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Realisation of fire and intrusion protection at the "Diabolo" train tunnel complex at Brussels Int'l Airport

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ABSTRACT

Between October 2007 and June 2012, the Belgian Railways Group and its partners built a new railway tunnel under the main runway of Brussels Airport, to unlock the – also enlarged – station from the unidirectional connection that was available at that time. To facilitate evacuation, intervention and rescue in this newly built 4 km long infrastructure of the so-called Diabolo project, we designed an automated fire scenario system which is part of the tunnel's and station's safety concept based on EU Directive 2001/16/EC, NFPA 130 and UNECE TRANS/AC.9/9. Furthermore we implemented access control and intrusion detection as part of the complex' security concept. In this paper we present our design and our experiences of setting up the system. We also present our real "burning" train test, which took place during the commissioning phase of the project and was a unique opportunity to test the system's response to "a train on fire" entering the tunnel complex.

The Diabolo railway line

Since June 2012, railway travellers can make use of the Diabolo railway line to travel more swiftly to and from Brussels Airport. Part of this railway line is a recently-built underground railway link that unlocks the airport to the north, ensuring a better connection to the city of Antwerp and the Netherlands (see Fig. 1).

The Diabolo project was the second step in Infrabel's strategy to provide an improved access to Brussels Airport by rail, after the construction of the "Nossegem curve" had already improved travel time from the east (Liège, Germany) in 2005. The recent construction works unlock the potential of Brussels Airport to attract travellers from neighbouring countries – and get them to the airport by rail.

The Diabolo project was a joint effort of several entities of the Belgian Railways Group:

- rail infrastructure manager *Infrabel* (acting as founder of the project), its engineering subsidiary *Tuc Rail*, its ICT department and some smaller specialist entities,
- train and station operator *NMBS*, its station development subsidiary *Eurostation*, its *Corporate Security Service* (*CSS*) and some smaller specialist entities,

in cooperation with private financing partner *Northern Diabolo NV* and several stakeholders such as the fire departments of the towns of Zaventem and Vilvoorde and the Brussels Airport Company.

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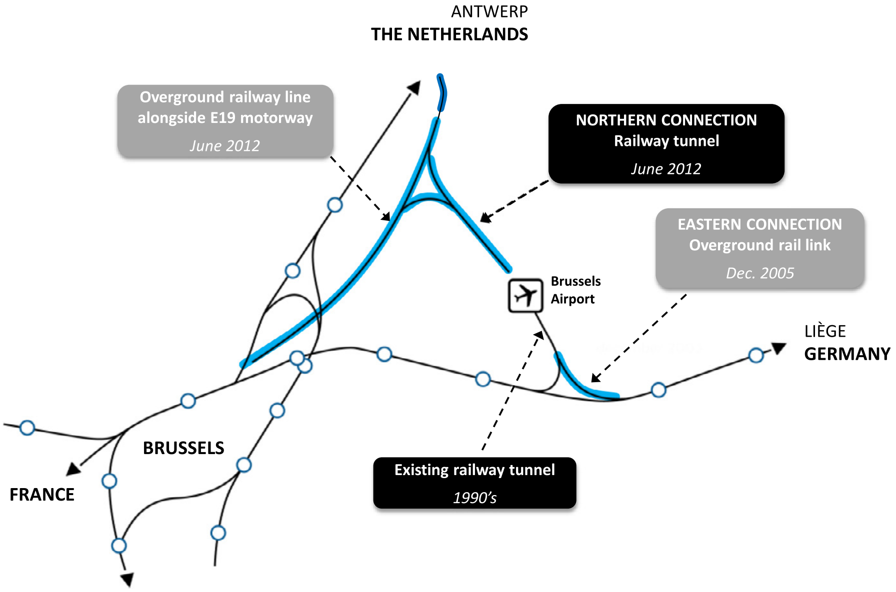


Fig. 1. The Diabolo tunnel realizes a direct rail connection from Brussels Airport to the north.

Required level of safety and security

The Safety & Security Steering Group of the project team (consisting of the owner, final users, architects, engineers and specialists) elaborated the project's safety requirements [1] based on the fire prevention report written by the fire brigades of Zaventem and Vilvoorde [2]. The entire complex – consisting of the new train tunnel as well as the already existing train tunnel and the enclosed underground railway station at Brussels Airport – is situated in three municipalities and is covered by those 2 fire brigades for fire intervention. *The fire brigades mainly based their joint fire prevention report on international tunnel safety recommendations*, as there are no specific national fire safety standards or bylaws for train tunnels in Belgium. In particular, the fire brigades referred to *NFPA 130* [3], *UIC-Codex 779-9* [4], *UNECE TRANS/AC.9/9* [5] *and TSI dir. 2001/16/EC* [6]. These documents give both input for the strategic setup of the safeguarding process as well as prescriptive rules on structure and technical installations to be followed. A good combination of all these measures has fully been studied and documented within the Safety & Security Steering Group. Also these 4 documents give a framework to introduce so-called *"fire scenarios" (this is the automatic and logical response of all safety equipment to a first or confirmed fire detection)* but this automatic response is *not* as such defined in their texts or only in a part of it (e.g. functionality of emergency ventilation). Of course the need for adequate detection and a wide range of safety equipment has been written down, but not the automatic link between those two domains of input and output. Later on in this paper we show a practical way to setup these automatic links.

