PASSENGER STATION AND TERMINAL DESIGN FOR SAFETY, SECURITY AND RESILIENCE TO TERRORIST ATTACK

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D7.4 – IMPLEMENTATION ROADMAP

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### D7.4 – IMPLEMENTATION ROADMAP

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LIST OF ACRONYMS

AASHTO   American Association of State Highway and Transportation Officials
APTA     American Public Transportation Association
BRP      Blue Ribbon Panel
CBA      Cost/Benefit Analysis
COUNTERACT Cluster Of User Networks in Transport and Energy Relating to Antiterrorist ACTivities
DHS      Department of Homeland Security
DOD      Department of Defence
DOE      Department of Energy
DOT      Department of Transport
FEMA     Federal Emergency Management Agency
ISO      International Standards Organization
MS       Member State
PTA      Public Transport Authority
PTO      Public Transport Operator
RU       Railway Undertaking
SEST-RAM SECURESTATION Risk Assessment Methodology
TSA      Transportation Security Administration
TVRA     Threat, Vulnerability and Risk Assessment
UIC      Union Internationale des Chemins de fer / International Union of Railways
UITP     L'Union internationale des transports publics / International Public Transport Organisation
1. INTRODUCTION

1.1. Background

SECURESTATION project aims to improve passenger station and terminal resilience to terrorist attacks and safety incidents through the implementation of technologies and methodologies enabling design that reduces the impact of blasts, fire and the dispersion of toxic agents on passengers, staff and infrastructure. As such, the project takes into account the user needs, exchange of best practices, barriers – such as legal barriers, regulation and standardization, and aspects of interoperability and harmonization.

(1) User needs.

To identify user needs, the project conducted a questionnaire based survey among passengers, infrastructure owners and operators, and exchanged information with other projects (for example, FP7 funded project SECUR-ED):

- **Passengers** – focusing mainly on the traveling public’s perspective and its willingness to accept a variety of safeguards to manage terror risks;
- **Infrastructure owners and operators** – a survey of methodologies, polices, methods, procedures, and also physical and technological safeguards to manage terror risks.

The exchange of best practices focused on three main issues: 1) risk management methodologies; 2) handbook and guidelines for architectural and engineering design of passenger terminals; and 3) analyses and simulations of blasts, dissemination of poisonous by inhalation (PIH) hazards, fire / arson and the movement of passengers during emergency evacuation.

(2) Barriers - legal constrains, regulation and standardisation.

The project surveyed legal barriers, regulation and standardisation associated with risk management and the design of passenger terminals to address terror threats.

(3) Interoperability and harmonisation issues.

Interoperability issues are examined in the project mainly from the perspective of the passengers’ use and the operation of a transport terminal, and less from technical perspectives, such as data communication and systems integration.

1.2. Purpose and Scope

The purpose of this document is to analyse and define the implementation roadmap for the SECURESTATION project deliverables in two key areas – exchange of best practices, and standardisation, harmonisation and regulation:

(1) Exchange of best practices:

- Risk assessment for passenger terminals;
- Guidelines for the design and assimilation of technological means, safeguards and architectural solutions for passenger terminals.

(2) Standardisation, harmonisation and regulation. Standardisation, harmonisation and regulation from the perspectives of physical and functional resilience, addressing the following attack scenarios:

- Use of explosives;
• Fire / arson;
• Dispersion of toxic materials belonging to the PIH category

1.3. **Document Structure**

This document is composed of two parts:

1. Identification of the domains that were researched / investigated / studied / reviewed within the framework of the SECURESTATION project, including:
   - Exchange of best practices in the risk assessment domain and design guidelines for passenger terminals
   - Standardisation, harmonisation and regulation in the areas of blast, dispersion of toxic materials and fire simulation

1.4. **Applicable and Reference Documents**

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2. DOMAINS IDENTIFICATION

2.1. Exchange of best practices

2.1.1. Risk assessment methodology

The risk management methodology developed within the framework of the SECURESTATION project – SEST-RAM – is unique in several aspects, when compared with other methodologies (SECUR-ED, COUNTERACT, EUMAS, Sandia’s RAM). These aspects are as follows:

- It focuses on transport terminals, while enabling the expansion of the model to also include other public transport infrastructures (rolling stock, tunnels, bridges, maintenance depots and stabling areas);
- A comprehensive mathematical model is provided to assess the probability of attack and the vulnerability, including alternate options for the quantification of certain parameters;
- Integrating with and complementary to the simulation methods, including the models used by the partners and the work done by D’Appolonia on functional resilience modelling.
- Assessment of the residual risk following the implementation of safeguards – policies, methods, trained manpower, procedures, physical means and protection technologies.

