EMERGENCY MANAGEMENT IN THE Swiss LÖTSCHBERG BASE RAILWAY TUNNEL

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Abstract

A long single-track line in a newly built tunnel through the Swiss Alps requires novel and sophisticated solutions for the handling of emergency situations and optimisation, which are provided by the Train Traffic Control system (TTC), AdmiRail®-AF. The TTC plays an important role in the provision of the overall safety for the tunnel. Important features of the novel TTC in this respect include the supervision of equipment, the supervision of train movement, the handling of alarms and the automatic evacuation of all trains out of the tunnel using ETCS reversing mode. Another important feature of the TTC is the optimization of train traffic. By proposing optimal speed – potentially well below the maximal one – to the driver the TTC firstly avoids almost all standstill cases of trains inside the tunnel and thus increases the overall safety of the tunnel, and secondly – not less important – it can gain a substantial amount of time and energy and hence it contributes to a stable operation.

1 Introduction

The new Lötschberg base tunnel (LBT) through the Swiss Alps is in operation since December 2007. The tunnel, which leads from Frutigen (Canton Bern) to Visp (Canton Valais), is 34.6 km long (see Figure 1). To reduce costs, it had been decided to equip the north half of the tunnel with a single-track line only. The tunnel is a high-speed line with a maximum speed of 250 km/h; therefore, cab-signalling is mandatory. The system supplied by Thales Rail Signalling Solutions is a radio-based system without line-side signals that is 100% compliant to the European Train Control System (ETCS) level-2 specifications (see [1] for details).

In Swiss mainline railways, the train traffic control and dispatching in regular operation is highly automated by means of Train Traffic Control systems (TTCs). Clearly, the expectations regarding traffic density and punctuality require at least the same degree of automation for the newly built tunnel. Hence the new TTC system forms an integral part of the signalling and train control equipment of the tunnel. The TTC system is supplied by Thales, while the software development had been subcontracted to systransis Ltd.

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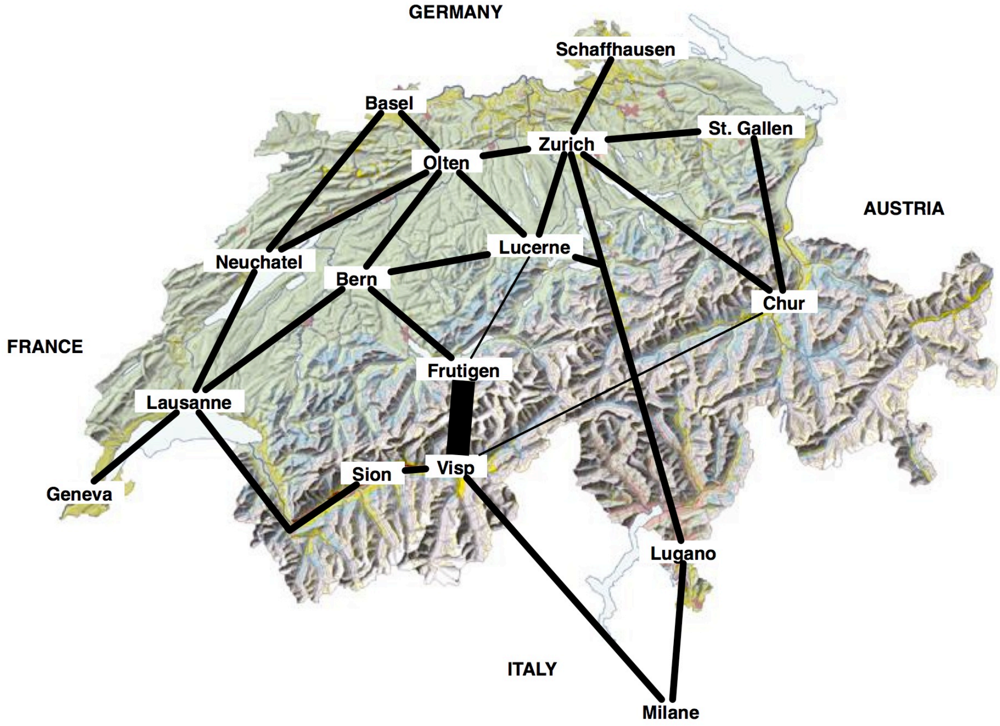

Figure 1: Location of the Lötschberg base tunnel (LBT) between Frutigen and Visp in Switzerland

As mentioned above, almost 20 km of the tunnel consist of a single-track line. Due to these specifics of the track layout, several new functional and integrative requirements were addressed in the design of new TTC. Innovative measures regarding the automatic dispatching of the trains and the control of their optimal speed were required [3].

