Introduction to train control, path planning and rail operations and their digitalisation initiatives.

1. Management summary

An infrastructure manager (IM) builds and operates the railway infrastructure, while a railway undertaking (RU) provides transport services on the infrastructure and is responsible for the rolling stock and staff required.

In order for trains to run safely, cleanly and punctually for our customers, close cooperation is required between SBB Infrastructure, as the infrastructure operator, and the railway undertakings (SBB Passenger Services, SBB Freight Services, third parties).

Four dimensions are particularly relevant and will change over the next few years with the consistent use of new technological/digital opportunities. In doing so, SBB is unlocking new potential such as ‘more flexible, more frequent and faster’.

A) Railway production is based on the timetable. Infrastructure and passenger/freight services agree on which trains will run between which stations at and at what times. A train path is used for a train journey on infrastructure. For production purposes, we jointly plan where the trains will be stabled and maintained and how many staff will be required for operations.

B) Deviations such as delays and cancellations occur during day-to-day train *production* due to various factors. Infrastructure (Swiss Rail Traffic Control Centre and train-control centres) and Passenger Division (Traffic Control Center) are responsible for minimising the negative impact on customers through active scheduling of trains and staff.

C) The actual train journey from A to B is monitored and controlled by interlockings, signals and safety systems along the route and on the trains. These systems, which have developed over many years, enable safe and punctual rail operations.

D) Customers can only plan and understand train journeys via customer information before and during their journey. This takes place both at stations (infrastructure), via digital channels and on the train (passenger services).

This reader explains how the upcoming challenges in train path and railway production at SBB are to be met by continuing digitalisation. It begins with an overview of the basic connections and the challenges ahead, followed by an overview of the changes resulting from the continuing digitalisation of train path and railway production.

2. Train path and railway production

In 2023, 1.32 million passengers travelled on SBB every day. They used at least one of the 7,889 SBB Passenger Services trains. 92.5% of the trains were on time and 98% of passengers made their connecting train.

This service for our customers involves complex machinery comprising planning and production processes, which ensure that rail services run safely and efficiently every day and that the trains arrive at their destinations on time and are cleaned for subsequent operations. Information at the station and on the train also provides passengers with ongoing information about the route and connections. This ensures passengers' ability to act along the entire travel chain.

The train path [1]and railway production processes behind these services form the operational core of the railway business.

In train path production, a capacity plan is[2] drawn up and then implemented in capacity management (operational management).

- Network usage is planned in capacity planning: The timetable that has been drawn up enables the optimal use of rail network capacity to meet the requirements of passenger and freight traffic and forms the basis for punctual rail operations.
- Network usage planning also includes the management of station tracks, sidings and shunting facilities, as well as the planning of possessions. The latter are temporary restrictions to the availability of facilities in order to enable asset maintenance or structural expansions of the network (construction measures). In many cases, a 'replacement plan' is planned during construction work (adjusted timetable or rail replacement).
- In operational management, rail traffic is continuously monitored by rail dispatchers and traffic controllers from the train-control centres (CZ). Rail traffic at SBB is essentially automated, i.e. points and signals are controlled by preprogramming in accordance with the timetable.
- Shunting movements for the formation of train compositions and for stabling trains are also controlled from the train-control centres.

In railway production, services and the use of resources are planned and the operational execution of rail traffic is then ensured in resource management.

- Planning involves planning for the use of vehicles, locomotive crew and passenger attendants, as well as shunting and cleaning staff. The aim is to create a robust and efficient plan that best meets customer requirements. The legal requirements (Working

[1] The term 'train path' has two meanings: 1. The track on which the tracks run. 2. The entitlement to travel on a specific section of the rail network at a fixed time with a train that has been registered in advance. This document refers to the latter definition.

[2] The term 'capacity plan' refers to medium-term network usage plans for train paths and intervals for construction work. Train paths for passenger and freight services will be included in the network usage plans (NNP) for the last seven planning years. Train paths will be allocated to RUs (applicants) based on the last NNP by the Confederation's train path allocation body. The result of the allocated train paths is the annual timetable.

Hours Act) are complied with during planning and staff's wishes are taken into account as far as possible.

- Changes made during the year are recognised by the management, e.g. due to increased demand from events and construction sites. The maintenance coordination of the rolling stock is also located there.
- In resource management, various roles in the Traffic Control Centres (TCC) coordinate the rolling stock as well as the SBB Passenger Division drivers and shunting and cleaning staff who prepare and clean the vehicles.

