SARA – A TOOL TO ASSESS AND IMPROVE FUNCTIONAL RESILIENCE FROM SECURITY ATTACKS OF PASSENGER INTERMODAL STATIONS AND TERMINALS

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ABSTRACT

Considering the rapid growth in urban population around the world, connectivity and accessibility become crucial factors for development and public transit systems, likely the preferred mobility options in densely built and populated areas. In the light of their growing significance, public transport stations and terminals are starting to be designed as complex intermodal interchanges through enhanced interconnection between transport systems. All these facilities attract large numbers of people and most of them need to remain open to the general public. The station itself needs to remain highly permeable, as its main function is to ensure the good operation of transport facilities and unobstructed passenger flows. Due to the combination of large infrastructure value and concentration of human lives, stations and their environment are plausible potential terrorist targets.

Under these premises, this paper is dedicated to the description of a systematic framework to support station designer to evaluate the vulnerability and availability of the station equipment. The framework would ideally enable the station functional resilience assessment, looking at individual equipment, the effects of their loss of functioning, the definition, evaluation, ranking and selection of countermeasures to reduce risk of terrorist attack, under economic and financial constraints. The framework has then been implemented in a tool called SARA (SECURESTATION Attack Resilience Assessment), which is herewith described.

The whole work has been developed in a EU funded research project called SECURESTATION, financed by the European Commission under the umbrella of the 7th Framework Programme.

Keywords: stations, terminals, functional resilience, security, risk assessment
INTRODUCTION
The aim of this paper is the description of a systematic framework developed to evaluate the vulnerability of equipment in passenger stations from security threats. Ideally, the application of the methodology enables designers and security experts to analyze a given station from a security point of view, focusing on the functional behavior of each individual piece of equipment (e.g., ventilation, communication, power supply, etc.) installed into. The results of the analyses performed accordingly with the methodology enable the definition, evaluation, ranking and selection of possible mitigation measures to be applied to the equipment of the station in order to improve its resilience from terrorist threats. In this context, the effects considered are related to the loss of components and functioning of the different pieces or parts of equipment. The activities of ranking and selecting the mitigation measures are performed either under constraints indicated by the station operator, e.g. a limited budget, using the ALARP (As Low As Reasonably Possible) approach, or targeting a degree of system resilience to be eventually achieved.

The process herewith described is based on the fact that equipment are modeled and studied with an analysis of vulnerability and availability aimed to identify the critical components and to rank their importance. The balance between investments to reduce vulnerability and consequences of the disruption is a typical “decision making” process driven by economical and technical factors.

In the proposed methodology, the equipment considered is related to the functioning of the building (allowing passengers to access and leave transport operation) rather than the operation of the transport service itself, which is usually subject to other types of safety and security analyses during design, construction, commissioning and operation.

Based on the above, a specific tool called SARA (SECURESTATION Attack Resilience Assessment) has been developed to implement this methodology.
OVERALL METHODOLOGY

In the methodology developed in this project, the station building is investigated from a functional and physical point of view by means of an appropriate way of modeling, able to represent and link together both these aspects. The model adopted also allows remedial options and cross-correlation aspects between the different equipment to be considered, in order to enable a decision maker to select proper actions to improve functional resilience to terroristic threats under well-defined constraints (Figure 1).

FIGURE 1 Methodological Approach.

In order to analyze the given station, two kinds of preliminary analyses are performed:

- Structural analysis: to represent both the topological structure of the station and the network of the equipment that allow the functioning of the station to be assessed;
- Functional analysis: to define the main functions of the station to be considered and to define an appropriate way of measuring them.

These two activities are based on predefined concepts and elements that are common to all the stations. Due to the modularity and flexibility of the methodology, the defined concepts and elements may be modified, or others may be added for specific situations.

A physical model of the building and its equipment is generated so that, in conjunction with the outcomes of the functional analysis and other information (e.g. presence of the passengers, schedule of the arriving/departing trains, etc.), it provides the basis for defining the critical elements of the equipment itself, and the necessary countermeasures and to select a sub-set of these under specific constraints.
A set of scenarios of attack are chosen defining a set of type of threat. For each scenario a set of user cases is defined specifying the position of the threat inside the building, its magnitude and defining the effects in terms of damage to the structure of the station and to each element of equipment. The selection of the user cases can take into account the information coming from the identification of the critical elements of equipment and is consistent with other operational information related to the arrival and departure of the trains, the access of passengers, etc..