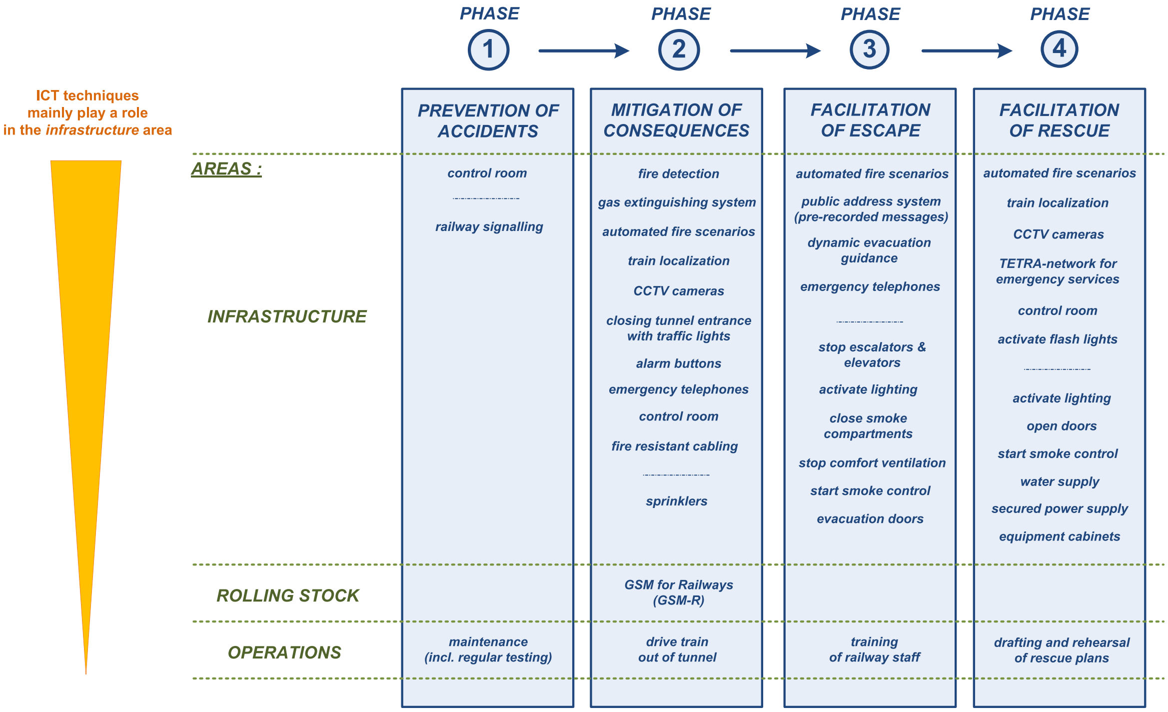
In the fire brigade report *the existing enclosed railway station and the existing train tunnel were considered as an integral part of the new enlarged tunnel infrastructure with respect to the application of the safety regulation*. Hence, the existing terminus station and tunnel (with a total combined length of 1.8 km) got an important technical upgrade to end up with the same safety and security level as the new tunnel (with a total combined length of 4.2 km together with the enlarged station and the existing tunnel).

Fig. 2 shows how the project team implemented the international tunnel safety recommendations. One of the basic premises with respect to this elaboration was the fact that this tunnel is only used by electric passenger trains, and the train speed is always controlled to a maximum of 90 km/h. As depicted in the figure, the use of ICT techniques fits into a larger context of tunnel standards and regulations that typically classify safety measures for tunnels into different areas (infrastructure, rolling stock, operations) and different possible phases of an accident (prevention of accidents, mitigation of consequences, facilitation of escape, facilitation of rescue). The measures fulfilled by the Diabolo ICT techniques mainly span the infrastructure area across the different possible phases of an accident.

Specific security requirements consist of the prevention and detection of unauthorized access to all non-public areas of the station and tunnel complex, and the dissuasion and obstruction of undesired human behaviour (aggression, terrorism).

Technical installations overview

The Diabolo ICT techniques mainly include an *integrated system* for the automation of fire scenarios [7], two *control rooms* that allow efficient remote management of the tunnel complex, as well as a number of *communication systems* used by the



AREAS :	PHASE 1 PREVENTION OF ACCIDENTS	PHASE 2 MITIGATION OF CONSEQUENCES	PHASE 3 FACILITATION OF ESCAPE	PHASE 4 FACILITATION OF RESCUE
INFRASTRUCTURE	control room railway signalling	fire detection gas extinguishing system automated fire scenarios train localization CCTV cameras closing tunnel entrance with traffic lights alarm buttons emergency telephones control room fire resistant cabling sprinklers	automated fire scenarios public address system (pre-recorded messages) dynamic evacuation guidance emergency telephones stop escalators & elevators activate lighting close smoke compartments stop comfort ventilation start smoke control evacuation doors	automated fire scenarios train localization CCTV cameras TETRA-network for emergency services control room activate flash lights activate lighting open doors start smoke control water supply secured power supply equipment cabinets
ROLLING STOCK		GSM for Railways (GSM-R)		
OPERATIONS	maintenance (incl. regular testing)	drive train out of tunnel	training of railway staff	drafting and rehearsal of rescue plans

Fig. 2. Implementation of the international tunnel safety recommendations by the project team.