In addition to the methodology itself, which is a written document (a report), a set of Excel spreadsheets (Figures 1 and 2) was developed within the framework of the project. The spreadsheets translates the quantitative methodology into a practical tool that can be used to conduct risk assessments in passenger terminals, based on the definition of assets, scenarios and inputs from the specific or generic simulations of blasts, dispersion of PIH, fire and smoke. The tool has been successfully demonstrated for a generic interchange station and is available to the partners for research work, but it is not in the form of ready-to-use package for generic third parties. The developed set of spreadsheets also includes the generation of an extensive series of diverse graphs which demonstrate how the results may be presented for technical discussions and for decision making.

At present, most of the risk assessment methodologies available in the public domain were developed in the USA\(^1\). The qualitative methodology developed under COUNTERACT is available on the UITP web site\(^2\). The UITP conducts workshops for its members, in which it imparts the relevant knowledge in this area.

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2.1.2. Passenger terminal design guidelines

The Constructive Design Handbook is one of the major outputs of this project and will be the main method through which the knowledge developed in this project will be disseminated to the end users. It will collate all of the relevant technologies and provide guidance on their use. It will include the risk assessment methodologies and provide recommendations based on results from simulations carried out to provide empirical evidence of how a typical station configuration can withstand the impact of various forms of terrorist attacks.

The design handbook will address a wide range of end users with various levels of expertise in security. Before presenting the actual guidelines stemming from the studies in the project, the information presented will cover some introductory chapters to describe and explain the following:

- The rationale behind introducing security measures within the design of new and retrofit stations
- General considerations for designing stations (basic station design principles)
- An overview of the most likely threats that can be mitigated

After presenting the reader with a clear overview on the topics of security, threats and station design, the final section of the handbook will include recommendations of counter measures that can be introduced into the station design (and adjacent site) to protect against the described attack scenarios.

To allow end users to quickly navigate the document and to extract the information according to their specific interest and level of expertise, each of the four chapters in the handbook is presented with its own separate table of contents and colour code. The graphics in the handbook will help the reader easily identify the content it is depicting by means of this colour code, and the page format will contain a clear reference of the content being presented by having the section title placed on the bottom-right corner.

The handbook is being conceived as an interactive PDF document / file, so a breakdown of the table of contents (up to four levels) will be placed on each page to allow the reader to quickly turn to previous sections, all the way to the main table of contents.

The information presented will be high-level, as the document needs to be made available for public dissemination. For that reason, any information will be of public nature, with confidential insight from the project to be requested by interested parties who will have to receive permission for obtaining it. The confidential sections will not be included in the handbook format, but will be disseminated in the existing project deliverable template.

2.2. Standardisation, harmonisation and regulation

2.2.1. Physical and functional resilience standards addressing attack with explosives

(1) Summary of modelling methods

Among the activities developed within the SECURESTATION project, blast attack simulations were carried out in order to identify and better understand the dynamic of the blast wave expansion, as well as its interaction with the buildings and structures of the terminal. In order to do that, a reference station model, built to include the characteristics that can most frequently be found in a typical European Railway station, was created and employed.

The simulated attacks were defined considering the historical background of terrorists’ attacks against public transport both in the EU and worldwide. Two categories of attack were specifically addressed: the
Vehicle Borne Improvised Explosive Devices (VBIED) and Person Borne Improvised Explosive Device (PBIEED) methods of attack.

Simulations were accomplished by means of three techniques of analysis:

- Empirical methods based on a wide set of empirical data reported according to a scaling technique (the scaling factor is the cube root of TNT equivalent charge mass) in order to be used for a wide range of stand-off distance and charge mass values.

- Semi-empirical methods that are based on simplified models of the physical phenomena and obtained by processing data form an extensive number of case studies.

- Numerical methods that make use of the numerical resolution of the mathematical system describing the physical phenomena. The mathematical system they typically solve is composed of mass, momentum and energy conservation equations, whilst the physical behaviour of utilised materials is described by proper constitutive relationships.