Customer information

- Timetable and operational data are processed to enable customers to run their journeys smoothly. Customer information includes details such as the planned timetable service, the location of 1st and 2nd class on the train, delays and connections, as well as platform changes and information about planned rail replacement services.
- Passengers are provided with customer information via displays and loudspeaker announcements at the station, on the train and digitally (app, website). Consistent and comprehensible customer information (via all channels) is becoming increasingly important – even in the event of disruption. It forms the basis for passengers' ability to act.

Disruptions and incidents

There are many causes for disruptions to rail operations: The resulting incidents can be attributed to the following causes:

- Around 25% of delays can be attributed to railway production (e.g. vehicle faults, locomotive crews)
- Approx. 25% is caused by infrastructure (e.g. system malfunctions, delayed line release) or external factors (e.g. weather).
- Around 50% of delays on the network are delays from abroad or minor delays for which no clear cause can be attributed to the deviations from the timetable (e.g. passing a train, difficulties gaining adhesion, changing trains).

The duration of the incident varies greatly. Around 80% of incidents are resolved within the first 30 minutes.

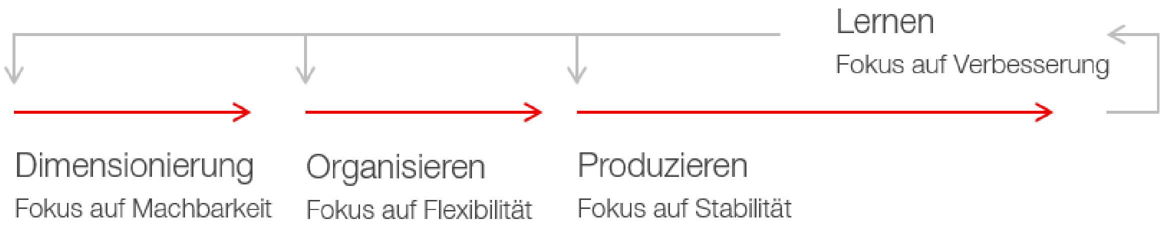
To deal with incidents, staff at the train-control centres work closely with those at the railway undertakings' control centres to implement deployment measures. The aim of these measures is to minimise the impact of disruptions on customers (both passenger and freight services) and to ensure that a return to a (possibly new) planned condition as soon as possible.

To this end, operations control centres and TCCs apply predefined operating concepts. These concepts summarise the measures required in train path and railway production which will be required at critical points in the network due to partial or total closures. Typical measures include diversions, early reversal of trains or replacement road traffic. Applying these concepts facilitates (comprehensive) communication between all parties involved and also enables customers to communicate with an adapted service in a simple and comprehensible way.

Should higher-level decisions be required for the overall system, the Rail Traffic Switzerland Control Centre coordinates and ensures that the impact on long-distance passenger and freight services can be minimised.

Reliability and robustness

A key success factor in train path and railway production is the reliability of the service offer for our customers. This is what the joint activities of the parties involved aim to achieve. A high degree of robustness of the overall system means that the customer promise can be implemented stably, even if there are minor deviations from planning.



- In long- and medium-term planning, all elements of railway operations are coordinated with each other and dimensioned in a higher-level manner.
- In preparing for day-to-day operations, various factors such as peaks in demand, events, availability of rolling stock and staff, as well as construction sites are taken into account. The extensive and iterative planning work has the character of 'organising'.
- Operations managers in train path and railway production will produce the planned and communicated service offer as stable as possible.
- Important lessons will be learnt from the implementation of the program so that train path and railway production and customer information can be continuously improved.

3. Challenges and answers from SBB

Train driving will continue to be at the heart of SBB's business activities in the future. What challenges do we face? And what answers do we at SBB provide?

Market needs in passenger services (and also in freight services) are becoming more volatile and require more flexible services.

- At international level, adjusted processes for train path planning and allocation are being prepared as part of the TTR (Timetable Redesign for Smart Capacity Management) project. In future, ordering horizons for train paths are to be adjusted to traffic needs, namely several years' lead times for stable traffic such as passenger traffic and wagonload freight traffic, as well as (rolling) orders placed during the year for event traffic and freight traffic block trains. The EU supports these process changes and it is to be assumed that the regulations in Switzerland will also be amended accordingly.[3]
- As the service offer becomes more flexible, the practical importance of annual planning and the annual timetable will decrease. In contrast, the importance of dimensioning the overall system will continue to increase.
- The high level of complexity of the planning and control tasks in train path and railway production will increase again. Greater collaboration between the parties involved, as well as the use of end-to-end IT tools, will become indispensable.