Next, a set of countermeasures are defined based on the experience of the station operator and the results from the identification of the critical parts of equipment.

All the defined countermeasures are applied to the use cases during the phase of ranking and selecting of the specific measure that best enhances the functionality of the station within defined constraints. This phase is performed using specific optimization and decision making techniques.

BACKGROUND AND LITERATURE REVIEW

A base starting point for the definition of the critical equipment and missions of a station can come from the listed requirements reported in R.[1] where among others the following are listed:

- Clear paths indications (signage, visual and auditable information) for all passengers, but especially those with visual or cognitive impairments;
- Clear and consistent displays with information about transport connections.

According to these statements, some interesting considerations relative to the importance and installation of the Public Address system in a station are reported in R.[2].

A significant study related to the maintenance of the stations is addressed in R.[3] where a model for evaluating the condition, or performing a diagnosis, of subway stations is developed taking into account the different equipment and the structural parts, while a detailed analysis and simulation of the activities of a passenger in a station are performed in R.[4] and summarized in details.

In R.[5] a detailed selection of the users’ priorities, grouped for categories of passengers (commuters, business travelers, leisure travelers and tourists, station visitors) and stake-holders (Station Managers, Train Operators, Transport Authority/Agency/Passenger, Transport Executive, Local Authorities and Commercial and Retail Operators), are reported. In this context the priorities related to the passengers are useful for the comprehension of the importance of the different equipment. This study also presents an interesting analysis of the zones of the station.

A similar spatial and functional analysis is performed in R.[6]. In the resulting scheme it is clear highlighted the importance of the path through “main entrance”, “core area” and “peripheral area”, that represents the main interest of the methodology developed in the current document.

Considering Euston Station in London as a typical station, significant information related to the needs of passengers used to define functions and to give importance to equipment and different systems, are reported in R.[5]. As in previous references, particular importance is given to each type of information and communication means installed in a station.
An interesting list of user-identified issues related to the sense of security within a station are reported in R.[7] and they are in some cases related to the presence and efficiency of the equipment. They can be summarized as follows:

- blind corners and hidden areas make station users less visible and less aware of others and create opportunities for anti-social behavior;
- poor lighting in and around a station makes it difficult for people to identify potential hazards and causes increased anxiety;
- lifts that provide little natural light placed in secluded locations are susceptible to vandalism, and people who rely on them may feel unsafe;
- closed circuit television (CCTV) is important for crime prevention (CCTV are seen as a deterrent) and prosecution, however a station dominated by CCTV can make some users feel more anxious.

In order to analyze emergency situations in the station building, the NFPA130 has been considered within the main references (R.[8]). This standard covers fire protection requirements for passenger rail, underground, surface, and elevated fixed guideway transit systems including trainways, vehicles, fixed guideway transit stations, vehicle maintenance and storage areas.

Unless the standard pertains to the fire protection concepts, the approach can be assumed as reference for the development of the current methodology.

For several aspects the abovementioned standards refer to NFPA101 (R.[9]). The standard as been considered as well within the analysis of specific aspects of design and emergency situation (e.g. underground and limited access structures).

Some significant considerations on emergency procedures about capability fo responding to emergency concerning a rail transit systems that are also applicable to the station building are reported, among others references, in R.[10].

Some helpful advice concerning the emergency procedures have been developed by a user panel regarding the emergency procedures and equipment functions (R.[7]). This advice can be summarized as follows:

- information on emergency procedures needs to be easy to find and understand for all users;
- emergency information and announcements need to be understood by all users, including those with vision and hearing impairments.

The issues of detection of emergency situation and mass-evacuation are addressed in detail in the SAVE ME Project (co-funded within 7th FP). The project aims to develop a system that detects disaster events in public transport terminals / vehicles and critical infrastructures (e.g. tunnels and bridges) and supports quick and optimal mass evacuation guidance to save the lives of the general public and the rescuers, giving particular emphasis to the most vulnerable travelers (R.[11]).