Empirical and semi-empirical methods were applied, benefiting from two software tools developed by D'Appolonia[^8] that are based on the experimental test results reported in the US DOD Unified Facilities Criteria[^9], whereas relating to numerical methods, the commercial code ANSYS® Autodyn®[^10] was utilised. The assessment of the results obtained through the methodological strategies described above led to the conclusion that the most suitable analysis method can be chosen depending on the blast environment type. In fact, if the explosion occurs in an environment where containment effects are not relevant, simplified methods can be adopted to gain accurate results. On the other hand, if the blast wave parameters need to be evaluated after the wave front undergoes one or multiple reflections (occluded and "shielded" environments), numerical methods shall mandatorily be employed[^11].

The results of blast analyses can be then used to assess the harm on passengers in the event of a bomb attack exploiting the specific diagrams, such as those reported in the US DOD Unified Facilities Criteria[^9], whilst to evaluate the damage of structural elements hit by the blast wave front, two approaches are suggested. The first approach involves the use of the so-called Single Degree Of Freedom (SDOF) method, which consists of a transient analysis of a mass-spring-damper equivalent system defining the structural element behaviour. Reducing the structural element to a single point system, the SDOF technique represents a simplified approach able to furnish an overall indication on the damage status. The second approach foresees the detailed numerical modelling and analysis. Such an approach allows to supply more detailed data on damage, but requires higher efforts in terms of user skills and computing resources availability.

The performed blast simulations dealt with the specific geometry of the reference model station. The obtained results were analysed, and recommendations and suggestions were formulated, addressing both the design and retrofit of generic train station.

### (2) Relevant audience and why the blast attack modelling is of benefit to them

The methodologies employed in the SECURESTATION project regarding blast attack simulations and their results are mainly presented for the benefit of professionals involved in the design of a new station or in the retrofitting of an existing one. According to the described methods, architects, designers and structural engineers can simulate the expansion of a blast wave so as to evaluate all the influenced zones and areas of the station. Once the critical structures and most affected areas are identified, reinforcement and countermeasures can be accordingly adopted. These modifications can also be included in the simulation model in order to numerically evaluate and verify their effectiveness.
2.2.2. Physical and functional resilience standards addressing fires from terror attacks

Fires are among the main potential threats to human life and to long-lasting functional unavailability in transit stations, with special reference to underground stations. Accordingly, fire safety is a principal requirement in the design of new stations and in the revamping of existing ones. Designing for fire safety is fundamentally linked to architectural layout, and the choice of materials implies a number of diverse technical provisions and norms addressing fire alarm and extinguishing systems, visual signalling systems, PAS, doors, emergency escape stairwells, etc. The most critical aspect of fire safety in transit stations, and particularly underground ones, is the safe evacuation of passengers, which requires that they have enough time for a safe egress out of the structure before being affected by smoke and heat.

Differences still exist between various European countries in their national legislation and the technical regulations applicable to stations, but a convergence has largely been reached in technical prescriptions and in the application of common European norms. Furthermore, in most cases:

- NFPA (National Fire Protection Association) US technical standards are widely applied (please refer to–D.6.4 for coverage of most applicable international and NFPA norms);
- Materials and appliances with the necessary rating are tested and approved with the same standards, or under mutual recognition between countries;
- Fire modelling and evacuation modelling are often used to complement the application of prescriptive norms.

The main reasons fire and evacuation modelling are widely and increasingly used are:

- Smoke is the prime factor determining injuries, deaths and evacuation difficulties during a building fire – the large dimensions and the variable architectural shapes and volume structures make prescriptive codes almost inadequate, while fire & smoke modelling adapts to all such cases;
- The demand for safe yet cost-effective fire safety solutions require the evaluation of a blend of countermeasures based on smoke venting, HVAC, pressurised stairwells, smoke barriers, water blades, etc. whose effectiveness requires the use of modelling, especially for these types of structures;
- Several national legislations nowadays accept performance-based design as an alternative to the application of fire codes, but require a safety demonstration based on a representative set of scenarios for which modelling is applied;
- Evacuation modelling may usefully complement normative evacuation time computing, such as the one of NFPA 130, and can provide information to identify the possible occurrence of hazardous crowd behaviour, including effects of panic;
- Evacuation modelling (except in case a prescribed fixed egress time is assumed) generally requires a prediction of tenability conditions along the escape routes over time, and this information requires fire and smoke modelling;
- Modelling results are of great importance also for emergency planning, and therefore in the preparation of procedures, within training programmes and in the design of drills.

A current general choice concerning evacuation assessment of transit stations is to require that the station design satisfy the requirements of NFPA 130, regardless of the results of evacuation simulations performed with a sophisticated software tool.