The volume of construction work will continue to rise in the coming years: Maintenance and upgrades will require adjustments to services that are planned as far as possible in a manner compatible with the customer.

- SBB is aiming to increasingly 'cluster' construction measures in order to reduce the number of major restrictions to rail services. The medium-term goal is to implement 4 to 6 clusters per year.
- Maintenance work is carried out in regular 'maintenance windows'. These windows are placed on the network in such a way that restrictions to passenger and freight services are kept to a minimum. Recurring restrictions can be implemented more easily and communicated to customers.
- Replacement timetables are developed and published at an early stage with the involvement of the parties concerned. There are no compromises in robustness or reliability for customers during planning.

The labour market is changing. It is becoming more challenging to recruit employees for recurring tasks, shift work and shift work and to keep them in the same role for a longer period of time. In addition, SBB will lose some of its previous holders of know-how when it retires.

---

[3] The amendments will mainly be made to the Network Access Ordinance.

– The automation of tasks supports employees in dealing with time-consuming and repetitive tasks and can be a (partial) answer to the shortage of skilled workers.
– Participation in IT projects and the iterative improvement of the tools used create interesting roles and development opportunities.
– Increasing consistency between the different areas of train path and railway production requires collaborative work and appeals to other groups of people.

The financing of public transport continues to come under pressure due to the limited funds available from the Confederation and the Cantons.

– Long-term efficiency increases through the use of IT solutions help to stabilise or reduce operational costs in train path and railway production.

For the reasons explained, the further development of IT support for train path and railway production is of great importance.

4. Digitalisation with TMS and IPP

The IT systems currently used in train path and railway production have largely been developed over the past 20 years. The solutions reflect the opportunities of the years of introduction in terms of computing power, connectivity and scalability.

Even though there have been some technical upgrades to the existing systems in recent years, it is only when they are replaced by TMS (Traffic Management System) and IPP (Integrated Production Planning) that we will make optimal use of today's opportunities in terms of flexibility, the use of optimisation algorithms and user-friendliness.

System	Role	Application strategy
Viriato	Train path planning Medium-term planning	Re-use
NeTS	Train path ordering and planning Annual and daily planning	Replaced by TMS-CM1
RailSys	Possession planning	Re-use
RCS-D	Scheduling	Integration into TMS 2030ff.
RCS-ALEA	Alarm and incident assistant, use by all those involved in railway production	Re-use
Iltis	Train control by controlling interlockings	Re-use

Sopre/Ceres	Resource allocation of staff and rolling stock	Replaced by IPP
CUS	Data hub Customer information from real-time data	Re-use
INFO+	Data hub Customer information from timetable data	Re-use
VIA	Passenger guidance	Re-use

Since 2020, new IT functions that are being created to support train path production processes have been assigned to the TMS project. Financing is provided with funds from the service level agreement and earmarked funds from the FOT. TMS is being developed by SBB for the entire industry (standard gauge railways). RUs' requests for TMS are addressed via an RU board.

The objectives of TMS include the following:

- Increased flexibility in planning and implementation (e.g. by ensuring consistency between systems and eliminating system gaps).
- Increase efficiency (e.g. by applying optimisation algorithms, automating recurring tasks, using existing topology data from asset management).
- Improved capacity utilisation and increased robustness of timetable planning (including by supporting precise driving on planned train paths and by applying a new planning philosophy).

The first TMS applications in the train-control centres have improved the consistency of data exchange and efficiency in the event of a disruption. With its punctuality display and the shunting warning function, TMS is already contributing to improving punctuality and safety.

Over the next few years, the existing tool for ordering train paths and creating timetables will be replaced by TMS. This will create the prerequisite for data communication via the TSI TAF (TTT) data format, which is standardised across Europe. There is great potential for automation and increased efficiency through mutually improved data exchange between railway undertakings and infrastructure managers.

Further TMS functionalities will use the algorithmic possibilities of linear optimisation to optimise capacity planning in real time. In addition, the processes for shunting movements will also be fully digitalised (currently largely based on oral communication and empirical knowledge).