A comprehensive study of cost related issues was done within the HEATECO Project (co-funded within 6th FP). The project developed a set of harmonized guidelines for project assessment and transport costing at the EU (i.e. value of accident risk reduction and value of accident risk reduction) (R.[12]).
Railway stations are not only seen as interchanges for both trains and other transport forms, but also, as places of commerce, social interaction, and, potentially, as drivers of urban development (R.[13]). Within the current methodology, the core function of the station is mainly taken into account. Therefore, the attention is focused on the movement of passengers between the platforms and station exterior.

**DESCRIPTION OF FUNCTIONAL RESILIENCE STATIONS AND EQUIPMENT**

The functional resilience of a station building has been evaluated in relation to the availability and vulnerability of its equipment in the two phases following an attack (Figure 2):

- **emergency**
- **post-emergency**

![Functional Analysis of the Station – Phases After an Attack.](image)

In the emergency phase the following functions related to the safety of the people in the station are considered essential to be preserved:

- **Evacuation**: the need for people to reach safe places and the outside the station as quickly as possible (e.g. according with NFPA 130 [R. 8]);
- **Search and rescue**: the activities of the rescue teams to localize the injured passengers within the station, reach them and give them first aid.

In the post emergency phases a selection the main functions are considered to be protected and enhanced are as follows:

- **Access to platforms**: the normal activities of the passengers to access and egress the
platforms from and to the outside of the station;

- **Restoration:** the activities of repairing the equipments (and architectural and structural parts as well);
- **Retail (including ticketing):** the commercial activities (including ticketing for the public transport) that are located within the station building;
- **Leisure:** all the related activities of the station/terminal related to opportunities for ease and relaxation;
- **Social interaction:** the opportunities of developing relationship between passengers themselves and with other people that work in the station/terminal or frequent the station to benefit of the services that are offered (e.g. bars, newsstands, other shops, etc.).

Although many activities are hosted in modern complex stations, such as commerce, social interaction, recreation etc., in order to simplify the problem in this context, only the main functions related to the transport system have been taken into account.

In order to minimise the impact of an attack on the station, equipment needs to be protected to ensure the continuance of critical functions in both phases. This methodology describes countermeasures for all the levels of the equipment, but refer mainly to the critical elements that, when affected, can lead to successive functional failure.

Based on the phases above, the following three missions are defined and relevant KPI (Key Performance Indicators) are used to measure the effectiveness of the system response, as summarized below:

**Mission 1:** functioning during the post emergency phase:
- KPI1 - measurement of the effectiveness of the station in the post-emergency phase related to service availability. Indicator: accessibility (time to access) to platform;

**Mission 2:** restoration of the integrity of the damaged equipment:
- KPI2 - measurement of the direct economical damage related to the disruption of the equipment (indicator: cost of replacement of the disrupted elements/systems);

**Mission 3:** emergency procedures:
- KPI3 - measurement of the efficiency of emergency procedure (evacuation and search and rescue) (indicator: variation of number of fatalities due to the unavailability of parts of systems).

**EQUIPMENT MODEL**

In order to evaluate the impact of the attacks on critical parts the equipment is represented using a network approach based on three different kind of elements:

- **system:** a piece of equipment that is composed by a complex of devices/machinery, usually located in the same room, that interact to provide the same service (e.g. the Ventilation Central System composed by ventilation unit, control and supervision system, plc, in/out measures devices, in/out control devices, connection with other equipment, connection with remote control room, etc.)
• **component**: a piece of equipment that is located in a single point and that is not mainly characterized by its dimension (e.g. a camera of the video surveillance system)

• **connection**: a piece of equipment connecting different other parts with a service and characterized by having one dimension predominant against the others (e.g. any cable or duct)

This type of approach enables the representation of station equipment defining a model using the technique of the PBS (Product Breakdown Structure). This technique is a tool for analysing, documenting and communicating the parts of a system or of a product. The PBS provides an exhaustive, hierarchical tree structure of components (physical, functional, or conceptual) that make up the system, arranged in whole-part relationship. The equipment of the station under the hypothesis of this analysis has been subdivided in several systems.

The PBS analysis has been applied to the physical components of station equipment considering as many levels as necessary for a comprehensive description within the scope of the present methodology. The results of the PBS analysis gives information related to the:

• physical components;

• data transmission (dependency);

• power distribution (normal, under UPS and under emergency generator).