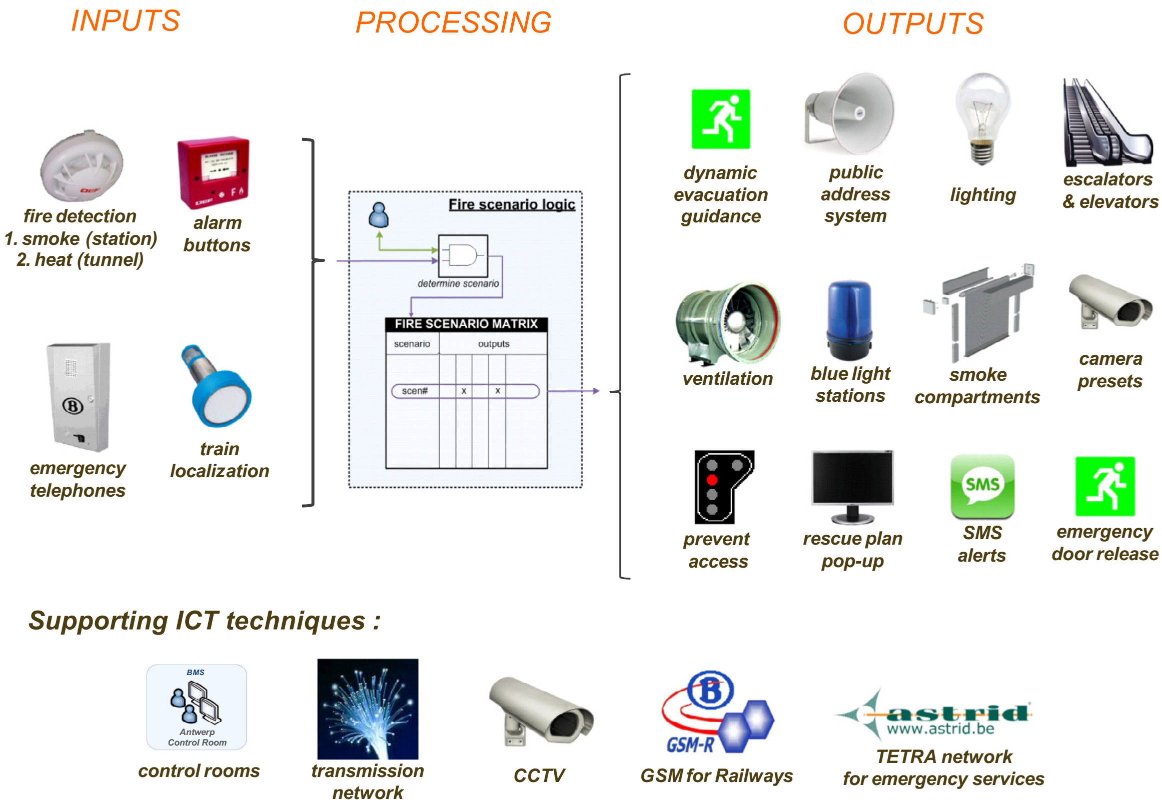


Fig. 3. Synoptic overview of integrated technical installations.

train drivers and emergency services (e.g. GSM-R network, "ASTRID" TETRA-network, emergency telephones). The integrated system architecture consists of following subsystems (see Fig. 3):

Input subsystems

- *Tunnel fire detection* by means of linear heat detection. This subsystem monitors the tunnel temperature, and continuously determines the location and the temperature of the hottest point in the tunnel;
- *Smoke detection* and *alarm buttons* in the station and evacuation complexes;
- A *train localization system* that determines the location of the trains present in the complex;
- *Emergency telephones* with automatic position reporting to the control room.

A processing layer

- An *automation layer* that contains the fire scenario logic and pilots the automatic control of equipment: activate the lighting, activate CCTV presets to visualize the affected area, provide visual dynamic evacuation indications to evacuees, broadcast pre-recorded spoken evacuation messages, start up smoke and heat extraction, shut down escalators and elevators, control railway signalling to prevent new trains from entering the complex, release emergency doors and some smaller equipment activations;
- A number of visualization screens in the *Antwerp Control Room* (located remotely in Antwerp Central Station) and the *Diabolo Control Room* (located on-site, next to the control room of the airport operator) for control and monitoring of the system.

Output systems

- A *dynamic evacuation guidance system* based on green moving guiding lights that suggest to fleeing people the shortest route to the nearest evacuation complex based on the system's knowledge of the location of the fire;
- A *public address system* (PAS) with pre-recorded messages depending on the selected fire scenario; this system also allows distribution of ad-hoc messages from the control room by microphone;
- A link between the fire scenario system and the railway signalling system, for *automatic control of the tunnel's railway signals* in case of fire;
- A link to the complex' *lighting and ventilation* systems;
- A link to the fire safety system of Brussels Airport to exchange information in relation to the selected fire scenario;
- Automatic screen *pop-up of rescue plans* on the visualisation screens;
- Automatic *SMS messaging* to the staff of the rail infrastructure manager and station operator.

Specific for security are camera surveillance, access control and intrusion detection to non-public areas and the tunnel entrance, electronic key management and the use of a public address system.

Elaboration of the automatic scenarios

Fire scenario triggers and safety actions

During normal daily operation all safety and security installations are standby and "waiting" for something to happen. As from the first fire detection (or manual input) the scenario system automatically starts a whole series of actions, following each other in several successive phases.

First, it is of main importance to know where the detected incident takes place and to assess the severity of the situation. So in first instance the lighting is activated and all cameras in the area of the incident will appear on the control screen. The cameras have been preconfigured in so-called 'camera salvos': up to 16 cameras will give a clear overview of the situation. The safety and security operator in the remote control room has 1 min (acceptance time "T1") to acknowledge the reception of the input-signal [see phase 1 and 2 in Fig. 4].

From that moment on, an extra time period of 5 min (exploration time "T2") is available for the operator to check – with the available technical resources and possibly with the help of railway staff on-site – whether the alarm is real or false. Based on his investigation, the operator acts logically: or he resets the configuration into normal mode if it turned out to be a false alarm, or he confirms the status of the accident. In the latter case, all necessary equipment is activated or put into safe mode with a push on a button [see phase 3 in Fig. 4]. At that time, the operator also notifies the fire brigades, and hands over control of the scenario to the on-site control room at the airport once the latter has been staffed and appointed as the command post taking care of the further course of the intervention [see phase 4 in Fig. 4].

