Report on a multilingual risk assessment tool

Deliverable 3.4

Lead Author: STAM

Contributors: FRAUNHOFER, MDM, RINA, EGO, LDO, RINA, WINGS, UNEW, INNO, ERARGE, MTRS, AC, ELBIT

Dissemination level: PU, Public

Security Assessment Control: passed

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 883532.

D3.4 REPORT ON A MULTILINGUAL RISK ASSESSMENT TOOL		
Deliverable number:	3.4	
Version:	V1.1	
Delivery date:	10/01/2023	
Dissemination level:	PU – Public	
Nature:	Report	
Main author(s)	Davide Ottonello and Giorgio Tardito	STAM
Contributor(s)	Emiliano Costa Claudio Poretti	RINA LDO
Internal reviewer(s)	Uli Siebold Atta Badii Stephen Crabbe	IC UREAD Fraunhofer
External reviewer(s)	Grigore Havarneanu	UIC

Document control			
Version	Date	Author(s)	Change(s)
0.1	22/02/2022	STAM	ToC
0.2	10/03/2022	STAM	Draft for internal review
0.3	23/03/2022	STAM	Consolidated version after reviews
0.4	25/03/2022	STAM	Consolidated version after reviews
0.5	04/04/2022	STAM	Internal version
0.6	04/04/2022	STAM	Consolidated version after PC review
0.7	07/04/2022	STAM	Update following further PC review
1.0	08/04/2022	Fraunhofer	Creation of V1.0 from V0.7 with some minor formatting and editing.
1.1	10/01/2023	STAM / Fraunhofer	Integration of Project Review feedback Specifically: ▪ Renaming from “network topology” to “network structure” wherever necessary ▪ Clarification about meaning of network structure at page 12, including reference to depict other alternative names ▪ Renaming from “fault tree” to “event tree” at page 21 ▪ Minor modifications ▪ Update of this page and footers ▪ Creation of clean version

DISCLAIMER AND COPYRIGHT

ABOUT SAFETY4RAILS

SAFETY4RAILS is the acronym for the innovation project: **Data-based analysis for SAFETY and security protection FOR detection, prevention, mitigation and response in trans-modal metro and RAILway networkS**. Railways and Metros are safe, efficient, reliable and environmentally friendly mass carriers, and they are becoming even more important means of transportation given the need to address climate change. However, being such critical infrastructures turns metro and railway operators as well as related intermodal transport operators into attractive targets for cyber and/or physical attacks. **The SAFETY4RAILS project delivers methods and systems to increase the safety and recovery of track-based inter-city railway and intra-city metro transportation.** It addresses both cyber-only attacks (such as impact from WannaCry infections), physical-only attacks (such as the Madrid commuter trains bombing in 2004) and combined cyber-physical attacks, which are important emerging scenarios given increasing IoT infrastructure integration.

SAFETY4RAILS concentrates on rush hour rail transport scenarios where many passengers are using metros and railways to commute to work or attend mass events (e.g., large multi-venue sporting events such as the Olympics). When an incident occurs during heavy usage, metro and railway operators have to consider many aspects to ensure passenger safety and security, e.g., carry out a threat analysis, maintain situation awareness, establish crisis communication and response, and they have to ensure that mitigation steps are taken and communicated to travellers and other users. **SAFETY4RAILS will improve the handling of such events through a holistic approach.** It will analyse the cyber-physical resilience of metro and railway systems and deliver mitigation strategies for an efficient response, and, in order to remain secure given everchanging novel emerging risks, it will facilitate continuous adaptation of the SAFETY4RAILS solution; this will be validated by two rail transport operators and the results will support the re-design of the final prototype.