### PROTECTION MEASURES AND STRATEGIES

The critical systems composing the station equipment need to be protected from possible attacks, and their functioning is required to be assured in the emergency and post-emergency phases. Designing the equipment is a complex process and needs to be integrated with the architectural and structural layout of the station. The equipment can be best safeguarded if this taken into account as a main requirement from the earliest stages of design, when its position may be established in relation to the general configuration of the station and harmonised with all other security aspects.

The design principles adopted to protect the equipment in the station need to be considered in two phases. Firstly, in the conceptual design phase, the overall layout strategy of the equipment has to be defined, to coordinate the relationship between the critical systems and to consider how they would continue to function both together and independently in case of an emergency. Then, in the detailed design phase, system components are to be protected independently and strategies to safeguard sets of components within the systems are to be applied, in order to prevent failures of the entire system to occur.

The distribution of the systems in the station depends on the building’s spatial configuration, so in order to secure equipment, the architecture itself can help protect the services, if conceived properly.

All the systems in the station rely primarily on the power distribution system. The elements of interaction between systems can be protected by adopting the same strategies that are used in case of an electrical distribution failure:

• Structure the system by compartments in different functional zones to reduce the area affected by failure;
• Provide critical systems with dedicated power supply circuits, to allow quicker restoration in case of failure and to reduce consequences of possible damages;

• Provide the system elements (e.g. switchboards, busbars, etc.) with adequate protection against attacks. By considering an integrated design of the equipment early on in the process, additional costs for post construction shielding of these components can be reduced.

• Consider a strategic location for the electrical generator and fuel tank that secures the access from outside through the layout configuration; the main voltage (MV) cable and transformer can then be integrated with the design for the reasons stated in the previous point.

The following measures should be implemented within each system or “locally” on particular elements:

• **Reinforcement through physical protection or through element segregation**: The necessity to increase the resilience of an element (node) of the equipment to the attack. Depending on the type of attack and element, different strategies can be applied. If the element is prone to effects of general attack based on physical damage (e.g. explosion or fire) the component can be protected through screens or physical barriers limiting the effect of the agent (e.g. cables can be protected by putting them under plaster). In the same way the protection of elements prone to sabotage, vandalism and any other targeted attack, can be achieved by limiting the access of the possible adversary (e.g. the cameras of a CCTV system can be protected from vandalism through cages or screens). The concept of segregation can be easily applied to any data server, building management system (BMS) and central electronic equipment, usually located in the station control room (SCR). A simple hardening procedure by means of segregation in case of sabotage could be a strict limitation of access to the SCR.

• **Hardening**: Quality improvement: Better resilience of systems is achieved by substituting an element with one that has better fabrication qualities to withstand a particular threat (e.g. in case of an explosion the element is able to resist higher pressure waves); Strategic location of elements — The element of the system is located (or relocated) in a place where the effect of the attack is assessed as lower and/or the attack seems to be less probable. Relocation, at a system level, spreads the key-elements of one or more equipment in different places in order to reduce the damage in case of an attack (e.g. in places that are unlikely to be affected by the same attack);

• **Element redundancy**: Increasing the resilience of the whole system (and the whole system where dependencies of other systems are in place) is provided by means of duplication (if possible) of the key-elements. These should be located in strategic positions to avoid making them prone to the same type of attack.

• **Compartmented distribution**: At system level increased resilience is obtained by subdividing the systems in different functional areas that are independent one from the other, as much as possible. The different areas are designed from a functional point of view “in parallel”, meaning that the damage of key-elements (e.g. peripheral switchboards) in
one area does not affect the functioning of other areas. This compartmented distribution is limited by the fact that some key elements cannot be duplicated (e.g. MV Power Supply or MV/LV Transformer are normally unique in a small or medium sized station) and the different areas need to share them.

As a general design principle to be applied to the equipment, for all the systems, the key elements that control their operation need to be safeguarded in a secured room in the station.

RELATIONSHIPS BETWEEN FUNCTIONS AND EQUIPMENT
The conclusions of the functional analysis present a series of general considerations of the disruption of critical functions caused by equipment failure during different types of attack. In order to represent them in a schematic way for the different type of attacks the level of importance of the equipment in relation to each station function is ranked as follows:

1. Highly relevant
2. Relevant
3. Slightly relevant
4. Not relevant

The (electrical generator and) electrical distribution system is the most important as all other parts of the station equipment depend on it. Even if some of the most relevant equipment (e.g. lighting, PA, PIS) are supported by batteries in case of electricity failure, they can only be supported like this for a short amount of time. Therefore, the electrical distribution system is fundamental.