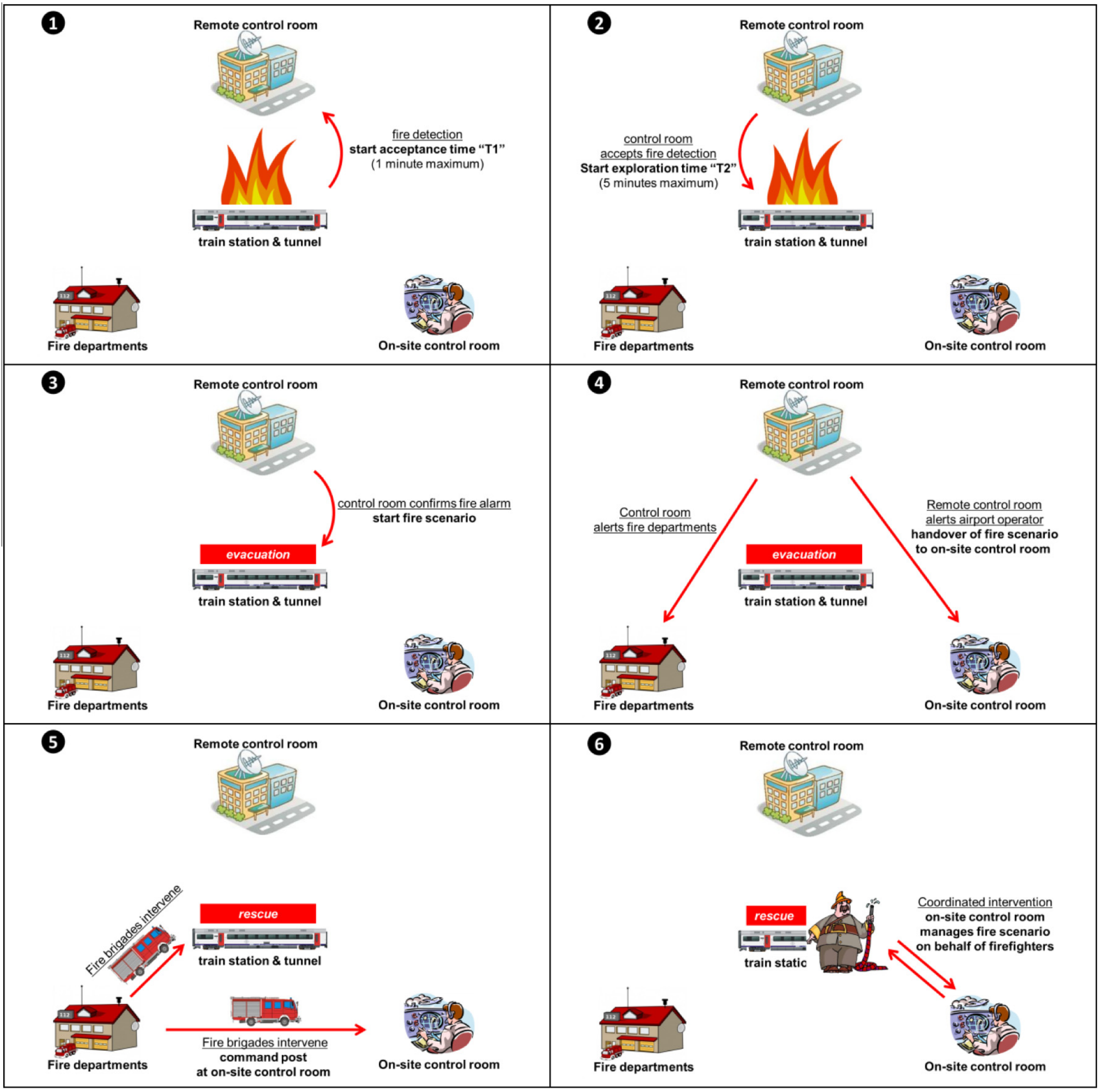


Fig. 4. Fire scenario startup sequence (1–4) and fire brigade intervention (5 and 6).

Fire scenario matrix allows flexible output configuration

It is clear that safety equipment can have different modes of operation, depending on the location of the fire. Indeed tunnel smoke ventilation can act in 2 directions, or the public address system can distribute various pre-recorded messages. In order to make this possible we divided the whole Diabolo complex into different fire scenario zones:

- 12 fire detection zones in the tunnel itself, resulting in 52 possible fire scenarios, (related to the evacuation route location and the relative position of a fire on a train: 'head-side', 'tail-side' or even fire without a train present);
- 16 fire detection zones on the tracks in the station (2 × 8 smoke extraction zones with distinct actuated dampers), resulting in 16 possible fire scenarios;
- 42 fire detection zones in the station of which 24 on the platforms, resulting in 42 possible fire scenarios;
- 44 fire detection zones in evacuation shafts, cross passages and distant technical rooms, resulting in 44 possible fire scenarios;
- 3 fire scenarios in the airport building itself (3 separate locations, adjacent to the train station).

All these 157 scenarios have a unique identification based on the location of the fire and (for the tunnels) also on the relative position of the fire in relation to the position of the train – if present. In other words:

- for the station there's a one-to-one relationship between the fire detection zones and their corresponding fire scenarios. The beginning and subsequent detection of a fire within a detection zone is determinant for the activation of the corresponding fire scenario. The number of scenarios is mainly determined by (1) the fire resistant enclosure of (a group of) separate rooms and (2) the possible actuation of safety equipment which can be (similar but) different, depending on the exact fire position;
- for the tunnel there's a one-to-many relationship between the fire detection zones and their related fire scenarios. This mapping is determined by the relative location of the fire with regard to the position of the train(s).

Our configurable fire scenario matrix establishes the link between a selected fire scenario and the corresponding equipment outputs (some 850 in total) to be driven (see Fig. 3). This method proved to be highly efficient during the commissioning phase of the project.

All 52 tunnel-related scenarios are also represented by a synoptic drawing that shows the smoke ventilation direction as well as evacuation possibilities (see Fig. 5). For the 'simple' fire scenarios this is not necessary as each detection zone defines the scenario zone as such.

Specific for tunnel smoke control: relative fire position and a mid-train fire

As shown in Figs. 5 and 6, the direction of smoke ventilation is determined by the relative position of the fire source in relation to the position of the train. This is possible due to the implementation of distinct fire detection (with an accuracy of 3 m) and train positioning detection (with a resolution of 20 m). The smoke is then extracted via the 'shortest' part of the train so the majority of passengers will not be affected by the smoke, nor will the fire brigades during their intervention.