The introduction of IPP has three key objectives:

- Flexible service offer through variant planning and faster response times.
- Increasing quality and efficiency through the use of algorithms and system-supported processes.
- Increase SBB's attractiveness as an employer by reducing monotonous work and involving staff more actively in production.

The current tools Sopre and Ceres at SBB Passenger Services will be replaced by standard software. The new software will support planning for all required resources across all time horizons. The use of automated optimisers is intended to generate service and production variants and plan them in scenarios, enabling more efficient and flexible production planning.

Railway production planners and TCC employees will also benefit from the increased automation of regular operations and improved system support in the event of an incident. Centrally controlled and high-performance communication of decisions taken to train driving, shunting, passenger attendance and cleaning employees and those responsible for managing rolling stock will enable more responsive resource management.

The introduction of IPP and the implementation of the associated processes and impact expectations require organisational adjustments (e.g. merging roles in planning). Role models are being rethought in order to take advantage of the opportunities offered by digitalisation. Monotonous work is being reduced through better system support to create more capacity for conceptual and value-creating work. Production employees benefit from better consideration of their preferences (interaction platforms with their requests for tours or tour exchanges).

There is intensive cooperation between the two projects TMS and IPP.

5. Digitalisation in customer information

The landscape of customer information systems has grown over the years. The former division of system responsibility into Infrastructure and Passenger Division has been abolished by creating a Digital Solution Customer Information (DSO KIS) as part of 'Together digital'. The further development of all systems is prioritised and the alignment with common strategic objectives for customer information is being pursued from an overall perspective. The creation of the CoC (Center of Competence) for customer information on 1 May 2024 strengthens the organisation's overall management and responsibility for the further development of customer information.

The focus of further development is on improving customer information in the event of disruptions. The automated feed of customer information output channels from the RCS and CUS systems normally works perfectly and in the event of minor deviations from the timetable. In the event of major incidents, the automated processing of operational data and the manually entered context-related incident information can lead to inconsistencies for customers. To reduce this, the processes and working environment for incident management employees will be simplified in future and the degree of automation in the systems will be further increased. This reduces personnel-intensive and manual data entry and avoids inconsistent data.

The focus of customer information is increasingly shifting towards contextual and personalised data, which accompanies customers on their journey in the form of 'journey apps' and provides them with information as required, which meets high customer demand. The successful use of such travel companions for national and international journeys depends on high data quality and professional data organisation.

SBB coordinates the further development of customer information with its public transport partners: it is a member of the National Commission for Customer Information (KKI) of Alliance SwissPass, which ensures the coordinated further development of customer information for public transport in Switzerland. The FOT also commissions SBB Infrastructure with various tasks to ensure that the customer information system (SKI) is responsible for the entire public transport sector.

6. Train control and signalling by ERTMS

Train movements from A to B are controlled, secured and monitored by the safety systems. Communication between the infrastructure's operations centres and the RU's locomotive crew takes place via railway radio.

Over 500 signal boxes throughout Switzerland provide points and signals as well as safe routes. The signal boxes are operated centrally in SBB Infrastructure's four train-control centres. Train movement is monitored geographically via track occupancy equipment (e.g. axle counters) installed along the route and, once the train has passed, the corresponding block of route is cleared again. Train protection monitors the correct implementation of movement commands by the locomotive crew and, if necessary, intervenes directly on the vehicle (e.g. when passing a signal indicating 'Stop').

SBB operates its own GSM-R mobile communications network along the lines to ensure secure and uninterrupted communication [4]. This network is used in particular for voice communication between the train-control centres and the locomotive crew. On a few lines already equipped with in-cab signalling (ETCS[5] Level 2), signal information is transmitted via GSM-R to the locomotive's systems.

Over the past 40 years, SBB has, in most cases, introduced new developments in safety systems before other European railways. For example, the continuous remote control of interlockings from train-control centres and the standardisation of train protection have been consistently implemented at an early stage by ETCS Level 1. Nevertheless, fundamental renewal in this area is expected over the next few years. In particular, the technical obsolescence of the interlocking technology used and the current GSM-R mobile radio standard require fundamental modernisation of railway control. This is also where the changes to ERTMS (European Rail Traffic Management System) come in.