The disruption of the lighting system is highly relevant for the degradation of all functions in both the emergency and postemergency phases.

The CCTV is vitally important in the emergency phase. In evacuation, using CCTV helps identify and assess the points of congestion and, in connection with the PA system, people can receive instructions. During the search and rescue activities, CCTV is used to help identify the location of passengers who need assistance and helps reduce the time for intervention.

The limited operation of PA and, to a lesser extent, PIS equipment impacts on the restoration of the station as information and specific procedures can be addressed through them. PA and PIS help accessing platforms in the post-emergency phase; passengers can get confused when information is unavailable.

FAS and FSS could have some importance in the emergency phase in the case of fire derived from the attack as collateral effect. They have even more limited importance in the post-emergency phase from a strictly functional point of view. Their importance can be connected to the necessity of a formal verification of the status to permit the operation of the station.

Disruption of the communication system for the accident response affects both functions in the emergency phase. Their functioning is fundamental to shorten the emergency response time and to
manage the incident in case of attack. It should be recognised that in case of an explosion the
wireless system is more resilient due to less fixed wiring, while the landline system is more prone
to disruption of wires and control panels.

In case of explosive attacks the ventilation system could be useful to reduce the presence of dust
in the air inside the station; FSS if equipped with systems such as “water mist”.

Lifts and escalators are not relevant in the first phase because common practice is to stop the lift
during an emergency situation and to use escalators only partially (e.g. NFPA 130). These
elements of equipment become more important during the post-Emergency phase. Their lack of
availability increases the walking time within the station and limits the accessibility of people with
reduced mobility.

In the event of an attack involving fire, FAS and FSS equipment become vital. The ventilation
equipment is considered of high importance due to its role played in applying the correct
emergency procedure with regard to containing fire and smoke and assisting with passenger
evacuation.

In case of attacks involving PIH (poisonous through inhalation) or CBR (Chemical, Biological and
Radiological) and TIM (chemicals and toxic industrial materials) the importance of the equipment
to the different functions is generally the same as for explosive attacks, except for some particular
aspects. For this type of attack, the specific equipment (detection of PIH and TIM) becomes
particularly important in the emergency phase.

Due to the fact that combined attacks are not frequent, the related equipment has to be considered
fully efficient and able to mitigate the consequences of the attack. The ventilation system can be
particularly useful because it allows putting in place emergency procedures to contain and reduce
the dispersion of the toxic agent. Similarly, the FSS (when equipped with ‘water-mist’) can be
used as a measure to reduce the concentration of the toxic agent.

OPERATIONAL FRAMEWORK

Description of the tool
In order to implement the methodology described before, a tool called SARA (SECURESTATION
Attack Resilience Assessment) has been developed. The tool is composed by different modules
that perform the specific functions needed to analyze the station and rank the countermeasures.
The implementation of different functions is described in details in the following.

The definition of the ontology of the model is implemented using Protégé (R[14]), that is a free,
open source ontology editor and knowledge-based framework. All the data describing the station,
the operational condition, the scenarios and user-cases are inputted

From the ontology model implemented in Protégé the XML model, and relative database, is
developed in order to perform the necessary calculations. The calculations are performed using a
specific module developed in VB.NET (R[15]) specific for this project.

The graphic representations are produced using Graphviz, that is open source graph visualization
software (R[16]). For an example of the representation of data realized using Graphviz refer to
Figure 6 where the LDUs (Lowest Damageable Unit) of the station model are represented.

The representation of the flows (e.g. flows of passengers) are represented using D3.js. D3.js is a JavaScript library for manipulating documents based on data. D3.js helps to bring data to HTML, SVG and CSS ([17]). For an example of the representation of the flows of passengers developed using D3.js refer to Figure 3.

**FIGURE 3: D3.js - Flow repres.**

**Application to the Model Station**

In order to optimize and fine tune the methodology, and the related tool a Test Station has been defined and used as a test case. The station and the analysis performed are briefly reported in the following.