In order to increase stability of operation and capacity, the TTC must provide automatic support for traffic optimisation and assistance to the dispatcher for the handling of critical events and alarm situations. The expected features of the TTC regarding the traffic control can be summarised as follows:

1. Provide stable, predictable traffic patterns according to the given scheduling plan.
2. In case of irregularities, minimize the exit delays, minimize stopping of trains in the tunnel, and optimize the speed of trains involved in conflicts in order to gain time.
3. Supervise equipment and train movements, such that potentially dangerous situations are identified as early as possible.
4. In case of emergencies, compute a scheduling plan, which shall lead all trains out of the tunnel as quickly and safely as possible.

The implementation of these demanding expectations asked for novel means. To our knowledge, this is the first system in a mainline rail system which makes use of the accurate odometry data provided by an European Train Control System (ETCS) [2] on Level-2 (radio-based control). The TTC receives train positions and speeds every 6 seconds from the ETCS Radio Block Centre (RBC). The TTC can influence the trains by transmitting a “Recommended Speed” through free-text messages of the ETCS, which are displayed on the onboard unit of the locomotive.

The novel tunnel required new procedures for emergency handling and the new technology imposes adaptations to the existing standard procedures. The contribution of systransis Ltd. was to develop, specify, in tight cooperation with the customer and the authorities, the new procedures and technical features supporting them, and implement them in the TTC.

During implementation of this novel TTC, it turned out that the challenges despite simple track topology are very substantial. The main challenge did not so much lie in the algorithmic aspects but much more in the integration of online data from many different heterogeneous and asynchronous sources and the overcoming of all possible cases of degradation of this highly complex system.

The following sections will explain the mechanisms for supervising train movement, and tunnel equipment. Then an emergency situation is shown, where the TTC is computing a new scheduling plan using reversal of train. And finally the underlying mechanisms for providing stable traffic patterns using speed optimisation are explained.

2 Principles of the Train Traffic Control System

In general, relatively little is known about feasible automatic approaches solving the aforementioned expectations in the context of an arbitrary railway network. The reason for the lack of practical application is manifold. One reason is that any optimisation in railway is not practically solvable in reasonable time, as the solution space is extremely large for an arbitrary topology, additionally the optimisation criteria is often unclear and generally difficult to formalise. Thanks to the simple track topology, however, semi-automatic solutions seemed promising and proofed feasible.

To implement the required functionality, the following principles are applied:

1. In general, the TTC dispatches the trains exactly – along the paths, according to the times, in the order – as specified by the scheduling plan. In other words, no automatic, unpredictable changes to the plan will be made, even in case of major delays.
2. The number of train routes automatically requested by the TTC fits the train properties. Fast trains or trains with bad brake characteristics tend to need more routes than slow trains or trains with very good brakes. Requesting too few routes must be avoided, as the train may unnecessarily be forced below the currently possible maximum speed. Requesting too many routes may lead to an overly long movement authority. Unexpected events or alarms may necessitate the shortening of a movement authority in the latter case, which in turn may lead to emergency brake applications – highly undesirable in such a long tunnel.
3. The TTC computes a forecast of passing times of each train. Based on these predictions the TTC detects conflicts, i.e., it observes the fact that one train will obstruct a second train, because the first train will release a certain track element too late, and hence the second train cannot travel according the currently defined scheduling plan. For those trains involved in conflicts, the TTC computes an optimal speed curve, which may be well below the maximal one. The optimal speed is then transmitted to the driver.
4. The TCC supervises many states of tunnel equipment elements (e.g. Battery operation mode of some critical equipment, fire detection sensors, etc.) As soon as such element's state is changing into an unexpected state the TTC reports this event to the operator in form of warnings or alarm proposals depending on the severity of the unexpected event.
5. The TCC supervises the train movement. E.g. as soon as the observed speed of a train falls outside of the tolerated band, or when some expected events, such as route reservation or route releasing don't occur within supervised time interval, the TCC issues a warning or an alarm to the operator.