Among all the fire modelling methods (theoretical approach, models based on empirical curves, etc.), Computational Fluid Dynamics (CFD) is the most powerful tool to analyse the impact of fire in a
terminal/station, with special reference to the large dimensions, structure complexity and the importance of HVAC, smoke venting, train movement effects and out-of-station air flows.

Evacuation modelling is generally carried out after fire & smoke modelling, and the complexity of the transferred evacuation is generally limited, often restricted to required clearance time for entire levels or parts of the station. A deeper modelling, coupling simulating the movement of persons along with the simulation time progression of fire & smoke CFD computing (e.g. by FDS-5), is still not frequently used, and can be generally considered unnecessary if conservative results from fire & smoke modelling are used to set the time limits for evacuation.

Due to the typically short times available for the safe egress of a station, the reduction of time from fire outbreak to the start of evacuation is quite important, and thus the whole modelling process require to estimate reliable values for alarm time, for the communication of the order to evacuate and for the reaction time to such a communication. This implies the adoption of technical solutions (e.g. fast efficient fire detection systems) and organisational measures (appropriate messaging from the PAS, cooperation of the employees of commercial activities, etc.).

The SECURESTATION project includes the application of CFD fire & smoke modelling using Ansys Fluent – a multipurpose CFD solver, and Fire Dynamic Simulator (FDS) – a specific fire-driven fluid flow solver. The two solvers showed similar results. Evacuation was modelled using the commercial simulation package “Legion”. Time available for evacuation was evaluated from simulation results for smoke temperature, smoke toxicity (concentration of CO) and visibility. The simulations also showed the effect of fire protection systems, ventilation, sectorization and extinction systems on smoke/fire dispersion.

Fire & smoke and evacuation modelling are very technical and complex activities that must be executed by trained professionals. A review of the modelling basis, of computational approaches and of simulation codes is included in the reports from WP6 of the SECURESTATION project.

Full-scale fire tests are sometimes executed to validate station design, and particularly smoke management solutions. These tests are valuable, but they have the disadvantage of being executable only at a mature stage in design implementation, and are problematic to execute in operating stations. In any case, only one or a few fire tests are generally carried out, and with practical limitations, e.g. in heat release rate. Thus they cannot be regarded as a possible replacement of modelling.

A very important issue for the SECURESTATION project is the applicability of fire safety standards, practices and regulations to fires originating from terror attacks, and particularly to arson, to the use of IIDs (Improvised Incendiary Devices) and to fires resulting from explosions of varying magnitude, caused by different types and quantities of explosives.

A first issue concerns the development of fire over the time, for which it impacts (mostly through smoke) passengers’ evacuation. Fire is frequently modelled as a heptane pool fire, but its growth rate is assumed to follow a model curve chosen from sets of analytical or numerical alternatives, often labelled by “speed” (fast, medium, slow, etc.) referring to combustion properties and to certain geometrical and structural arrangements for the relevant materials. In most cases of arson or use of IIDs, a highly flammable liquid (often called the “accelerant”) is spilled on the floor or spread on combustible materials, and ignited. Even though the accelerant is frequently used in limited quantity, its effect is reducing to a few tens of second the steep initial rise of the heat release rate (HRR), often reaching more than 1 MW in less than 30 seconds. The initial effect is almost purely related to the burning of the accelerant, but then the resulting flame size has the potential to rapidly ignite a considerable amount of pre-existing combustible solids (e.g. commercial products and exposition furniture in a shop). This data about fast HRR initial fire scenarios have been studied and are described in some open literature sources.

The modelling work is based on scenarios, and the addition of security scenarios (particularly terror scenarios) to the basic collection of safety scenarios should carefully consider that terrorists generally
optimise their modus operandi (attack place, time, operating details) to maximise damage. In this respect, the use of standards such as “EN 1991: Eurocode 1, Actions on structures, Part 1-2: Actions on structures exposed to fire” [R12] for defining and choosing the reference scenarios may lead the user to miss some very significant scenarios of fire resulting from arson or the use of an IID; in fact, such a standard does not adequately consider the use of accelerants (in terror attacks), the possibility to harm passengers and install panic among the public with the IID act itself, and the potential to generate large volumes of smoke in the very few initial minutes and in a critical location for evacuation.

In the particular case of explosion scenarios involving terror attacks (detonation of IEDs, PBIEDs and VBIEDs) fire modelling should also consider the fire that often follows the explosion, often consisting of multiple fire instances. Moreover, the explosion itself generates a cloud of hot and toxic gases that should be ideally considered together with the growing contribution from the fire following the explosion.