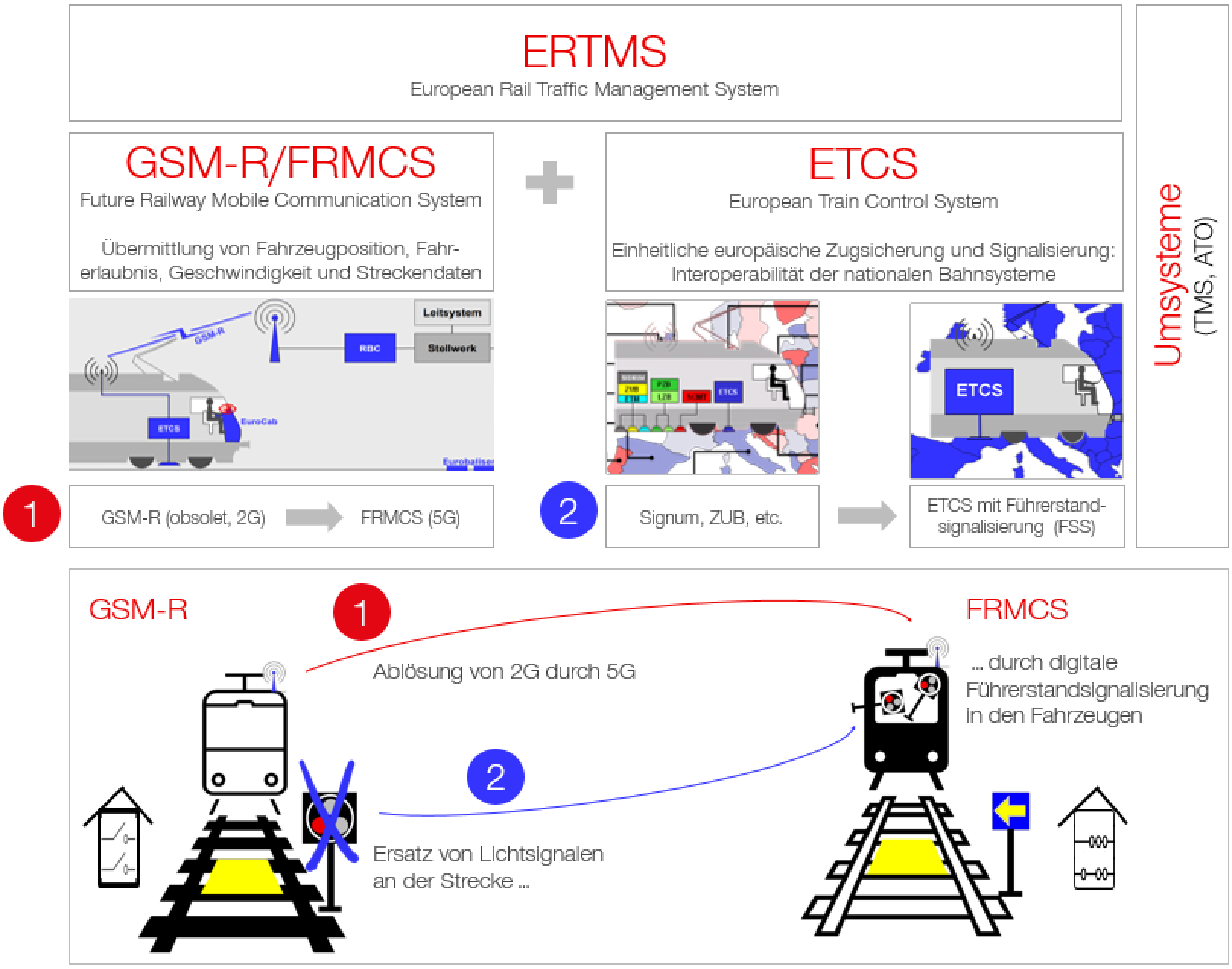
[4] Global System for Mobile Communication – Railway

[5] ETCS = European Train Control System (ERTMS component). A single interoperable European train control and signalling system which will replace the various existing systems in Europe. This will make rail traffic more efficient and simplify cross-border traffic.