TABLE OF CONTENT

List of tables

List of figures

Executive summary

Deliverable D3.4 reports on the development and implementation of SecuRail 2.0, a quantitative risk assessment application dedicated to railway infrastructures. This document describes the different components of the tool, the User Interface, the commands available to the user and the information that can be visualized. For example, the tool comprises functionalities devoted to carry out modelling of the infrastructure, risk analysis, and cost benefit analysis. Indeed, the main operations undertaken by the user are the representation of the railway network, the launch of different analysis, and the visualization of consequent results. Furthermore, the logic of the calculation engine for the risk assessment process is explained step-by-step with the main formulas. The system will calculate the risk indicators considering likelihood of occurrence and potential impact of threats. The results that the user can obtain are described, as well as the purposes and context of their use. The typical scenarios when the tool can be useful include cyber-physical attacks against metro and railway network. Usage of SecuRail is reported not only as a stand-alone tool, but also as part of the S4RIS platform. Indeed, integration with other tools (for example with the BB3D tool) is addressed to highlight mutual benefits of ensuring interoperability.

1. Introduction

1.1 Overview

Following the DoA, this deliverable reports on the development of the tool primarily responsible for the risk assessment within S4RIS platform. In this deliverable, the final release of the tool and the algorithms used for it are described in detail.

The tool developed for the risk assessment in the SAFETY4RAILS project has to deal with a huge array of of threats (see the deliverable D3.1 [1] for instance) and risks (see the forthcoming Deliverable D5.1). The organizations that operate in the railway infrastructure need tools capable of analysing and predicting the effects of the threats, both physical and cyber related to railway infrastructure and need to estimate in quantitative and monetary terms how those threats can affect their activity. These kinds of tool are fundamentals for such organizations in order to support decision makers and to better plan future activities. The tool presented in this deliverable has been designed following the requirements drafted in [2] and [3].

The tool that has been developed to achieve the aforementioned goals is called SecuRail 2.0 which is the improvement of a previously developed tool called SecuRail, developed by STAM in a previous European Project called RAMPART. For the sake of simplicity in this deliverable when there is written SecuRail it refers to SecuRail 2.0.

1.2 Structure of the deliverable

This document is composed of six chapters as follows:

- **Chapter 2**: Analyses how far the requirements and specifications of SecuRail from the point of view of WP3 have been met to date.
- **Chapter 3**: Describes the interface of the tool in detail and how the end user can model their infrastructure.
- **Chapter 4**: Describes the algorithm used to compute the risk in terms of all its constituent elements
- **Chapter 5**: Sets out the results displayed to the end user and the information this can provide.
- **Chapter 6**: Explains how the SecuRail tools communicates with the other tools created and used during this project.
- **Chapter 7**: Presents the conclusions and highlights the features of the tool and how it has supported the use-cases that have been conducted to-date in the project.

2. Requirements and Specifications

In D1.4 [2] the tables regarding the functionalities and requirements of SecuRail have been introduced, here they are reported but not in their entirety (Table 1 to Table 7). Table 8 reports SecuRail specifications.

TABLE 1: SECURAIL REQUIREMENT (1)

Req.-ID	*SECURAIL_1*
Short name	Creation of libraries of the Railway environment to create and model the railway infrastructure to be analysed with the tool
Key objectives	• Allow the user modelling its own infrastructure and network • Allow the definition of features of the infrastructure • Facilitate the modelling by providing pre-defined railway items such as assets and countermeasures
Description /Comments /Constraints	The modelling of the user railway infrastructure should be possible, as well as easy and intuitive thanks to a graphic mechanism. Libraries to model areas, assets and the related attributes are necessary. Moreover, they are needed to define security countermeasure of the infrastructure, all cyber-physical threats, incident, natural hazards. Finally, the user has to define the model should allow the definition of the number of users in each area and the features of the areas and assets present.
Priority rank	***Essential***

TABLE 2: SECURAIL REQUIREMENTS (2)

Req.-ID	*SECURAIL_2*
Short name	Localization on the Map
Key objectives	Visualize the railway network on a map to facilitate exploration and visualization of the model
Description /Comments /Constraints	Items / Elements of the Model should have geographical references. The localization of the railway infrastructure of the map should allow to find easily items within the model and check the proper modelling of the environment during the process.
Priority rank	***Conditional***