In order to allow evacuation of passengers from the 'shortest' part of the train, a time algorithm has been implemented to introduce a time delay before starting up the longitudinal smoke ventilation [8]. During this time delay, smoke will stratify at the tunnel ceiling which is more likely to have a less negative effect on the passengers evacuating from the 'shortest' part of the train. This time delay is minimal (0 min) when the fire is located at the head or tail of the train, and is maximal (5 min) when the fire is located in the middle of the train. Intermediate values are determined by means of interpolation.

Implementation and ICT integration

To automate the fire scenarios we designed a *distributed automation architecture* (see Fig. 7) consisting of distributed I/O islands on the lowest architectural level (implemented with so-called "Modular Service Points" or "MSPs"), the fire scenario logic being implemented in redundant technical rooms inside and outside the tunnel complex, and the visualisation and remote control being effectuated in a remote and on-site control room.

Our contractor installed the *Modular Service Points* every 100 m along the rail tracks in the tunnel. The MSPs serve as an aggregation point for distributed inputs/outputs (I/Os) and also as a voltage conversion node to save on power cabling.

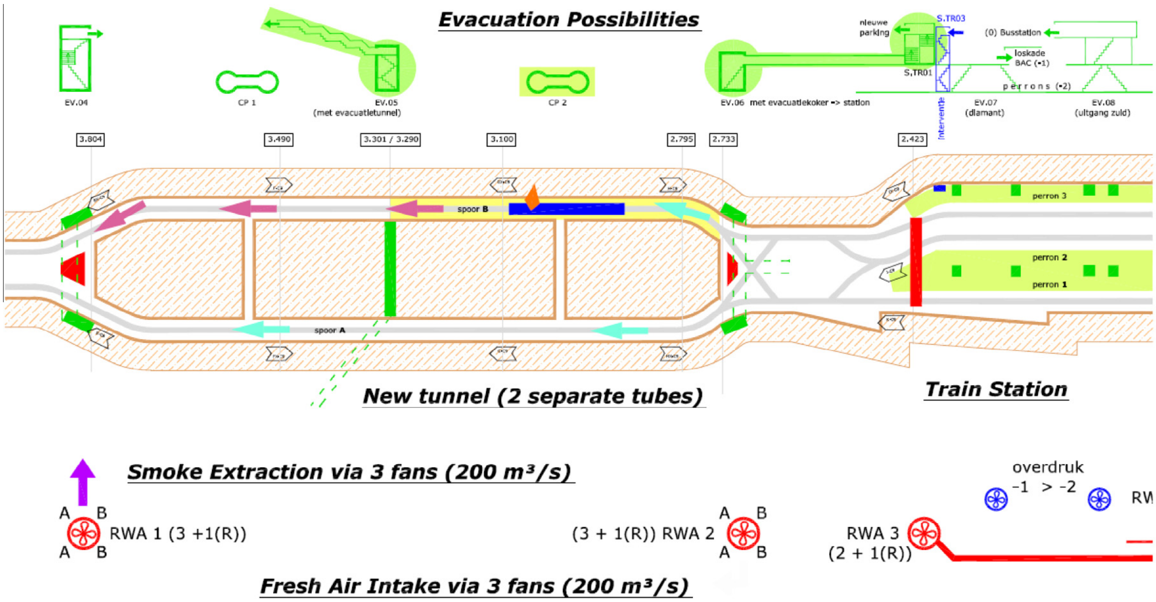


Fig. 5. Synoptic representation of a tunnel fire scenario.

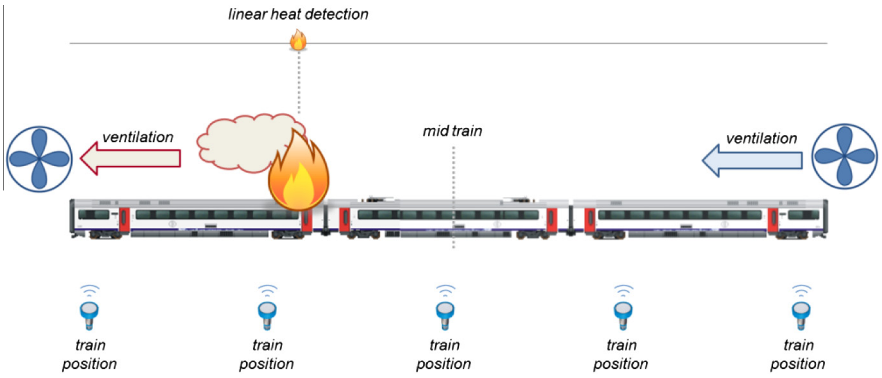


Fig. 6. Fire and train localization determine the direction of smoke control (in the tunnels).

Ultrasonic *train sensors*, attached every 20 m to the cable tray along the tracks, take lateral samples of the position of the trains and allow to determine when a train has stopped. We've chosen an inter-sensor distance of 20 m for 2 reasons: (1) 20–25 m is about the length of a single train car so with this sensor resolution the system is able to locate the smallest possible train and (2) a decelerating train will need some 15 s to trigger the next sensor when slowing down to less than 5 km/h. Within the project's Safety & Security Steering Group, these 15 s have been considered as an acceptable delay for determining whether a train has stopped.

For the purpose of redundancy each consecutive train sensor has been connected with fire resistant cabling to the other of 2 consecutive MSPs. In this way we ensure that train localization functionality is still present with a degraded resolution of 40 m when a Modular Service Point has become faulty or damaged by fire. The MSPs themselves have consecutively been connected onto different optical rings to ensure Profinet fieldbus connectivity to the main technical rooms in the case an MSP becomes unavailable.

For the purpose of *dynamic evacuation guidance* (DEG), the Modular Service Points drive ribbons of green light emitting diodes (LEDs) which have been arranged continuously in a hand rail housing along the tunnel evacuation path. These LEDs form a system of green moving guiding lights that suggest to evacuees the shortest route to the nearest evacuation complex based on the system's knowledge of the location of the fire. The location of the fire "T_{MAX}" (see Fig. 7) is derived from the linear heat detection system as being the tunnel location with the highest temperature. Our contractor engineered the electronic drivers of the DEG ribbons in such a way as to provide a redundant control path to the DEG ribbons from 2 consecutive MSPs, as a part of the DEG ribbons are expected to be damaged in case of a fire.