3 Supervision and Alarm Handling

The length of the tunnel, as well as the long single-track section, results in a series of complex questions regarding the safety of operations, particularly in the case of critical events, such as fires. The overall safety concept allocates the TTC a substantial range of responsibility in the area of supervision of equipment and trains, as well as in the alarm handling. The considered objects include a vast amount of tunnel equipment which is not directly related to railway safety in the classical sense, such as fire alarms, pressure sensors, mountain water flow meters, various types of doors, etc. In order to facilitate communications between the TTC and this type of equipment, an interface to the tunnel control system (TCS) has been designed, which focuses on those data and commands relevant for the railway operation.

The list of equipment taken into account for supervising and alarming is quite long. It includes:

- Sections of the high voltage train power supply
- Optional neutral section of the high voltage train power supply
- Tunnel doors, that are orthogonal to tracks and close off sections of the tunnel for maintenance
- Sliding doors (see Figure 2), that close off equipment cabinets and places of safety
- The interlockings and objects controlled by it (e.g. position of switches, connection to interlocking, etc.)
- The RBC and its controlled objects (e.g. trains, temporary speed restrictions, etc.)
- The TCS and objects controlled by it (e.g. Smoke- and Fire detection, Battery-operation of critical elements, etc.)

Supervision of expected states

A vast amount of discussion between suppliers, operators and the authorities, and went into clarifying and specifying the automatic reactions with which the TTC should respond to unexpected state changes. As an example, suppose that some maintenance personnel working in an equipment cabinet operated the handle of the sliding door depicted in Figure 2. The TCS will report the new state of the sliding door (as “Door unlocked”) to the TTC. The TTC immediately issues a warning to the operator and installs temporary speed restrictions of 40 km/h along the “unlocked Door”. The operator can now decide whether to escalate the warning into an alarm maybe after contacting and talking to the maintenance personnel on-site.

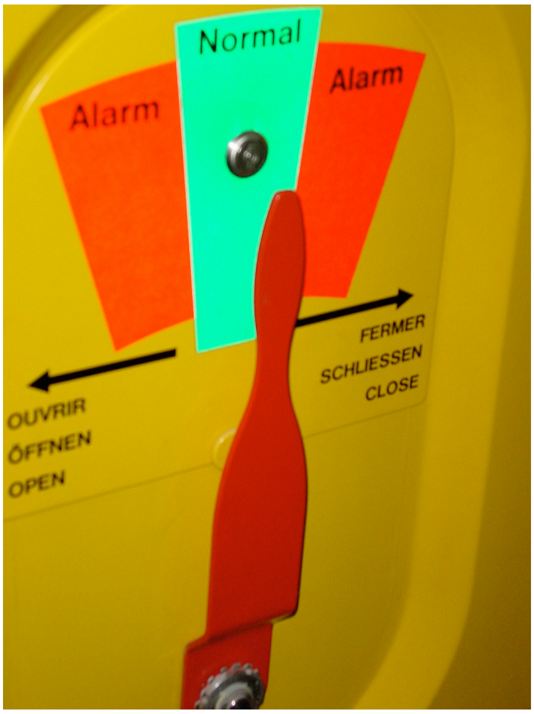

Figure 2: Example of tunnel equipment taken into account for alarming by TTC: lock of sliding doors closing off equipment and places of safety

Supervision of Trains

Special attention is given to the supervision of trains in two respects.