Area	Today	In the future
Staff	Trackside signals and radio (data and voice) (GSM-R)	In-cab signalling and FRMCS
Vehicle	GSM-R and balises, trackside signals	FRMCS and balises, signals in the driver's cab
Infrastructure	Data from local interlockings via cable connection	Digital interlockings from data centres, data on actuators and sensors (points, shunting signals, train vacancy detection systems)

The current GSM-R (2G technology) train communication system will reach the end of its life in 2035 and will be replaced by FRMCS (5G). ETCS replaces existing signalling and train protection technologies by a European standard. This standard also makes it possible to implement in-cab signalling (FSS), which allows operation without trackside signals. Together, these two elements form the ERTMS (European Rail Traffic Management System).

SBB is involved in European standardisation and in test activities for the further development of ERTMS. By participating at the European level, SBB ensures that international standards meet the high ambitions of Swiss public transport and that SBB will be able to procure standard components on the market in future. In addition, this will further reduce the barriers to the use of SBB vehicles for passenger and freight services in neighbouring European countries.



Graphic representation of the significant changes resulting from the ERTMS strategy. In addition to implementing the state-of-the-art mobile radio and interlocking technology, trackside signals will be removed and transmitted directly to the vehicle via the railway radio.

Switzerland has had an ERTMS migration strategy since 2000. As a first migration step, the entire network was made ERTMS-compatible between 2011 and 2017 by replacing balises (ETCS Level 1, Limited Supervision).

Around 250km of the SBB network is currently equipped with ETCS Level 2 cab signalling (e.g. Bahn2000 line, GBT, CBT). These lines are amongst SBB's top routes and offer the best availability and performance as an overall system (route and vehicle).

Since a large proportion of SBB's approximately 500 interlockings are still equipped with electromechanical components (e.g. relay technology) from the 1960s and their maintenance is reaching the limits due to spare parts management and expertise, outdated interlocking technology and vehicle communication must be replaced with state-of-the-art digital technology (ERTMS). However, financing and implementation also represent a 'clump risk'.

ERTMS will be implemented on the basis of cab signalling (FSS) with ETCS Level 2. This must be implemented in coordination between Infrastructure and the railway undertaking. Infrastructure and vehicles must allow parallel operation with GSM-R and FRMCS during the migration phase ('dual mode').

The migration of SBB's 1,500 vehicles will take around 5 to 7 years. Due to the required TSI standardisation by ERA, the actual series conversion work will hardly be able to start before 2032. Finalising the migration before the GSM-R shutdown date in 2035 represents a major risk from today's perspective. Experience will be gained from using FRMCS in Switzerland over the next few years with a view to reducing risks using test vehicles.

With the digitalisation of signalling technology and train protection through ERTMS ('digital interlocking') the aim is to systematically separate the interlocking logic (centrally located in data centres) from the required infrastructure (mainly points, track vacancy detection systems and shunting signals). This will lead to a reduction in complexity, greater flexibility and ultimately an increase in capacity on the existing network. The ongoing tender process for a new generation of interlockings marks the first step towards a digital interlocking. The existing infrastructure-side signalling (side signals) will increasingly be transferred from the line to the vehicles. This is a sensible solution from the perspective of the overall system.

ERTMS investments	Period
Migration of train communication (GSM-R to FRMCS)	2027 – 2035
Maintenance of interlockings (new digital interlockings)	2028 – 2050
Rolling stock (GSM-R replacement and train control systems)	2030 – 2037

The ERTMS strategy was updated by the FOT in 2023. By implementing the ERTMS strategy, the overall system for train path and railway production will be further developed. The efficient and error-free transfer of data to vehicles and interlocking will be increasingly important and internationally standardised. To ensure that the risks involved in implementing the ERTMS strategy remain manageable, implementation will be carried out step-by-step and, on the part of infrastructure, largely as part of asset maintenance measures.

When the ERTMS strategy is implemented, interlockings that are no longer technically viable will be replaced by state-of-the-art systems. This will create the basis for increasing timetable stability and capacity on the existing infrastructure as well as operational flexibility. Thanks to its international interoperability, ERMTS is making an important contribution to the further development of cross-border freight and passenger services.

7. Train path and railway production: safe, clean, punctual. And in future: more flexible, more frequent, faster.

The further development and digitalisation of the processes and the renewal of the overall system with ERTMS are prerequisites for robust and efficient train path and railway production in the future. Digitalisation therefore represents an effective response to the emerging challenges for SBB's core processes. In addition, the developments presented make a key contribution to achieving the vision of 'more flexible, more frequent and faster'.

Overview of the different planning steps, the actors involved and the resulting benefits.