) will be used. The most important deviations are outlined in Table 17.

Planning foundations of overall concept of smartrail 4.0		
smartrail 4.0 overall concept	Comparison with STEP AS 2035	Reason for deviation
Signalling and train control system		
Signalling according to smartrail 4.0 as described in Section 2.	Conventional signalling and ETCS Level 2 where possible	New technological possibilities of smartrail 4.0
Planning precision		
0.1 minutes (6s)	1 minute	Reducing headway times thanks to smartrail 4.0
Stopping times		
Dispatch time generally 0.2 minutes for passenger service trains.	Train dispatch time of 0.5 minutes for IC and IR products.	Adopted as the target condition of smartrail 4.0. More precise production specifications allow the departure process to be initiated parallel to the movement authority issuing process thanks to precise production specifications from TMS. Train crew board as the "last" passenger. Feasibility is yet to be confirmed.
Minimal turning times		
For S-Bahn trains of 300m and shorter, a minimum turning time of 4 minutes is adopted when there are two engine drivers.	5 minutes	Adopted as the target condition of smartrail 4.0 and corresponds to long-term planning. Feasibility yet to be confirmed.

Table 17: planning foundations for smartrail 4.0

The planning philosophy must also be defined in addition to the basic planning premises. This is described below.

- The timetable is basically designed to provide as many connections as possible in one nodal point. Priority is given to connections where only a half-hourly service is operated.
- Connection prioritisation and direct connections are primarily based on demand.
- The timetable is symmetrical, so that connections always work in both directions throughout the day.
- The systematisation of the schedule is the top priority. The groups of frequency are structured as follows:
  - 30-min service (minimum cadence).
  - 15-min service
  - 7.5-min service
- The east-west connection, the IC1 Geneva-St.Gallen, will not be slowed down and will be treated as a premium service. The service provided by other trains will be adapted as required.
- Long-distance services and long-distance freight services take high priority. If possible, they will not be slowed down for the purposes of conflict resolution.
- All other factors from Section 3 are assumed to be "at least as good as today".

6.4 Process of designing an overall concept

Based on the methodology from the STEP AS 2035, the design of the overall concept of smartrail 4.0 further optimises the content-related approach, which is described below.

1) *Determining location/corridor for beginning of planning*
   The first step is to determine where planning should begin. So far, the bottleneck in the Heitersberg Tunnel has proved to be an ideal starting point. The Bern and Zurich nodal points will also be considered from the outset.

2) *Developing a basic concept with all network-relevant trains, their travel times and connections.*
   In most cases, several variants are prepared in order to determine the design that makes the most sense and offers the most benefits.

3) *Reviewing drivability using planning software*
   This is where the iterative process begins. A high degree of flexibility is required from all participants in order to ultimately find the best mobile solution.

4) *Developing regional sub-concepts in detail*
   For less complex regions, the network developer directly prepares a timetable proposal, the design of which is then reviewed by the team.

In terms of processes, working in a small group with members of the infrastructure management team as well as from the various railway undertakings has proven to be an effective approach. The procedure is briefly described below.

1) *Introductory workshop (T+0)*
   At the beginning, a three-day intensive workshop was held to develop the network-relevant basic concept.

2) *Follow-up workshop (T+2 weeks)*
   Review, further development and consolidation of the findings from the first workshop. The planning foundation was completed at this point.

3) *Workshops on detailed planning (T+5/8/11/14/17/20/23 weeks)*
   Review, further development and consolidation of the designs created by the network developers since the last workshop. As described for the content-related approach, the planning is extended to the regional concepts in this iteration.

6.5 Distinction from STEP AS 2035

It is particularly important to distinguish the results of the overall concept for smartrail 4.0 from the STEP AS 2035 service concept.

1) *smartrail 4.0 laboratory environment*
   The study assumed that smartrail 4.0 had been rolled out in its final version across the network, infrastructure and rolling stock. The study is therefore based on numerous hypotheses, the empirical evidence of which is still pending. What's more, intermediate steps and aspects of migration planning were not taken into account.

2) *2035 investigation outlook*
   An outlook was deliberately chosen for the study for which demand and supply needs are known in detail. This guarantees realistic assumptions for the extrapolation of the results for the smartrail 4.0 overall concept. The study is explicitly not to be seen as a competitor product to STEP AS 2035, but as a test plan to assess the effects of new technologies.

3) *Planning foundations and philosophy*
   In the preparation of the overall concept of smartrail 4.0, significantly changed planning foundations and a new, optimised planning philosophy were applied.

Taking into account the above-mentioned distinction criteria, conclusions cannot be drawn from one concept to the other.

6.6 Findings and next steps

The major projects included in STEP AS 2035 (Brüttener Tunnel, Zimmerberg Base Tunnel II, 4th Zurich-Stadelhofen track, Neuchâtel-La Chaux-de-Fonds direct line) remain unaffected. These major projects make it possible to offer train paths and save travel time in a way that cannot be achieved by the new technological possibilities of smartrail 4.0 alone.

At the time this paper was being submitted, planning was still in progress. It was therefore not possible to determine the exact increase in capacity and infrastructure requirements. It is, however, clear that further infrastructure expansions will be necessary in order to be able to produce the newly created service.

Since the overall concept of smartrail 4.0 was developed under the premise of hypothetical ideal conditions, the technological possibilities of smartrail 4.0 must be empirically proven and the planning foundations consolidated further. The necessary migration steps of smartrail 4.0 must also be aligned with the STEP planning process and the concepts must be coordinated and optimised using “rolling planning”. This requires a strategic decision in favour of smartrail 4.0. The strategic decision regarding smartrail 4.0 will be crucial with regard to the revision of the ETCS strategy by the Swiss federal government planned for 2020.

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