The fibre optic cables of the *linear heat detection system* are not connected to the MSPs, but immediately connected to the technical rooms where the heat localization logic is situated. Two detection cables are present in each section of the tunnel, i.e. one detection cable on each side of the tunnel, connected to different technical rooms.

Although not especially mentioned in Fig. 7, the Modular Service Points also serve as an I/O point for the CCTV cameras, emergency phones and blue flashing lights (indicating the proximity of extra fire department intervention material, available in a proper closet). The tunnel radio communication equipment (mainly antennas and repeaters) has been connected immediately to the base equipment in the technical rooms, as well as the loudspeakers which form a part of the public address system (PAS). The majority of the 3rd party systems (like ventilation and lighting) have been integrated in the technical rooms with the LonWorks building automation protocol as this was a contractual condition with respect to the integration of those systems. Here also, our contractor designed a redundant control path to drive the connected equipment.

Whereas the MSPs function as distributed I/O points, the mere *fire scenario logic* has been implemented on Programmable Logic Controllers (PLCs) in the main technical rooms of the tunnel- and station infrastructure. These main technical rooms serve as each other's backup in a hot-standby configuration. They are located approximately 2.5 km apart: one of them is situated outside the tunnel close to the motorway to the city of Antwerp, the other is located inside the railway station at the airport. The equipment in these rooms implements the train localization logic and the heat localization logic. The output of these 2 functions is subsequently used by the fire scenario determination logic to determine which tunnel fire scenario to launch. Besides the tunnel fire scenario logic, the same integrated system also implements the fire scenario logic of the railway station. Whereas the linear heat detection system has been chosen for the tunnel due to its reliable operation in harsh environments, the fire detection system in the railway station and the evacuation complexes consists of "classical" smoke detectors divided into detection zones. These detection zones are the basis for fire scenario selection in the railway station and evacuation complexes.

With respect to its functioning in degraded mode, the system as a whole provides *3 levels of autonomy*:

- The fire detection systems with their detectors, push buttons and sirens on the lowest architectural level provide a local level of autonomy should the fire scenario logic be unavailable (this autonomy also holds for the sprinklers in the station and the gas extinguishing systems in a number of technical rooms);

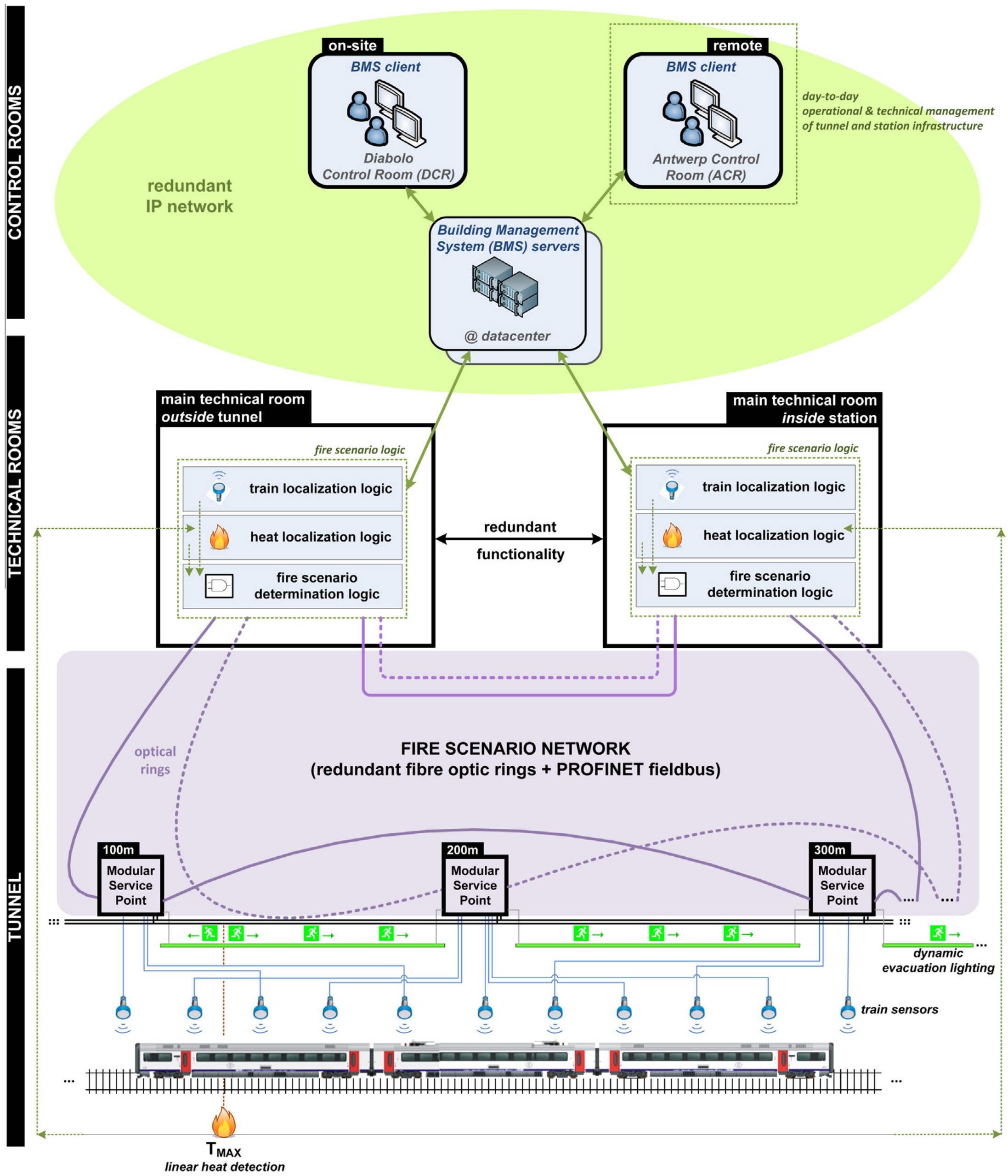


Fig. 7. Automation architecture of the fire scenario network.

