

A passenger flow oriented security and safety approach in international railway stations

Simon Collart-Dutilleul^a *, Stephan Maurer^b, Philippe Bon^a, Peter Kaul^b

^a *Université Lille Nord de France, IFSTTAR-COSYS-ESTAS, F-59650 Villeneuve d'Ascq, France*

^b *Institute for Safety and Security Research, Bonn-Rhein-Sieg University of Applied Sciences, Rheinbach, Germany*

Abstract

In the context of the Franco-German research project Re(h)strain, this work focuses on a global system analysis integrating both safety and security analysis of international and/or urban railway stations. The Re(h)strain project focuses on terrorist attacks on high speed train systems and investigates prevention and mitigation measures to reduce the overall vulnerability and strengthen the system resilience. One main criterion regarding public transport issues is the number of passengers. For example, the railway station of Paris “Gare du Nord” deals with a bigger number of passengers than the biggest airport in the world (SNCF open Data 2014), the Atlanta airport, but in terms of passengers, it is only around the 23rd rank railway station in the world. Due to the enormous mass of people, this leads to the system approach of breaking out the station into several classes of zones, e.g. entrance, main hall, quays, trains, etc. All classes are analysed considering state-of-the-art parameters, like targets attractiveness, feasibility of attack, possible damage, possible mitigation and defences. Then, safety incidence of security defence is discussed in order to refine security requirement with regard to the considered zone. Finally, global requirements of security defence correlated to the corresponding class of zones are proposed.

A case study based on the works in Re(h)strain is used as an illustration to demonstrate how the above-mentioned security and safety requirements may be implemented and handled at train stations. Therefore, the different security measures proposed for an unaffected flow of passengers are correlated to existing ones, such as video surveillance and security personal patrolling. The results of sensor set-ups realised within the project and tested in real environment show new ways of implementing innovative techniques to security applications. Depending on the technology, sensor portals at the entrances of train stations or sensor nodes distributed throughout the station increase the level of protection achievable for the detection of threats as part of preventive security concepts. The fusion of data gained by different sensor systems, including person-tracking by non-visual object recognition and trailing, enables a core function of a security assistance system. This assistance system makes security personnel aware of threats and the location of possible carriers of suspicious material as a prior condition to successful intervention measures. The high level of automation reduces human intervention to a minimum. In the conclusion it will be recommended to think of international railway stations as complex interconnected systems which are made for sharing traffic flows. It means that thinking about local solutions may produce safety problems to connected zones due to possible overcrowding.

Keywords: Railway safety and security; Detection and protection; Non-cooperative passenger control; Gas sensing

* Corresponding author. Tel.: +33 3 20 43 83 20; fax: + 33 3 20 43 83 98.
E-mail address: simon.collart-dutilleul@ifsttar.fr

1. Introduction

The railway station of Paris “Gare du Nord” deals with a bigger number of passengers than the biggest airport in the world (SNCF open Data 2014), the Atlanta airport, but in term of passengers it is around the 23rd rank railway station in the world. Considering the state of the art dealing with security, a specific approach integrating its specific aspects of passenger flows has to be considered. Control check points, for example, may produce some heavy queuing phenomena.

A short analysis of the state of the art and best practices concerning overcrowding in railway provide some preliminary safety requirements. Those particular requirements have to be considered as soon as possible in the design phase of security protection measures. Focusing on technological solutions, it seems possible to control luggage and passengers without stopping people and putting luggage on conveyors.

The first part of this document focuses on a proposition of integrated approach. It first considers the state of the art of over-crowding in railway station. Then a specific structure for leading a preliminary study is introduced. This leads to define preliminary requirements for additive security devices like gates and checkpoints. A second part details a particular proposition which uses the technological state of the art. A smart combination of up to date technologies leads to a pragmatic proposition which is shown to be well adapted with regards to the first level requirements. Finally, the conclusion describes the limitations of the proposed study and gives some elements concerning the necessary following steps.