Permission to enter tunnel: Firstly, the TTC has to give each train an explicit permission to enter the tunnel automatically – the TTC checks the plausibility of train data reported by several data sources. In the regular state, the entrances to the tunnel are closed off by direction-dependent interdictions, which are implemented in the interlockings but controllable by the TTC. These interdictions prevent the interlocking from automatically setting regular train routes in one direction only. In other words, this direction-dependent interdiction controls the entrance such that trains may not enter the tunnel automatically but can leave the tunnel. A direction-dependent interdiction at a tunnel entrance is only temporarily removed if all of the following conditions are met:

- According to the scheduling plan, a train is supposed to enter by this track and the train is close enough to the tunnel.
- The train is reported to be connected to the RBC and hence capable of using an ETCS Level-2 line.
- This train has passed a train data consistency check, which includes the comparison of data provided by the OBU and by the nation-wide train data supplying system.
- The train will not cause a deadlock in the tunnel.
- There is no alarm situation.

The direction-dependent interdiction is put back as soon as the commissioning of the train route at the entrance is observed by the TTC. In this manner, the entrance is immediately blocked for subsequent trains.

Again, the TTC reports by means of immediate control of the interdictions at the tunnel entry and by warnings to the dispatcher, that some train data reported from surrounding systems inhibit further smooth operations, and it is up to the operator in charge to take appropriate measures.

Speed Supervision: Secondly, the TTC supervises a speed for each train in the tunnel in order to detect trains with technical problems in an early stage. There is a long list of rules, which identify suspicious train movement, amongst which the following:

- When a train falls below a minimal speed
- When a train stops too far away from its end of authority
- When a train fails to accelerate if allowed to do so, an alarm is issued for this train.

The rules are designed in a relatively flexible manner to prevent false alarms and to take into account the differences in the driver behaviour. As an example see Figure 3: As soon as a train leaves the area of tolerated speeds, the TTC starts a timer. The TTC escalates the reporting depending on how long the train's speed violates the "band of tolerated speeds": First, by a message to the driver and operator, then by a warning to the operator and finally by an alarm proposal to the operator. Again, the TTC issues some immediate reactions, such that the operator wins some time for his/her decision-making. After all, the dispatcher in charge has different possibilities to tackle the situation reaching from "ignoring the warning" up to "declaring Alarm in the tunnel".

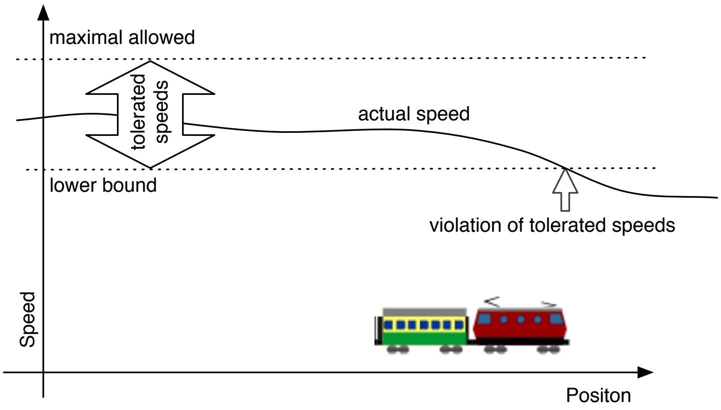

Figure 3: Speed supervision of each train

Classification of Alarms

In general, the TTC recognises degraded states of each object. The specification of degraded modes depends on the type of equipment. For instance, interlockings are supervised to ensure that a regular exchange of heartbeat is possible and that train routes can be commissioned and are released in time. It has to be stated that in addition certain objects are supervised by the interlockings directly, such as open tunnel doors. In this manner hazards that may cause direct danger to train traffic are excluded with SIL-4.

Aberrations from the normal state are reported to the dispatcher. There are several levels of severity:

1. **Alarm Serious Event:** Imminent danger for persons in the tunnel, clear tunnel as fast as possible
2. **Alarm Non-serious Event:** No imminent danger for persons in tunnel, but longer disruption of service has to be expected. Not all trains may be able to clear tunnel forward in a regular way.
3. **Alarm Technical:** No danger, trains can leave tunnel in a regular manner.
4. **Warning:** No immediate impact on train operation.

There is a well-defined allocation of degraded equipment states to alarm categories. In any case, in order not to overly reduce the availability of the tunnel to regular operations, the dispatcher has to confirm the issuing of any alarm. The same principle applies to reactions to state changes and revocations of alarms.