TABLE 3: SECURAIL REQUIREMENTS (3)

Req.-ID	*SECURAIL_3*
Short name	Computation of Risk

Key objectives	• Perform Risk assessment • Evaluate damages to people, infrastructure and services • Assess likelihood and impact of threats • Definition and quantitative estimation of the Security Risk Assessment Index
Description /Comments /Constraints	Computation of risks in a qualitative and quantitative way. The process of risk assessment should be easy and done automatically as far as possible. Risk and other relevant metrics should be visualized to the user in an intuitive way through indicators and charts. Moreover, cascading effects should be modelled within the analysis to consider this relevant phenomenon. The risk computation should gather as outputs several indicators, among them a Security Risk Assessment Index will be implemented to provide the user with an overall score about its own infrastructure.
Priority rank	***Essential***

TABLE 4: SECURAIL REQUIREMENTS (4)

Req.-ID	*SECURAIL_4*
Short name	Real-time automatic risk assessment
Key objectives	Risk assessment in real-time triggered automatically by warning from monitoring tools
Description /Comments /Constraints	In case of an occurring threat the risk should be computed in real-time and automatically based on data gathered from monitoring systems or sensors.
Priority rank	***Conditional***

TABLE 5: SECURAIL REQUIREMENTS (5)

Req.-ID	*SECURAIL_5*
Short name	Multilinguality
Key objectives	Provide the tool to the user in its native language
Description /Comments /Constraints	The tool should be able to provide means of multilinguality, therefor the text in the graphic user interface of the tool should appear in the native language of the user
Priority rank	***Optional***

TABLE 6: SECURAIL REQUIREMENTS (6)

Req.-ID	*SECURAIL_6*
Short name	Cost-Benefit Analysis
Key objectives	Evaluation of the overall costs of countermeasures compared to the reduction of risk
Description /Comments /Constraints	The tool should be able to compare (CAPEX+OPEX) and benefits (reduction of risk, mitigation of potential economic losses) of a possible of a set of potential configurations modelled by the user. Common indicators should be compared, pros and cons should be highlighted in a dedicated dashboard.
Priority rank	***Conditional***

TABLE 7: SECURAIL REQUIREMENTS (7)

Req.-ID	*SECURAIL_7*
Short name	Conformity with overarching and S4RIS platform specific requirements included in section 2.2
Key objectives	• Ensure that any work connected with this tool conforms to the overarching and S4RIS platform specific requirements included in section 2.2
Description /Comments /Constraints	Ensure that any work connected with this tool conforms to the overarching and S4RIS platform specific requirements included in section 2.2. No development should be carried out in SAFEYT4RAILS which would negate the possibility or even make it extremely hard to fulfil 1 or more of the requirements determined as essential for the S4RIS product(s).
Priority rank	***Essential***

TABLE 8: SECURAIL SPECIFICATION

Specification ID	Requirement ID	Description

SPEC-1	*SECURAIL_1*	Implementation of an interface with graphic mechanisms that allows users to model the network infrastructure
SPEC-2	*SECURAIL_1*	Implementation of a bar chart in which the user can represent the occupancy of the station for given timeslots
SPEC-3	*SECURAIL_1*	Implementation of an interface that allows user to add assets present in the model
SPEC-3	*SECURAIL_1*	Implementation of a search engine to add existing station to the model of the network
SPEC-4	*SECURAIL_1*	Presence in the tool of pre-defined libraries of assets, areas, and countermeasures with corresponding features to
SPEC-5	*SECURAIL_2*	Integration of an interface that displays a geographical map where the elements of the model are displayed
SPEC-6	*SECURAIL_2*	Identification of every element of the model through the use of coordinates
SPEC-7	*SECURAIL_3*	Capability to compute the risk in a quantitative manner
SPEC-8	*SECURAIL_3*	Capability to estimate the damages in monetary terms
SPEC-9	*SECURAIL_3*	Capability to estimate the likelihood of a threat occurring
SPEC-10	*SECURAIL_3*	Capability to model the cascading effect within risk calculation algorithms
SPEC-11	*SECURAIL_4*	Capability to receive information from sensors
SPEC-12	*SECURAIL_5*	Interface of the tool in different languages
SPEC-14	*SECURAIL_6*	Capability to store several economic values of the elements present in the model
SPEC-15	*SECURAIL_7*	Capability to send the structure of the network (including all information entered by the user) as JSON messages
SPEC-16	*SECURAIL_7*	Capability to receive alerts from monitoring tools as JSON messages