Another important terror attack issue is that the chosen tactic may include the sabotage of safety systems (e.g. ventilation or sprinkler systems), and that such safety systems may be damaged by the single action strikes as well (especially in the case of a bomb attack). This important issue has been treated within SECURESTATION in the analysis of resilience, and in the model developed to estimate the effects of unavailability of safety functions due to random failures, the impact of attack events, accidents and their evolving effects.

Evacuation modelling is also affected by specific considerations, when dealing with terror scenarios. Particularly, explosion based scenarios, are characterised by the presence of several persons assisting in the evacuation, who may be partially impaired. Most of the best modelling software do take this into account, with a resulting longer evacuation time or a larger share of non-evacuated persons in due time.

A further consequence of terror attacks, with special reference to bombing, use of firearms and PIH dispersion, is that a high number of persons may be unconscious, or not in the condition to evacuate on their own, mostly because of injuries. Additionally some persons may remain trapped. It is therefore necessary to consider this in evaluating the adequacy of rescue plans and the possible need for design solutions facilitating search & rescue.

Because of the above-mentioned, reasons, a station design (including fire protection system and complemented by organisational means) may be appropriate and conform to SotA for the conventional safety risk, yet may be inadequate to offer the desired resilience for one or more possible terror attack scenarios.

The SECURESTATION project has provided guidelines, methods and solutions to extend stations’ resilience, also including security, and terror threats in particular, but the current set of norms and regulations is partial and inhomogeneous concerning the requirements addressing terror threats. This is one of the reasons the risk analysis methodology described in the project aims to present decision makers with the information required to make well-informed decisions on possible investments that would reduce risks that terror threats adds to the safety accidents baseline.

2.2.2. Physical and functional resilience standards addressing attack with PIH (Poisonous by Inhalation)

(1) Summary of modelling methods

Computational fluid dynamic (CFD) modelling of a range of different compounds, with different dispersion methods were carried out within the SECURESTATION project to advance the understanding of the impact of chemical weapon attacks within station environments. The simulations were carried out using the Ansys Fluent solver and modelled a range of different chemicals dispersed either as gases, aerosol or as an evaporating liquid. For the purpose of these simulations it was assumed that military and sophisticated
dispersion methods using an explosive burster would not be used and was considered outside of the scope of the SECURESTATION project. The chemical compounds were simulated included toxic industrial materials: chlorine, ammonia and hydrogen cyanide; and nerve agents: sarin and VX. The different compounds chosen had a wide range of physical properties and toxicity to demonstrate the impact of properties such as material density and volatility.

The simulations demonstrated the impact that airflows through the station, due to ventilation system design and railway vehicles arriving and departing, have on the dispersion of chemical compounds and the consequent harm caused to passengers. The simulations would not be directly relevant to all stations, as the geometry will differ from the model station simulated in the project. However, the simulations highlight the design features which should be considered in the station design with regard to minimising the impact of a chemical weapon attack. The recommendations from the simulation results have been combined with guidance on the design of buildings and ventilation systems to resist chemical and biological attacks from publicly available literature, to provide a more complete set of guidelines which have been included within the SECURESTATION handbook.

(2) Relevant audience and why is the dispersion modelling is of benefit to them

The results from the chemical dispersion modelling work is aimed principally at those involved in the design of new or the refurbishment of existing stations, this includes architects, designers, structural engineers and the infrastructure manager as a client. The SECURESTATION chemical dispersion work helps them to identify potential risks and provides guidance on what they should consider within their design allowing the end user to make decisions about the potential risk reduction.

The chemical dispersion work is also relevant to station operation and security staff, it demonstrates and explains the potential consequences of the ventilation and air flow systems on chemical dispersion and from this they can consider how to react in the case of an attack. For example whether to stop ventilation systems and railway vehicle movements in the case of an attack, or whether the increased dilution from ventilation systems can have a positive impact.

2.2.3. Functional resilience standards addressing attacks

(1) Summary of modelling methods

The focus on the analysis of the functional resilience of a station under terror attack within the SECURESTATION project has been related to the definition of a methodology and a tool consisting of a systematic framework to evaluate the vulnerability of the station structure and availability of safety systems. In this methodology, the equipment is modelled and studied through an analysis of vulnerability and availability aimed to identify the critical components and rank them by importance. The optimal balance between investments to limit the vulnerability and the reduction of the consequences (functional, direct economic and consequences related to the human life) of the failure has been determined, and defined as a typical “decision making” process derived on the basis of economical and technical factors.