2. Integration of safety and security criteria

2.1. Overcrowding

In the context of the 2012 Olympic Games in London, deep studies concerning overcrowding management in railway stations have been conducted. From these studies, Watson and Little (2016), using “Crowd management at stations, a Good practice guide” (2004) from RSSB, said: “*The negative effects of crowds may be more than service delays and unhappy passengers. Crowding can also lead to injuries: anything from minor slips and trips to more serious incidents at pinch points and the platform edge.*” In other words, overcrowding phenomenon leads to safety problems.

Talking about good practice, the document presents, in page 6, an approach called “FIST”, based on four parameters:

- **Force:** flow path studying, domino’s effects,
- **Information:** various kind of information delivery like static and visual, dynamic and visual, audible or face to face;
- **Space:** capacity, bottlenecks, obstructions,
- **Time:** timetable, effect of delay, other transport facilities,

They provide constructive propositions in order to avoid over capacity of critical zones using well-adapted passenger information. They point out effects of timetables on inter modality services. This aspect is more detailed in the present work in the next section.

2.2. A global traffic flow management in order to deal with physical layout

In conformity with the FIST approach, passenger flows have to be managed with regards to infrastructure characteristics. Namely, maximal capacity of critical zones has to be taken into account in order to avoid bottlenecks. The challenge is to manage globally with the physical layout.

Watson and Little (2016) said: “*There is a need for multi-stakeholder cooperation*”. In conclusion, there is a need to model the passenger flows through and around the station. Obviously, stakeholder’s data is needed but infrastructure holders are needed too. As an example, from Heddebaut and Di Clommo (2017), we know that 35% of people crossing the “Lille-Flandres” railway station are not future train passengers. They may be in the station to buy a newspaper. In fact, there is a political vision, as shown in Région Nord-Pas de Calais (2015), to confirm that railway stations are economic and cultural hubs. As a consequence, today the maximal capacity of a given zone may be reached even when the number of passengers looks not critical and this situation will increase in the future.

Consequently, as recommended in the FIST approach, there is a need for information sharing in order to manage with safety and security. Information has to come from all the actors including infrastructure manager, railway undertakers and shop owners. From Kadri et al 2017, we can also notice that, for crisis management, synchronization has to be done under the authority of a single leader. It is an efficiency parameter; nevertheless, in order to perform synchronisation effectively, a centralised information system is useful.

Providing an efficient integrated safety/security approach is a matter of balance. For instance, in order to secure a given area, a control point may be added or a corridor may be closed. With these types of measures, a bottleneck can be created and have safety consequences when the limit of capacity of the zone is reached.

A railway station is a complex socio technical system including a lot of couplings. As a consequence, a final decision has to be taken on the basis of a deep analysis using real industrial data. The added value of the presented paper is to provide a preliminary analysis in order to identify which kind of security devices can be considered and where they can be placed.

2.3. Protection

Using a classical automatic control approach, dynamic protection measures may be classified into three kinds of activities:

- Detection
- Diagnosis and identification
- Corrective action

Detection means that you know that something dangerous is about to happen. You may have enough knowledge to claim that it is dangerous. But you may not know exactly what is happening.

The aim of the diagnosis is to analysis the available data in order to identify the source of danger: who is holding the source, where is it, when is he supposed to reach his target, etc.

On the basis of the available diagnosis a specific action is triggered in order to eliminate the danger. When terrorist action cannot be stopped, then a crisis management strategy may be engaged. The present document does not go further in this direction: other works from the Re(h)strain project may be consulted on this particular subject (Kadri et al 2017). Nevertheless, focusing on protection, the place of detection devices has to be planed integrating the fact that a corrective action has to take place. For example, a potential danger has to be detected and corrected before a critical zone in the station and consequently, neutral zones where the danger could be isolated or neutralized have to be identified.

In a safety and security integration analysis, a basic principle about protection is proposed: specific measures against potential attacks or accident may be introduced considering safety or security weaknesses they may create. As an example, systematic luggage checking using gate may generate overcrowding phenomenon which can be considered as weakness for safety and security.

2.4. Operational safety

This last definition is uncommon. The motivation to add a local attribute to a zone is to allow a local evaluation for a particular safety component. In this case, the question is to check if a fundamental function of the zone or of the global system is degraded. For instance, when a gate is installed, the queue may prevent to access a restaurant. The same device may have a different influence on the performance of the system when it belongs to various zones. Consequently, a global cost/benefit analysis is needed.