The General Model Station adopted within the SECURESTATION project has been developed within the Project and it is a transport interchange node constituted by a train station, a metro station and by a bus station and can be described in brief as follows (Figure 4). The interchange station consists of three different levels: the first level (level 0) is located at the level of road platform; the second level (level -1), under the road platform, coincides with the intermediate floor; the third level (level -2) coincides with railway platform and metro platform. The first level (Level 0), is characterized by four different areas separated by roadways: the railway access; the underground access; the bus station; the parking ramps.

The second level (Level – 1), corresponding to the intermediate level where the users can change the travel mode; the connections with railway and metro characterize this floor. This level is constituted by different areas directly connected, such as: a central lobby where are situated: different commercial areas; ticket office; information office; general service (cafeteria, public toilets); a parking area; a lateral lobby with underground access.

The third level (Level -2), corresponds to the rail platforms and metro platforms. This level is constituted by different areas, not directly connected, such as: a central lobby with railway platforms access where are situated: different commercial areas; concessionaire office; information office; a parking area; railway platforms and bays; metro platform. These areas are connected with areas destined to facilities
In the present contest, in order to apply the methodology described in the previous paragraphs, the general model presented in the previous paragraph has been simplified. The considered part of the station has been limited to the railway station.

Simulation Results
The following analysis has been conducted defining a total budget for the countermeasures sets equal to 500,000 Euro. In the following Figure 5 the topological elements graph of the test station is depicted as reported in SARA Tool. Note that the element colored in yellow are “rooms” and the ones colored in white are “corridors”. As a result of the analysis of the base configuration of the system the criticality of the LDUs (Lowest Damageable Unit) has been ranked. The LDUs ranked in terms of criticality have been represented in Figure 6 using color-codes where red stands for critical, and white stands for not critical.
In the following Figures 7, the disrupted configurations after an attack are calculated without the application of any countermeasures in terms of the status of the LDUs for the two considered user cases, and then reported:

- UC1: Improvised Explosive Device (IED) at platform (explosive threats);

The LDUs colored in orange are not functioning due to a physical damage and the yellow ones are not functioning due to the not functioning of LDUs providing them needed services (e.g. power, data, etc.). The LDUs colored in white are functioning. The LDUs colored in grey are not installed (e.g. related to countermeasures that are not activated).
FIGURE 7: Model Station – UC1 – Disrupted Configuration without Countermeasures

CONCLUSIONS
This paper addresses the achievements of the activities related to the development of a systematic framework to support station designer to evaluate the vulnerability and availability of the station equipment. The methodology developed is based on the fact that the equipment is modeled and studied with an analysis of vulnerability and availability aimed to identify the critical components and to rank their importance. The balance between investments to limit the vulnerability and the reduction of the consequences of the failure is a typical “decision making” process derived by economical and technical factors.
The main goals of the methodology developed can be summarized as follows:

- Representation of the station building and its equipment in a systematic way that allows to analyze them applying the theory of graphs;
- Definition of a formal representation of the equipment based on Product Breakdown Analysis (PBA);
- Definition and evaluation by using numerical indicators (KPIs) of the main function of a station building;
- Identification and rank of the critical parts of the equipment considering functional and physical cross-correlation of the equipment;
- Definition of scenarios of attack and user cases characterized by their impact on the whole station and its equipment;
- Representation of countermeasures and evaluation of the effects on station for the defined user cases
- Selection of one or more sets of countermeasures to be adopted given different constraints (e.g. a limited budget for the implementation).

The methodology developed so far covers all the essential aspects of the assessment of the resilience. Its framework is characterized by a modularity approach and it allows to adapt the assessment to the different necessity of the assessor. Presently the methodology is developed at an advance research level. In order to enhance it to a industrial level of development some areas could need further research activities. Among the others the more interesting are related to be investigated are represented by:

- the definition of the KPIs both in terms of functions of the station and evaluation of the numerical indicators;
- representation of the equipment and analysis of the cross-correlation among different systems.

The SARA tool has been developed at a prototype level so far. It allows to implement the methodology using the basic tools. The main area of development is related to the realization of a comprehensive interface graphic that allows to evaluate all the implemented functions and to manage the modularity and possible expansion allowed by the methodology.
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