- In the overlying layer the fire scenario logic (together with the fire detection systems and the MSPs connected through the fire scenario network) provides a global level of autonomy should the control rooms and its building management system be unavailable;
- The operator workstations in the control rooms – situated at the top level of the system architecture – offer a rich functionality on top of the basic functionality of the fire scenario system. This workstation functionality allows the monitoring and individual control of the equipment taking part in a fire scenario (this is the so-called "freeze" function).

Two *control rooms* intervene in the handling of a fire scenario:

- A *remote* control room at the city of Antwerp, which is manned on a 24/7 basis and is also used to guard the station and tunnels of Antwerp Central Station. The operators in this so-called Antwerp Control Room (ACR) vouch for the day-to-day

operational and technical management of the tunnel, the station and their safety and security systems. This control room serves as the Central Supervising Station as mentioned by NFPA 130.
- An *on-site* control room (DCR) at the fire department building at the airport, with the same functionality as the ACR but only manned in case of an accident.

Minimum Operating Conditions

Notwithstanding the several safety and security systems have been designed and implemented with system availability in mind, the Safety and Security Steering Group has defined a set of Minimum Operating Conditions (MOCs) for the Diabolo railway line [9]. These MOCs define the system functionalities that need to be available for tunnel operation, and determine the allowable maintenance intervention and solution times in case a functionality is unavailable.

Based on their interpretation of eventual technical warnings or alarms on the Building Management System, the control room operators apply the Minimum Operating Conditions in the event that the functionality of a system (or a subfunction of it) becomes unavailable due to a technical defect. In a broader sense, the Minimum Operating Conditions offer a framework for allowing railway operations to continue even when there's a maintenance session going on due to a minor technical defect.

Fire brigade intervention

As already explained in the 'automatic fire scenarios' section, this system of ICT driven actions has been put in place to help the fire brigade and traffic control to prevent a larger accident with difficult evacuation and intervention conditions. Hence, these automatic responses cannot be seen separately from the operational actions they try to facilitate. Therefore any 'technical' fire scenario has been complemented with an 'operational' alarm sheet (see Fig. 8). These alarm sheets aggregate 4 major types of information of particular interest to those in charge of the operational handing of an intervention:

- The position of the train in the tunnel and the relative position of the fire on that train;
- The signalling state of the traffic lights in the tunnel (keep closed or imperative closure);

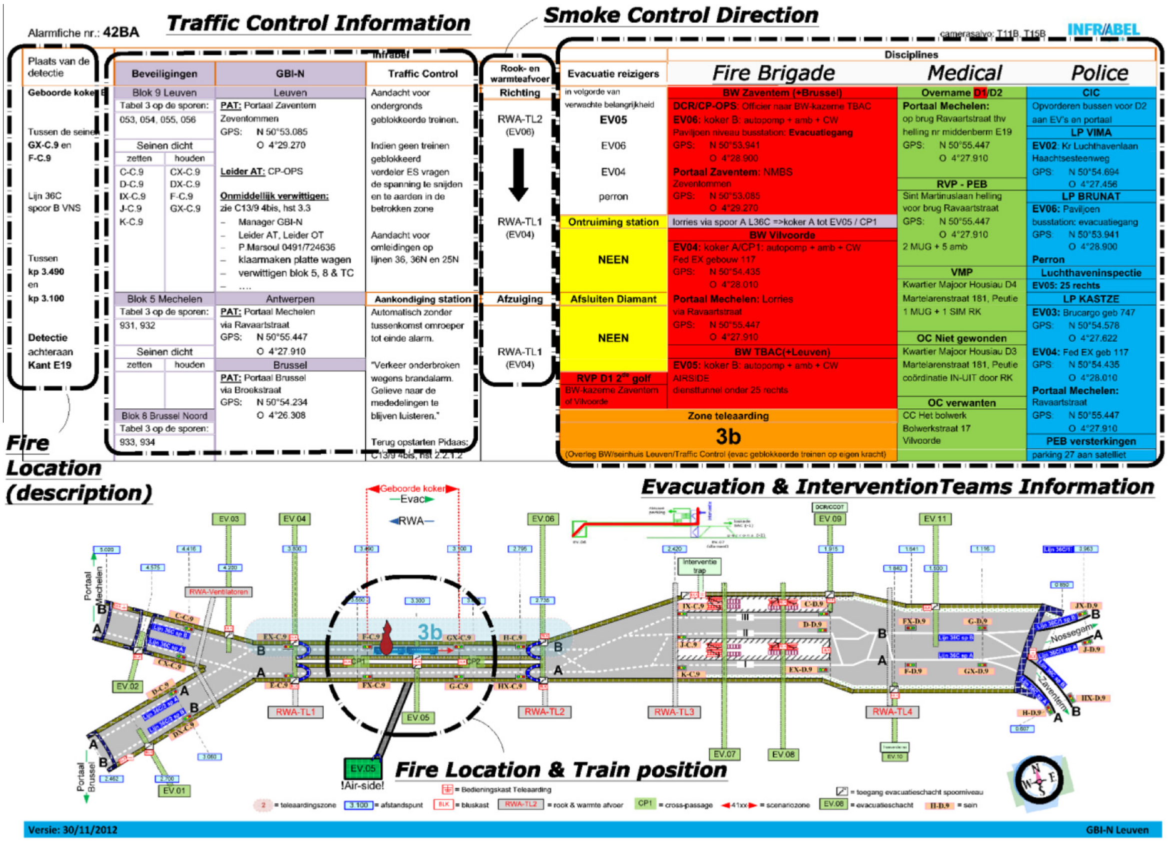


Fig. 8. Example of an "operational" alarm sheet (complements a "technical" fire scenario).