Concerning, protection against terrorist attack, RSSB best practice report (2004) says “*Early inclusion of such measures at the design and pre planning stage are often cost neutral and highly desirable*”. Authors’ understanding of this recommendation is that the security approach shall take into account the global system design including its global contract of services. When a passenger flow is slowed down or stopped by a control component, some people may never enter the zone. Then depending on the nature of the zone, they may never buy goods in the shops and they may not take the train they previously planned to take.

As an example, when you oblige people to register for a particular class of train the day before they travel, they would not take this class of train in case of unplanned advance or delay. The cost of this disposition is not high, but the operational safety cost is high. The corresponding railway company will lose some clients every day and the operational safety cost becomes heavy. Considering this parameter, a control gate may be cheaper.

As for overcrowding problem, to manage operational problems we have to take into account the stakeholders view (Stephen and Little, 2016). Obviously, companies are differently impacted when they provide different kind of service to passengers. Moreover, the type of concerned economical actors becomes wider when the concept of city-hub is becoming a reality, as described in Monzon et al (2016)

2.5. Railway zone partitioning

The set of zone presented in this document is rather basic. The idea is not to provide an exhaustive structure which corresponds to every specific station design, but to propose a kind of generic structure which may be enriched or adapted in order to model various kinds of design. The main goal is to perform a global safety and security evaluation of a railway station, using safety characteristics of its composing zones.

The zones can be presented in three classes:

- Quay platforms
- Entrance corridors
- Main halls

Depending on station organization, some particular commercial zones may be considered as separated from the main hall and from the entrance corridors. Physical separation may lead to split a zone. As an example, escalators introduce a decoupling in the crowd density and it may be better to study upstream and downstream zone separately.

2.5.1. the Zone attributes

The global structure of a Zone is presented on the figure 1. The first attribute is a global safety value. Global means that it takes into account both safety and security aspects. Contribution of security to this value depends of attractiveness attribute, because the probability that the zone is considered as an interesting target by a terrorist as a great impact. The interested reader may analyse the following web resources to go deeper considering terrorist attractiveness of various component of a railway system[†].

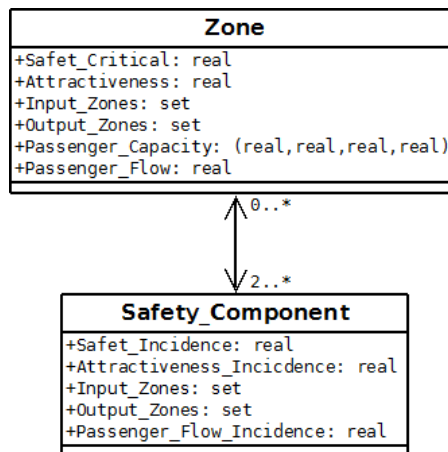


Fig. 1 Simplified UML Class diagram of Zones and Safety components.

The zones receive passengers from a set of other zones and send its passenger flows to an output set of Zones. It is assumed that passenger flows are directed flows, as safety controls may decrease the passenger flow value in a direction, but not in the other.

The maximum value of respectively, the summation of passenger flows of output sets and a static capacity of traffic of the zone gives the maximum passenger flow of the zone.

[†] The Global Terrorism Databank, (GTD) under <http://www.start.umd.edu/gtd/search/Results.aspx?search=train&sa.x=23&sa.y=9>
 The "List of Attacks on rail-based Transportation" https://de.wikipedia.org/wiki/Liste_von_Anschlagen_im_Schiienenverkehr

When the attribute passenger flow is less than the summation of the attribute of zones belonging to the output set, then the passenger capacity attribute becomes a critical parameter. The attribute “Passenger_capacity” is a tuple of four real values. These values correspond to the four levels of crowd density defined by the best practice guide of the RSSB (see figure 2). Actually, the density is computed considering the global area of the zone (which is a static internal parameter) and an initial value of passenger numbers (internal parameter), which may increase or decrease with regard to the differential value between input and output zones passenger flows.