Automatic Reactions to Alarms

Depending on the level of the alarm there is a well-defined set of automatic standard reactions. These include:

- Reporting the alarm to the TCS, which will forward it to the authorities
- Closing of the tunnel for any further automatic train entrance
- Closing off affected areas (problem zones)
- Not extending existing allocated routes for trains heading towards problem zones
- After the dispatcher's decision: Computing and automatically executing a new scheduling plan to clear the tunnel from trains as fast as possible.

  This last automatic reaction is quite revolutionary indeed. It includes the use of the ETCS Reverse Mode. The algorithm, which computes the new scheduling plan, decides for each train whether it shall be cleared forwards or backwards. Hereby certain priority rules apply. The goal of this concept is to remove every train from the tunnel within the time within which the equipment is generally considered to be fire resistant.

Additionally, depending on the cause for warnings or for an alarm, there are particular automatic reactions pertaining to the peculiar situation, such the setting of speed restrictions in case of unlocked sliding doors as explained above.

4 Rescheduling in Severe Emergencies

In case of an emergency situation, it is the goal to safely guide all trains out of the tunnel. A single impassable track, which is in the single-track section of the tunnel and ahead of a train already prevents the forward-evacuation of at least this train. Therefore, the automatic evacuation must be able to evacuate trains by using the ETCS reversing mode.

In case of an emergency, the dispatcher manually defines either a fixed region of the tunnel as the “problem zone” or a specific train as the “alarm train”. As an alternative, the TCS can report an alarm state. The dispatcher can initiate the evacuation, without the need of prior alarm definition.

Rescheduling in case of a tunnel evacuation is structured into the following phases, which are detailed in the following sections:

1. Keep trains away from the problem zone (where possible)
2. Transform the current operational schedule into an evacuation schedule, which must ensure specific conditions for the evacuation
3. Guide trains out of the tunnel according to the evacuation schedule

Keep trains away from the problem zone

This goal is achieved by ceasing to request routes for trains that are heading against the problem zone. As a consequence, such trains are stopped by the OBU at their End of Authority. In addition, direction-dependent interdictions prevent trains outside of the tunnel from entering the controlled area and thereby further increasing the risk potential of the situation.

Transformation of the operational schedule into an evacuation schedule

The algorithms classify trains as follows:

1. Trains, which can be evacuated in forward direction.
2. Trains, which must be reversed.
3. Trains, which cannot be evacuated.

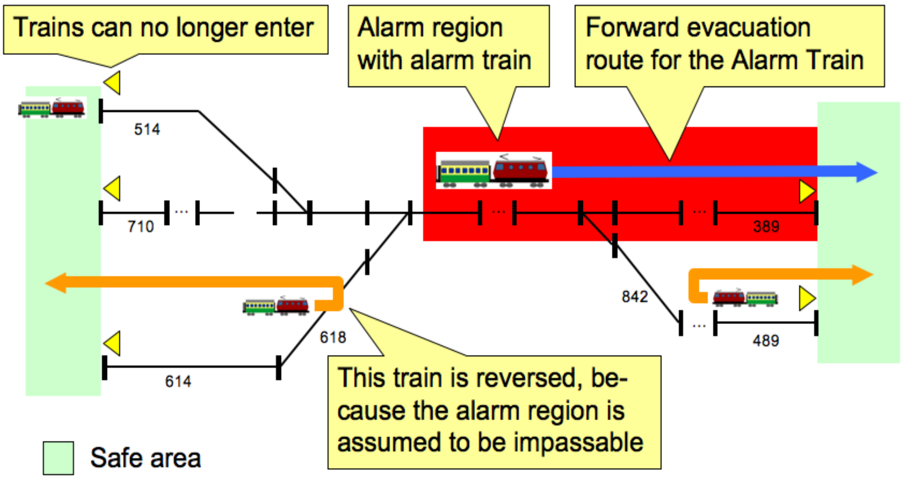

Figure 4: Example of an evacuation schedule in the case in which the alarm train is on the single track line.