In this context, the effects considered have been associated with the loss of elements and functioning of the different equipment. The activities of ranking and selecting the countermeasures are performed under constraints that are indicated by the user (e.g. a limited budget under the ALARP approach, or a determined level of enhancement of the system resilience to be achieved).

The adopted modelling methodology can be summarised on the basis of the following key points:

- Analysis of the station from the perspective of the structure, considering the architectural aspect and the equipment affecting the functioning of the building itself;
● Definition of one or more scenarios of attack in terms of damage to the structure and equipment;

● Evaluation of the consequences of the defined attacks in term of:
  ▪ Functional consequences;
  ▪ Direct economic losses;
  ▪ Consequences on human life;

● Definition of a set of countermeasures, each characterised by its impact (reduction) of the vulnerability, and on the consequences of attacks and their cost;

● Definition of constraints to be taken into account and the goals to be achieved when applying countermeasures;

● Ranking the set of remedial measures in order to define a sub-set able to fulfil the constraints or to reach the goals previously defined.

SARA (SECURESTATION Attack Resilience Assessment) is a specific tool that has been developed to implement the methodology defined within this task.

(2) Relevant audience and why the dispersion modelling is of benefit to them

The results of the analysis of vulnerability and availability of the equipment from a functional viewpoint, in conjunction with the possibility of ranking remedial measures to limit the consequences of terror attacks are of interest to those who design a new station/terminal or refurbish an old one, as it provides them with valuable information concerning the necessity to allocate at least a limited budget to address these issues. The activities developed in the SECURESTATION project allow them to gain a better understanding of the functional approach to the equipment and the decision making process that can be applied to protect equipment that enhances the functional resilience of the station / terminal. Specifically, the main goal of this methodology is to focus their attention from the perspective of the conceptual design of the station/terminal or refurbishment activities, to the following issues:

● Representation of the station structure and its equipment in a systematic way that allows to analyse them by applying the theory of graphs;

● Definition of a formal representation of the equipment based on Product Breakdown Analysis (PBA);

● Definition and evaluation using numerical indicators (KPIs) of the main function of a station building;

● Identification and ranking of the critical components of the equipment, considering functional and physical cross-correlation of the equipment;

● Definition of scenarios of terror attacks and user cases characterised by their impact on the entire station and its equipment;

● Representation of countermeasures and evaluation of the effects on the station for the defined the user cases;

● Selection of one or more sets of countermeasures to be adopted, taking into account different constraints (e.g. a limited budget for the implementation).
3. IMPLEMENTATION ROADMAP

3.1. Implementation roadmap for best practices

3.1.1. SEST-RAM: From methodology to software based tool for risk assessment

On the basis of our knowledge of risk assessment methodologies and handbooks developed in other FP7 projects (such as D31.2 & D31.4 in SECUR-ED – [R4] & [R5]), we believe that the implementation roadmap of the project’s risk assessment methodology for passenger terminals (SEST-RAM) must include continued development. This should focus on two elements: (1) software tools to be used in risk assessments in passenger terminals of metro and railway systems; and (2) continued research in developing damage assessment models, following blasts, fire and dispersion of PIH, to be included in the risk assessment process.

(3) Software tools for risk assessments in passenger terminals in metro and railway systems

We believe that software tools based on SEST-RAM, which will allow end users – public transport operators, infrastructure managers, station owners and operators – to conduct risk assessments independently, will be extremely beneficial. This process is presently conducted mainly through the implementation of qualitative tools based on Excel spreadsheets or similar, without the possibility of carrying out a cost-benefit analysis with financial values – which can be done by implementing SEST-RAM’s quantitative methodology. Beyond SEST-RAM’s ability to rank terror risks more precisely, this methodology also allows ranking risks with high probability and low consequences (vandalism, graffiti, theft, etc.) also which are faced by end users and quite significant to them. Furthermore, it can be easily expanded to cover additional infrastructure elements in the transport system – bridges, tunnels, line of route infrastructure, rolling stock, maintenance depots, stabling areas and more.