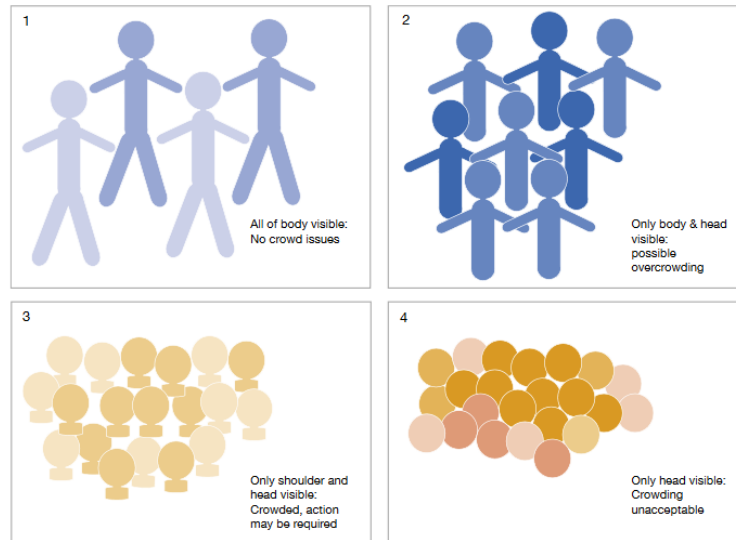


Fig. 2 Normalized density of crowd (RSSB 2016)

The quantity of people of the zone is compared to the 4 numbers of capacities corresponding to the four density values applied on the zone area. Comparing with the density levels is used to modify the global safety of the zone.

2.5.2. Safety component structure

The connection between two zones (including the connection of the zone with itself), may use a safety component (see figure 2). Actually, they are supposed to increase the security level of the downstream zones. Safety component may modify passenger flows. By the consequence, a safety component may decrease the safety attribute of upstream zones, when the modification of the crowd density leads to reach a critical level. Last but not least, safety control component may produce queuing phenomenon which can increase the terrorist attractiveness or by the contrary may produce a dissuasive effect: this is register in the attribute called “Attractiveness_incidence”.

The produced overcrowding may have an influence on the so called operational safety of the upstream zone: people not going in restaurants, missing their train, etc.

2.6. Preliminary requirements for a safety component

This section proposes a preliminary formalized hierarchy of safety/security requirements extracted from previous works mentioned in the beginning of this article. The high level one is the following:

- R*: A safety component shall increase the global safety of a railway station.

In fact, the global safety of the railway station is difficult to compute without a detailed simulation of the station. The needed level of detail is not achievable with the presented approach.

The high level requirement can be break out in 2 parts:

- R1: a safety component shall allow identifying threats.
- R2: A safety component shall allow creating a defence action.

R2 requirement can be break down:

- R2.1: Safety components may be put rather near the input of the system.
- R2.2: A safety component rather not decreases the passenger flow.

- R2.3: A safety component is rather not placed before a zone which is safety critical.

Actually, considering a sequence of zone corresponding to a goal that people may want to achieve, all the zones downstream of the safety component will increase their level of safety. In other word, you protect more people using the same component when the component is at the beginning of the sequence.

When passenger flow is decreased, the added value of the component is not easy to prove. As it increases the security on one hand, it may decrease the safety on the other hand. Actually, overcrowding phenomenon rather decrease defence actions possibilities. The reason is that detecting a threat is not enough: the downstream zone has to allow a defence action.

When a danger or a threat is detected in a critical zone, the corrective action is quite difficult to perform. In this case, there may be no direct influence on the security level, but only a dissuasive effect.

Now, the above requirements contain the main analysis which has been performed on the state of the art. The next question concerns the possibility of designing protection systems fulfilling these requirements. The next section presents a particular technical proposition including not really an out breaking innovation: this is mainly a smart use of modern technologies.

3. Case study IED/dirty bomb detection and person tracking

In a case study within the Re(h)strain project possible measures to detect hazardous materials were evaluated and tested under lab conditions. The respective threat scenario deals with an attack on trains or train infrastructure by terrorists with explosives or dirty bombs. At the moment there are no security measures in use regarding the continuous control of passengers or luggage, and therefore potential attacker's activities are unhindered. Due to the structure of this means of mass transportation as a free accessible environment, the use of contact-free or non-cooperative control facilities or surveillance are of special interest, remaining the passenger flow unaffected by any possible technical or organizational measure.