3. Modelling of the railway network

One of the main functionalities of the new SecuRail tool is to provide the user the possibility to model its network infrastructure through a simple user interface. Having the model of the railway network is fundamental to enable risk assessment algorithms to have all the data needed to carry out computations and generate the outputs of the analysis. Furthermore, the creation of a model on the SecuRail tool enables the user to dynamically update it over time and, of course, visualize different components under the logic of the risk management process.

The modelling functionality of SecureRail allow the creation of what, in this scenario, is called the *network structure*. The network structure consists of all the assets that are present in the railway systems that is wanted to be modelled. The assets considered sometimes can be called either “sites” or “risk entity”. *[4]* The structure of the network will be comprised of stations, sections and assets located inside the mentioned locations. The assets that can be represented are both the ones typically physical (e.g. bench) but also cyber-physical (e.g. router,server).

The interface has already been presented in the deliverable D3.2 but it was just a mock-up version done in Figma *[4]*. In the following, the interface of the actual tool (in its almost final release) is presented.

3.1 Graphical Interface

HOMEPAGE

Upon logging on the platform, the user is presented with the home screen of the SecuRail tool (Figure 1). In this page is presented a map in which is represented the network that has been modelled. The information that are displayed in this page are: the map of the country, the type of network, the number of stations and sections. The user can then edit the model of the railway network by clicking on the Edit button.

In the homepage page of the tool are also presented some cards below the indication My Configuration; these cards correspond to pre-created configurations which can be used to run the risk analysis, can be deleted and modified, and other configurations can be added. Configuration is a set conditions in which the railway network can find itself according to temporal factors and countermeasures active. Moreover, in the homepage there is also the possibility for the user to switch from the English version of the web app to the Italian one. For the next releases more languages will be implemented such as Spanish and German.

From the home page, the user can enter into the editing of the network or can make operations on the network configurations. Specifically, the operations that can be performed are:

- Add a new Configuration
- Edit an existing Configuration
- Delete an existing Configuration
- Run the risk analysis for an existing Configuration