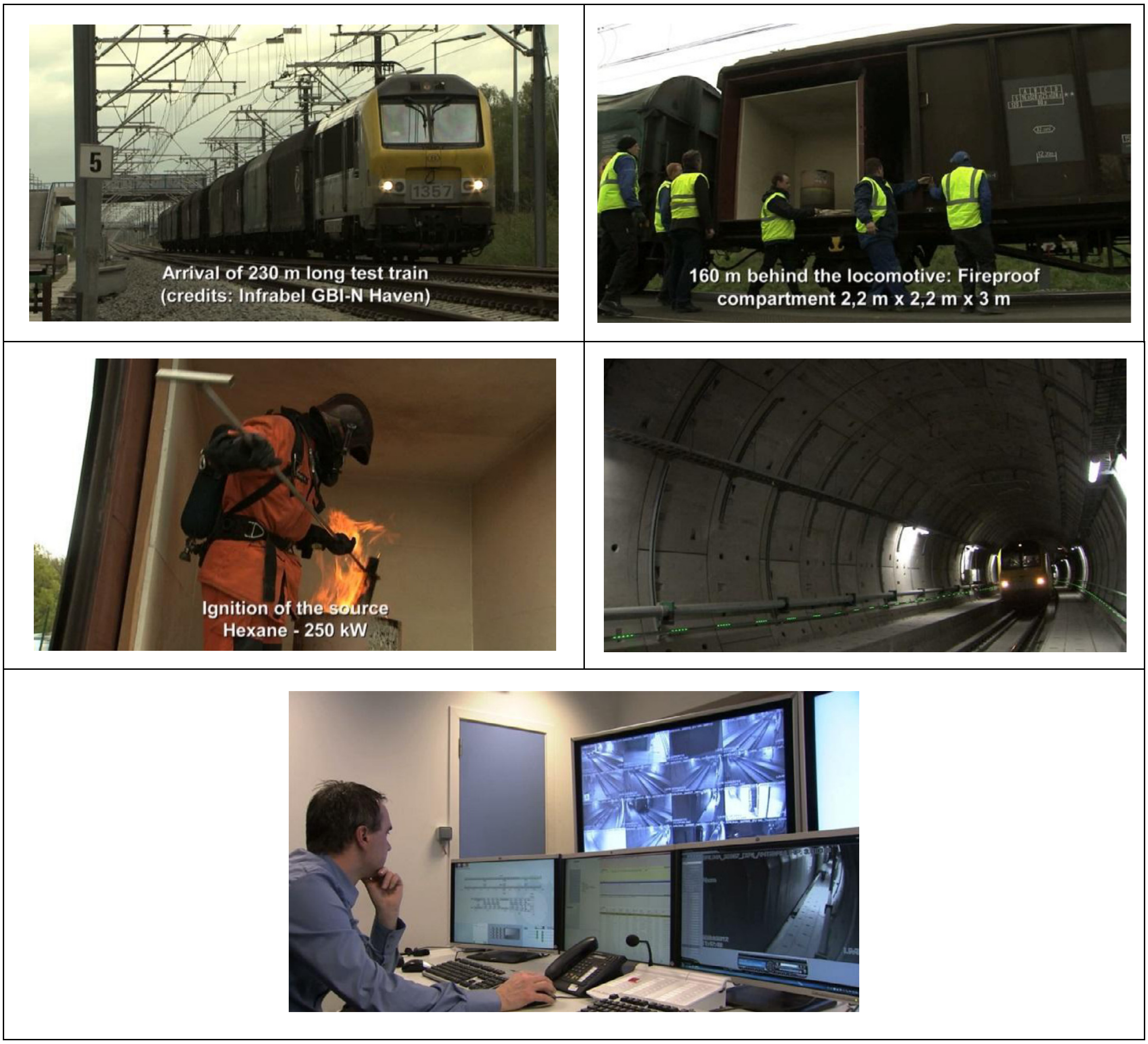
- The direction of the smoke ventilation system;
- The procedures to be followed by the intervention disciplines (fire, medical, police).

During start-up of a scenario, the system transmits the applicable alarm sheet to the subscribed stakeholders by means of on-screen visualisation and an SMS text message.

Real train fire test (April 2012)

During the commissioning phase of the project we organised a "burning" train test to evaluate the system's response to "a train on fire" entering the tunnel complex. Therefore we realised a fireproof compartment in a specific wagon of a 200 m long test train. Inside the compartment the firefighters ignited a flame source of 250 kW (hexane in a barrel) before driving the train into the tunnel. Our video [URL: http://youtu.be/BZ9d7Koii8w] shows how the integrated system – after the train has stopped – correctly determines the contours of the train as well as the hottest point in the tunnel, leading to a correct fire scenario selection and output activation. Notable however is that the power of the heat source (when located inside the train) has to exceed 250 kW in order to exceed the 'customary' detection threshold of linear heat detection systems (see Table 1).

Table 1
Photos from real train fire test: (1) Arrival of test train; (2) Fireproof compartment for heat source; (3) Ignition of heat source; (4) Train stopping in tunnel; (5) Test supervision at on-site control room.



Conclusions

In this paper we showed how a set of well-considered automatic responses can contribute positively to the implementation of the safety and security policy of a railway tunnel, based on international recommendations. The automated scenarios (and the systems behind it) assist control room operators and intervention teams in the quick assessment of possibly dangerous situations, and assist them in the selection and swift activation of the appropriate escape and rescue facilitation measures. Mainly being infrastructural measures, these ‘technical’ pre-configured fire scenarios are a useful complement to the operational measures which continue to be of utmost importance to safeguard the tunnel infrastructure and its users.

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Figs. 1, 4 and 8 by courtesy of Frédéric Petit, Derrick Naets and Peter Marsoul respectively.

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