Within the above mentioned threat scenario, two main means had to be taken into account. The first one was the detection of an improvised explosive device (IED) and the second one was the detection of radioactive sources, carried hidden or inside of luggage. Additionally a person tracking system should be established to follow an identified threat carrier within a specific area and make security personal aware of a possible attacker and to initiate counter measures.

3.1. Detection of IED

For the detection of explosives, explosive related compounds, or inflammable chemicals, different techniques have been proposed or are in use. The most common is the use of X-ray devices to check luggage e.g. at airports. Other methods are based on neutron activation spectroscopy or MRI resonance spectroscopy (Maneesha et al. 2003, Lockwood et al. 2003, Womble et al. 2001). A drawback of these techniques is that an identification of a chemical itself is impossible. They can only differentiate between metals/non-metals, state the effective nuclear charge numbers, or determine the elementary composition. Moreover there are high demands on the infrastructure, high investment costs, and the need to use harmful radiation.

As an alternative, explosive trace detectors can be used. The analytical techniques operating are miniaturised and adapted methods of instrumental analysis and wet chemistry, ion mobility devices, electronic noses, biological sensors, like sniffer dogs, and anti-body rapid tests (NIAG 2005, Moore 2005, Kolla 1997, Gardner et al. 2004, Zalewska et al. 2013, Lopez et al. 2014, Bouhadid et al. 2012, Caron et al. 2010, Blue et al. 2013, Lazarowski et al. 2014, Maurer et al. 2015). The detection can be done by examination of volatile explosive related compounds in the gas phase, or particles adhered to surfaces.

In the Re(h)strain project we proposed the application of metal oxide semi-conductor sensors (MOx). These sensors are cheap, common and available for a broad range of substances. They are widely used for automotive applications or environmental monitoring purposes (Fine et al. 2010). Especially in the field of detection of homemade explosives, like triacetone triperoxide (TATP), strong efforts of further developing sensitivity and selectivity are made (Warmer et al. 2015). Combining several MOx-gas sensors of different selectivity to an array of sensors and a subsequently statistical evaluation of the signals of sensors exposed to different airborne chemicals gives unique patterns which allow the chemical identification. Fig. 3 shows exemplified a plot of gas sensor responses to different decomposed chemicals from previous work (Becher et al. 2010).

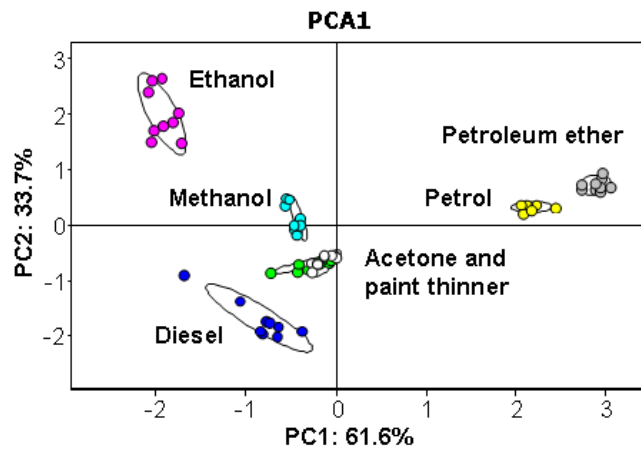


Fig. 3 Score plot of the principle component analysis (PCA) of gas sensor responses to various test agents (Becher et al. 2010)

To realize the concept of a non-cooperative control facility, we developed a walk-through portal based on previous works within the HAMLeT project (Becher et al. 2010). Figure 4 shows the basic principle. A horizontal air stream generated by a blower ventilator (1) and a suction ventilator transport volatile compounds released from a passing person to the sensing unit (3).