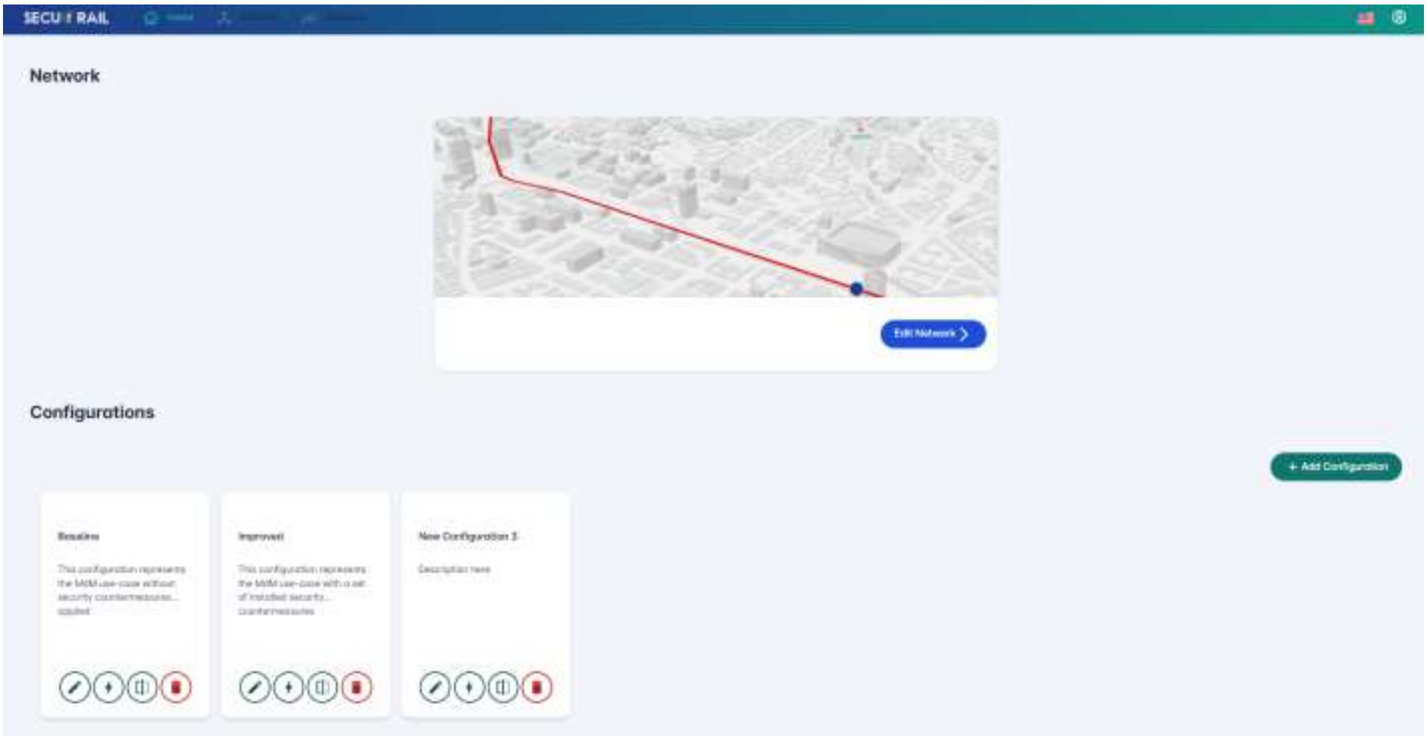


FIGURE 1: SECURAIL 2.0 HOMEPAGE

CREATE A NEW CONFIGURATION

If the user wants to add a new configuration, he/she is directed to another page of the web app. (Figure 2) In this page the user provides a name for the configuration he/she is creating, the size of the company, the number of employees, and the average costs of employees and technicians. Moreover, there is the possibility to add a description to every configuration, it is also possible to specify the starting and ending day, and if the configuration is repeated weekly or monthly. Then the user can edit the occupancy of the stations present on the line. After saving the configuration the user is redirected to the homepage of the application and the new configuration can be seen among the others.