Although the train schedule is deadlock-free in regular situations, the occurrence of an impassable problem zone might immediately cause a deadlock within the tunnel. Hence there are indeed worst cases in which a train cannot be evacuated at all. In this case there are rescue-road accesses by which passengers still could be evacuated.

The decisions on how to evacuate trains are made as follows:

1. The alarm train, if there is one, is always evacuated in forward direction (in addition, it is evacuated as the last train).
2. Trains cannot be evacuated through an "impassable" section. A section is "impassable" in the following cases:
    a. There is an active interdiction or a direction-dependent interdiction (by selectively adding/removing interdictions/direction-dependent interdictions, the train dispatcher can directly influence the generated evacuation schedule)
    b. A problem zone covers the section
    c. The alarm train covers the section
3. A train can be evacuated in forward direction if there is a path from its current location and the tunnel exit in forward direction without any problem zone on it (including the potential problem zone caused by the alarm train, if any). It is assumed that all trains lying ahead of the train under consideration – including the one train having no further trains in front of itself – can be evacuated in forward direction, thereby subsequently freeing a path for their succeeding train.
4. The same principle also applies for the possibility of reverse evacuation.
5. Forward evacuation is always preferred if it is feasible.
6. Additional rules ensure e.g. that no train passes a problem zone in the opposite tunnel tube later than a specific delay after the start of the tunnel evacuation.

As soon as the evacuation direction of each train is determined, the details of the evacuation schedule are computed. Later on, there are no attempts to adapt it to possible new evolvements of the situation. Yet, the dispatcher can always adapt it manually.

Guiding trains out of the tunnel according to the evacuation schedule

The system ensures, as far as possible, that the alarm train always has a secured headway to drive at speed 80 km/h. For trains that are evacuated forward, forward evacuation routes are requested. Trains, are planned for reversal, are stopped by not prolonging their End of Authority. As soon as the train comes to standstill, reversing routes are requested for it and the driver is requested to confirm the reversing mode on his DMI. With a maximum of 80 km/h, he can then drive “backwards” out of the tunnel. As soon as the train reaches the tunnel borders, the neighbouring TTC requests reversing routes according to a set of pre-defined evacuation paths.

In case of an evacuation (and in some other degraded situations), the following information is transmitted to engine drivers:

1. As the train moves, the position of emergency stopping locations (where people could be evacuated by rescue-roads) is periodically announced to the engine driver via the DMI.
2. Engine drivers in the geographic area around the tunnel are informed via GSM-R voice, that there is a serious problem in the tunnel.

By this procedure shown above, it is expected to provide a strategy to master each situation with some standardised means.

5 Conclusion

An overview of the rescheduling strategies in regular and emergency operation of the Lötschberg Base Tunnel was given. Although its track layout is quite simple, it still turns out to be very challenging to provide a stable real-time optimisation, which is capable of coping with all issues caused by potential shortcomings of the underlying online-data. The system is, however, in regular operation since December 2007 and proofs its capability of taking decisions and optimising train speeds daily, thereby contributing to an increase of capacity and stability on the overall system.

In an additional set of novel functionality, AdmiRail®-AF, the Lötschberg TTC, implements many functions for alleviating the management of incidents of higher severity. In this area, as usual, the fine line between providing the required level of safety and availability had to be approached as best as possible. In extended discussions and testing scenarios, those equipment failures had to be identified which require immediate automatic action in train operation, and those excluded which are not immediately relevant and would unnecessarily restrict the availability. The quintessential principle is that the automatic responses of the system should initiate the obvious immediate actions, thereby giving some time to the dispatcher in charge for analysing the situation and react appropriately. Let’s hope, that many of these functions will never be needed in real emergency situations. However, the managed incidents in numerous testing exercises, that have been conducted, proofed the feasibility and usefulness of the applied principles.

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Author Biography

Dr. Erwin Achermann, born 1968 finished his PhD at ETH in 2002. He works for systransis Ltd. since 2004, mainly in the development of the TTC software.

Dr. Markus Montigel, born 1961 finished his PhD at ETH in 1994. He was a professor at the University of New Orleans. He has extensive expertise in the fields of railway and safety applications. He is the CEO and founder of systransis Ltd.