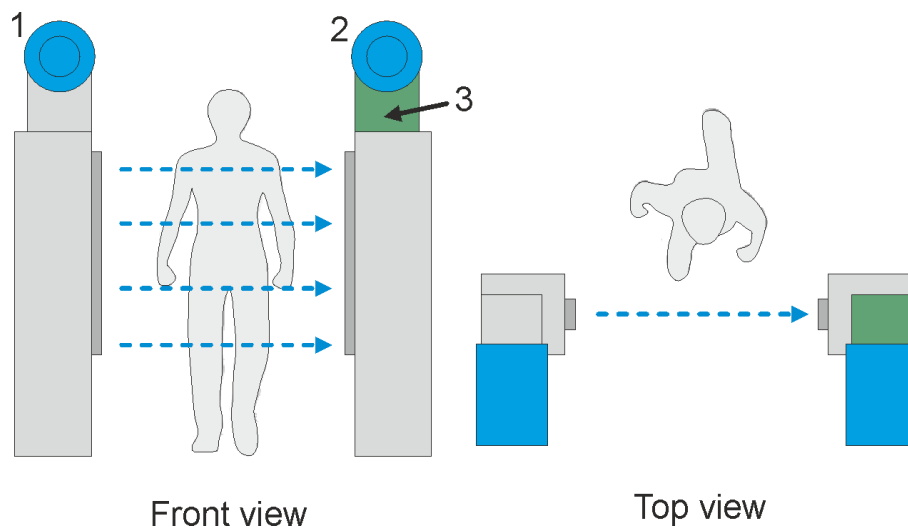


Fig. 4 Sketch of the experimental setup for the non-cooperative control of persons. (1) Blower ventilator, (2) suction ventilator, (3) sensing unit, the blue arrays indicate the horizontal airstream.

A set of chemical compounds for the gas sensing applications was defined in the Re(h)strain project and the sensing unit detection capability was tested.

3.2. Detection of dirty bombs and person tracking

The investigations related to dirty bomb detection and person tracking were carried out by the project subcontractor Fraunhofer FKIE in Wachtberg, Germany. The work was focused on the detection of radioactive radiation released from γ -nuclides. A set of gamma detectors was placed in a test environment and distributed NIR Kinect cameras were installed in about 3 m height to monitor moving persons. The test environment is shown schematically in figure 5.

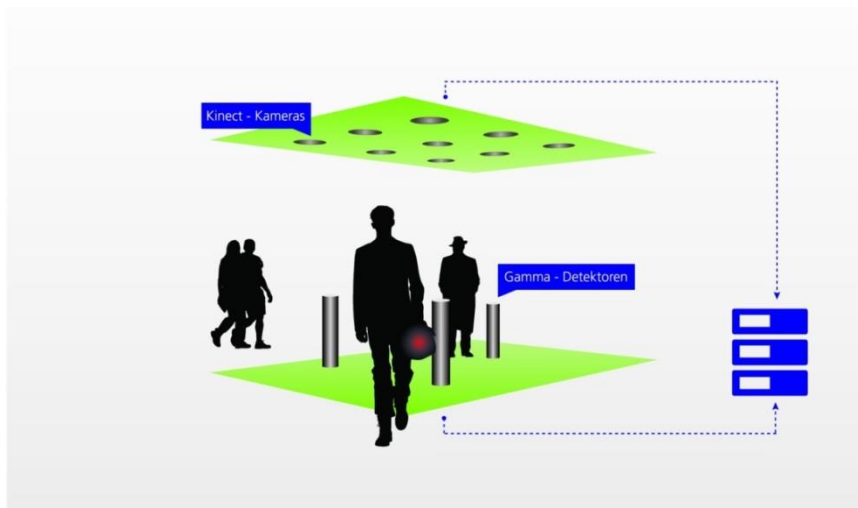


Fig. 5 Schematic of the experimental setup of gamma detection and person tracking. © Fraunhofer FKIE, Germany

The intensity of gamma rays detected depends on the distance of the source to the detector. Due to the poor spatial resolution of gamma sensors a multi-sensor data fusion concept was developed which combines information of distributed sensors and 3D cameras to localise and track persons carrying a dirty bomb. This real time data fusion process is based on the works of Wienecke et al. (2008, 2009, and 2012) and Brscic et al. (2013), enabling a classification and tracking of persons within a certain area, using different attribute information.