Beyond the evident advantages of cost-benefit analyses, including the assessment of safeguards, software based tools will allow end users to benefit from the following advantages, when conducting risk analyses:

- Implementation of a uniform methodology for all the passenger terminals, stations and additional infrastructure elements;
- System-wide coverage, including all the passenger terminals, stations and other infrastructure elements of the transport system (bridges, tunnels, line of route infrastructure, rolling stock, maintenance depots and stabling areas and more);
- Simplicity and effectiveness in conducting a periodical process of risk assessment, as the parameters and definitions of the system and the scenarios are saved in the software’s data base, and they can be adapted and modified as necessary;
- The methodology is also applicable for defined day-to-day high probability – low consequences scenarios, such as graffiti painting, vandalism, theft and more, including in data and statistics collected by the entity performing the assessment (number of incidents, financial damage).

In our view, the development of a SEST-RAM software suite would be extremely beneficial, vs. the current test implementation based on multiple spreadsheets.

Particularly we envisage the implementation of a web application that will be based on the use of a standard browser. This web application will benefit from the following
• Centralised management and maintenance of a single system, including security, backups, hardware;
• Centralised modelling services with the contribution or supervision of domain experts (fire, smoke, gas dispersion, explosions, etc.);
• Centralised and better file management, such as AutoCAD files.

(4) Continued research in realising damage assessment models and simulations

The SEST-RAM methodology included research on the consequences, in terms of harm to people and property, resulting from the realisation of scenarios involving the use of explosives (blast of IED, PBIED and VBIED), the dispersion of PIH, arson / fire. This research was based on a broad design basis threat, however, the analysis itself was performed on the basis of the model station type that was developed as part of the project.

We believe that more research is required in order to expand the knowledge on the effects of the above scenarios, in the interest of developing a more complete database of stations with generic characteristics, for example: the type of system – metro or train; the size of the station – large, medium or small; a station located above ground or underground. This would enable the determination of more precise conclusions based on a broader scope of data, as compared with the conclusions previously arrived at within the framework of the project, which related to a specific station. This will serve the model better, and will allow the different end users (e.g. IM, PTOs and PTAs) to receive data without performing a specific analysis of these simulations.

3.1.2. Constructive Design Handbook

To ensure the implementation of the SECURESTATION guidelines, the Constructive Design Handbook targets the institutions that are responsible for policy making in each member state.

At the same time, the guidelines included in the Handbook should be made known to planners and designers, so that they will integrate them into the design from the concept phase. By making operators aware of these guidelines, they can further establish them as requirements in project briefs, and this would ensure their implementation. Therefore, the roadmap for implementation is to disseminate the Handbook widely to the target audience specified above. The first workshop organised for this purpose will invite as many European representatives as possible from these groups, and the purpose will be to explain the importance of standardisation of these guidelines in modern stations. The dissemination process will be continued until the end of the project, and policy makers, operators and architectural boards in all European member states will be contacted and informed via email and constant updates on the SECURESTATION website.

3.2. Implementation roadmap for standardisation

3.2.1. Including SEST-RAM in the risk management standard (ISO/IEC 31010:2009) – risk assessment techniques

According to ISO31010 (risk assessment standard), risks are the combination of the consequences of an event or hazard and the associated likelihood of its occurrence. Consequences are the negative effects of a
security incident expressed in terms of human impacts, economic and environmental impacts, and political / social impacts.

The commission staff working paper – risk assessment and mapping guidelines for disaster management relates to situations in which preventative behaviour and measures are implemented. It is necessary to express this mathematically, therefore\[R7]\:

\[
\text{Risk} = \int (p \cdot E \cdot V)
\]

Whereas, the probability of occurrence is represented by \(p\), vulnerability \(V\) is defined as the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard, and \(E\) represents the exposure of people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses.

Using the concept of vulnerability makes it more explicit that the impacts of a hazard are also a function of the preventive and preparatory measures that are employed to reduce the risk. For example, for a heat wave hazard, it may be the case that behavioural preparedness measures, such as information and advice, can critically reduce the vulnerability of a population to the risk of excess death. Effective prevention and preparedness measures thus decrease the vulnerability, and therefore the risk.

According to SEUCRESTATION risk assessment methodology (SEST-RAM), the assessment of risks is performed by evaluating three variables – (1) the likelihood that an adversary will perpetrate an attack (specific asset and tactic, for example: shooting at a passenger train); (2) the probability that the attack will succeed, from the adversary's perspective; and (3) its potential results. These three variables appear in the traditional formula used in quantitative methodology, as presented below\[3]\:

\[
\text{Likelihood of adversary attack} \times \text{Likelihood that the adversary succeeds} \times \text{Consequences of the attack} = \text{Risk}
\]

In words:

We estimate the risk \(R_{ij}\) for each analysed scenario (tactic \(i\) and target \(j\)), using the fundamental equation:

\[
R_{ij} = \left[ P_{A_{ij}} \left( 1 - P_{I_{ij}} \right) \right] C_{ij}
\]

(Equation 1)

Or as:

\[
R_{ij} = P_{A_{ij}} V_{ij} C_{ij}
\]

(Equation 2)

And the overall risk equation is presented as follows:

\[
R_T = \sum_i \sum_j \left[ P_{A_{ij}} \left( 1 - P_{I_{ij}} \right) \right] C_{ij}
\]

(Equation 3)

Or as:

---

\[ RT = \sum_i \sum_j P_{Ai} V_{ij} C_{ij} \]  
(Equation 4)

Where:

- \( RT \) is the overall risk
- \( R_{ij} \) is the relative risk – a specific risk related to tactic \( j \) applied to target \( i \).
- \( P_{Ai} \) is the probability that an adversary will attack the direct target \( i \) during a certain time period using the tactic \( j \), and
- \( P_{ij} \) is the probability that an adversary attack against the direct target \( i \) during a certain time period adopting the tactic \( j \) is foiled, and
- \( 1-P_{ij} \) is the probability that an adversary will successfully attack the direct target \( i \) during a certain time period adopting the tactic \( j \) and
- \( C_{ij} \) quantifies the expected damage (direct and indirect)

With reference to the element of vulnerability – whether in relation to the quantification of the risk posed by natural hazards, as presented in the European Commission’s working paper[87], or based on the risk function as defined in SEST-RAM – it is necessary to integrate this element into the risk function when performing a quantitative risk analysis of security threats.

As previously stated, the mathematical expression used in the assessment of risk resulting from natural hazards matches the quantitative assessments of risks resulting from security threats. Therefore, we believe that the quantitative risk assessment methodology developed within the framework of the SECURESTATION project (SEST-RAM), is suitable for use risk management standard (ISO/IEC 31010:2009) – risk assessment techniques.

### 3.2.2. Blasts simulation

Blast attack simulations are useful to identify critical station elements and areas, as well as to evaluate possible improvements and reinforcements, and to quantify the effects of countermeasures in case of a terror attack involving explosives (IED, PBIED, VBIED).

Several analysis tools are available to perform this type of analysis, based on empirical, semi-empirical and numerical methods.

In order to obtain reliable and effective results, blast simulations must follow some basic rules:

- If a model of the station is required, it must maintain the main geometrical and physical characteristics of the actual structures; this will ensure that all possible issues with blast wave reflections and containment effect will be considered in the analysis;
- Referring to the distinction made between open environments and occluded and “shielded” environments mentioned in previous sections, the tools based on simplified methods (empirical and semi-empirical) can be employed to analyse open environment scenarios;
On the other hand, if the blast scenario can be classified as one taking place in an occluded or “shielded” environment, the only tools that can be reliably employed to carry out analyses are those based on numerical methods;

For both numerical and simplified method tools, two of the main important parameters that must be evaluated are the peak overpressure and the peak specific impulse acting on the target structure; knowing the level reached by these parameters will enable the subsequent analysis of the behaviour of a structure subjected to blast loading.

A particular emphasis must be placed on tools based on the numerical method. These tools are founded on the resolution of the mathematical system describing the physical phenomena. In the SECURESTATION project, the general-purpose commercial code ANSYS® Autodyn® has been employed. With respect to the evaluation of the values of physical variables of interest, this software solves a system of differential equations composed of the mass, momentum and energy conservation equations. Furthermore, the correct representation of the explosives' behaviour is ensured by the adoption of proper material constitutive relationships (i.e. the Jones-Wilkins-Lee equation of state).

Assessing the effects along a time axis, the numerical model is able to reproduce the blast wave expansion even after interacting with obstacles and after reflections. The main disadvantage of these tools is the high computational resources requested to run simulations, though thanks to modern calculus machines and techniques (parallel computation) the time needed to obtain the results can be considerably shortened.

The use of a numerical tool should become the requirement for a detailed investigation of the effects of a terror bomb attack. Because of the great variety of explosives that can be employed, a reference explosive material should be chosen for numerical calculations in order to facilitate comparisons and studies. In the literature, the blast design evaluations relative to high-detonation explosives use TNT as a reference explosive. To consider other types of high-detonation explosives, conversion factors obtained taking into account energy relationships, are typically adopted. These coefficients can be found in the literature (see [R7] for example), and come with built-in material data bases in several advanced commercial codes, such as Autody.