3.3. Adequacy of the case study with regards to the preliminary requirements

Let us recall minding the preliminary safety requirement:

- R*: A safety component shall increase the global safety of a railway station.
 - R1: a safety component shall allow identifying threats.
 - R2: A safety component shall allow creating a defence action.
 - R2.1: Safety components may be put rather near the input of the system.
 - R2.2: A safety component rather not decreases the passenger flow.
 - R2.3: A safety component is rather not placed before a zone which is safety critical.

Focusing on R1 requirement, it is clear that the proposed sensors are able to identify specific core which are used to make explosives bomb. The type of detected core gives an indication on the potential nature of the threat. Let us now consider the R2.1 requirement. The proposed concept is a walk through portal which does not use a separated conveyor for luggage. Even if the detection may need few seconds for computation; the tracking technology (see Fig. 5) allows people to walk freely. Depending on the performance of the device in a real operating context, we can expect that R2.1 and R2.2 will be fulfilled. Considering the tracking technology, it will be possible to track the threat until it reaches a non-critical zone. As a consequence, the R2.3 can be fulfilled.

Due to the previous arguments, we can conclude that the proposed solution may fulfill the R* requirement as it detects some threats, allows some corrective actions without really decreasing passenger flows.

4. Conclusions and future works

This paper focuses on specific railway societal contract of services. It identifies that a high number of passengers in a railway station is a critical parameter. Using the state of the art and best practices guides, some specific requirements are highlighted. A zone model is proposed in order to integrate the specific needs ensuing from high level passenger flows. Based on this partition, some preliminary requirements for specific safety/security components are presented. Then a technical proposition is presented. This solution combines detection and person tracking based on industrial vision. Finally, a short evaluation is presented and shows that the solution functionally fulfils the preliminary requirements.

The results of the Re(h)strain project showed that the proposed security measures may increase the security level of the train infrastructure and may avoid overcrowding phenomena due to the introduction of comprehensive passenger and luggage control measures.

In fact, the presented analysis uses only preliminary high level requirements which are not integrating the detailed operational conditions. In the future, the proposed concepts must be adapted and tested in real environments, thus giving reliable information on the usability and practicability in everyday life. Moreover counter IED efforts to increase safety and security of railway users and public areas have to be addressed not only on the national or binational level, like the Re(h)strain project, but also European- or even worldwide.

5. Acknowledgements

This work was funded by the French Agence Nationale de la Recherche (ANR) and the German Federal Ministry of Education and Research (BMBF).

6. References

- RSSB, Crowd management at station- a good practice guide, (T605 Good practice guide), Railway Safety & Standard Board, Oct 2004, <https://www.rssb.co.uk/pb009693>, pp. 14
- Stephen Watson, Arthur D. Little, 2016, "Management of passengers at Stratford Station in London during a period of substantial growth in patronage", International Railway Safety Council, Paris, <https://www.rssb.co.uk/irsc/Documents/Paris/Presentations/T10%20Tuesday%20-14H05-Stephen-Watson.pdf>, pp. 13
- Heddebaut O., Di Ciommo F., 2017 "City-Hubs for smarter cities. The case of Lille "Euraflandres" station", in Topical collection on Smart Cities and Transport infrastructures, European Transport Research Review, under revision, pp. 20
- Monzon, A, Di Ciommo F (Ed) , 2016, "City-HUBS: Sustainable and efficient urban transport interchanges", CRC press, Taylor and Francis, 280p.
- Région Nord-Pas de Calais, 2015, Réseau Express Grand Lille, Dossier du maître d'ouvrage, Débat public sur le projet de lien rapide ferroviaire entre la Métropole Lilloise et le Bassin Minier, <https://www.debatpublic.fr/file/1914/download?token=yYbxWJA7>, pp 130
- "SNCF Open Data — Fréquentation en gares en 2014", https://ressources.data.sncf.com/explore/dataset/frequentation-gares/table/?q=Paris&sort=voyageurs_2014
- Hela Kadri; Simon Schleiner, Simon Collart-Dutilleul, "Proposition of a formal model for crisis management in the context of high-speed train networks in border areas" Abstract accepted for transport Research Arena TRA 2018, Vienna, Austria.
- S. Maneesha, S. Sameer; "Explosives detection systems (eds) for aviation security"; Signal Processing; vol. 83; P. 31–55; 2003
- J.R. Lockwood et al., J. MacDonald; "Alternatives for landmine detection", RAND, 1700 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138, www.rand.org.; 2003
- P.C. Womble., C. Campbell, Vourvopoulos G., Paschal J., Gacsi Z., and Hui S.; "Detection of Explosives With the PELAN System at Application of Accelerators in Research and Industry"; Sixteenth Intl. Conf. American Institute of Physics; (2001)
- NIAG, NATO Industrial Advisory Group; "Executive summary: Countering Improvised Explosive Devices"; NIAG/SG-84; vol. 4; 2005
- P. Kolla; „Anwendung analytischer Verfahren zur Detektion versteckter Sprengstoffe -das Aufspüren von Sprengvorrichtungen"; Angew. Chem.; vol. 109; p. 829–839; 1997
- D.S. Moore; "Instrumentation for trace detection of high explosives"; Review of Scientific Instruments; vol. 75; p. 2499-2507; 2004
- J.W. Gardner, J. Yinon; "Electronic Noses & Sensors for the Detection of Explosives" Kluwer Academic Publishers; 2004
- A. Zalewska, P. Wojciech, W. Tomaszewski, Limits of detection of explosives as determined with IMS and field asymmetric IMS vapour detectors, Forensic Sci. Int. 226, p. 168–172 (2013).
- M. López-López, C. García-Ruiz, Infrared and Raman spectroscopy techniques applied to identification of explosives, TrAC, Trends Anal. Chem. 54, p. 36–44 (2014).
- M. Bouhadid, T. Caron, F. Veignal, E. Pasquinet, A. Ratsimihety, F. Ganachaud, P. Montméat, Ability of various materials to detect explosive vapors by fluorescence technologies: a comparative, Talanta 100, p. 254–261 (2012).
- T. Caron, M. Guillemot, P. Montméat, F. Veignal, F. Perraut, P. Prené, F. Serein-Spirau, Ultra trace detection of explosives in air: development of a portable fluorescent detector, Talanta 81, p. 543–548 (2010).
- R. Blue, Z. Vobecka, P.J. Skabara, D. Uttamchandani, The development of sensors for volatile nitro-containing compounds as models for explosives detection, Sens. Actuators B: Chem. 176, p. 534–542 (2013).
- L. Lazarowski, D.C. Dorman, Explosives detection by military working dogs: olfactory generalization from components to mixtures, Appl. Anim. Behav. Sci. 151, p. 84–93 (2014).
- G. F. Fine, L. M. Cavanagh, A. Afonja, R. Binions. Metal Oxide Semi-Conductor Gas Sensors in Environmental Monitoring, Sensors 10, p. 5468-5502 (2010)
- S. Maurer, R. Makarow, J. Warmer, P. Kaul, Fast testing for explosive properties of mg-scale samples by thermal activation and classification by physical and chemical properties, Sensors and Actuators B, 215 p. 70-76 (2015)
- J. Warmer, P. Wagner, M. J. Schöning, P. Kaul. Detection of triacetone triperoxide using temperature cycled metal-oxide semiconductor gas sensors, Phys. Status Solidi A 212, p. 1289-1298 (2015)
- C. Becher, P. Kaul, J. Mitrovics, J. Warmer; "The detection of evaporating hazardous material released from moving sources using a gas sensor network", Sens. Actuators B 146, 513 (2010).
- M. Wieneke; K. Safenreiter, W. Koch, Combined person tracking and classification in a network of chemical sensors, in '2008 11th International Conference on Information Fusion'. (2008)
- M. Wieneke, W. Koch, 'Combined person tracking and classification in a network of chemical sensors, International Journal of Critical Infrastructure Protection. (2009)

- M. Wieneke, W. Koch, H. Friedrich, S. Chmel, Localization and tracking of radioactive source carriers in person streams, in '2012 15th International Conference on Information Fusion', pp. 1860-1867 (2012)
- D. Brščić, T. Kanda, T. Ikeda and T. Miyashita, "Person Tracking in Large Public Spaces Using 3-D Range Sensors," in IEEE Transactions on Human-Machine Systems, vol. 43, no. 6, pp. 522-534 (2013)