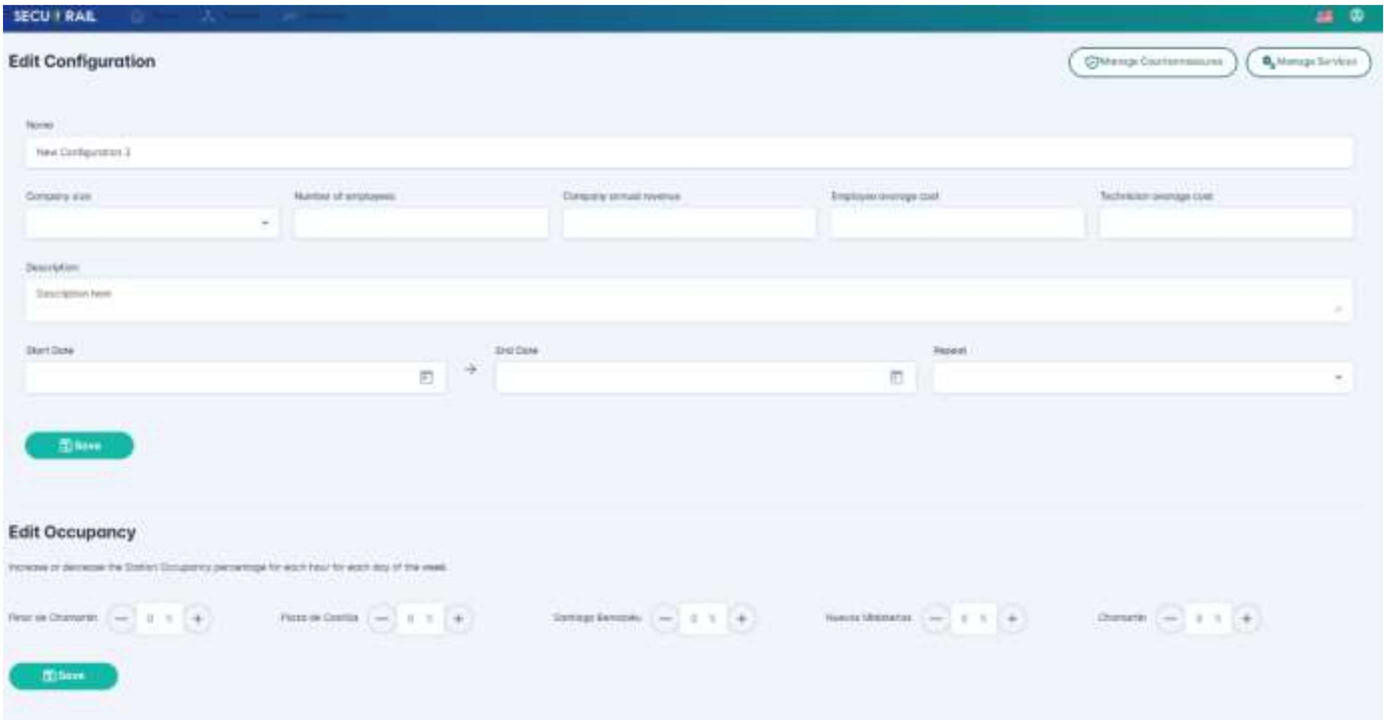


FIGURE 2: SECURAIL 2.0 CONFIGURATION PAGE

MODELLING OF THE RAILWAY NETWORK

Concerning the modelling of the network infrastructure, the user can perform it directly using the User Interface (UI) of the tool. Within SecuRail, the main components to model the railway network are:

- Stations
  - Areas
    - Station assets
- Sections
  - Section assets
- Services
  - Lines

The level of details of the element that the user can insert in the model can be subdivided in three main areas: Stations, Sections and Services. In those levels of details are contained other sublevels which are used to represent elements of the network more in depth. For example, in the preliminary level the user can define the station, in a second level of detail he/she can define the areas present inside the station, and then inside those areas he/she can specify the assets present. The same process is applied for the sections (with the exception that the areas are not present). On the other hand, the Services are created automatically by the platform depending on the elements that are present in the model with the exception of the lines which the user can specify in a specific part of the interface of the application.

Concerning Assets or Services that are common to the infrastructure but are not located in a specific station or a section, like for example a Command and Control Center, the user could represent such kind of elements in a separate fictional “Station” of the network or in an area associated to a real station but outside its premises.

So, the user can indeed add to the network different types of elements: from the entire station (with different areas) or railway section to small assets such as equipment (e.g. ticket machine, turnstiles etc.) and IT devices (e.g. router).

The network can be created (and visualized) on a 2D and 3D map, which is navigable through standard commands (zoom in, zoom out and pan). The maps are provided by a webservice called MapBox. [5]

The user can add a new station in three different ways:

- He/she can search a new station to be added through textual search, i.e. by writing the name of the station in a search bar (Figure 3)
- He/she can use the bounding box option, i.e. the tool can show all the section in the current frame of the map and the user can select the station among the ones visualized (Figure 4)
- He/she can use the pin search, i.e. the user can select a position in the map putting a pin and define the range of the area in which the tool should highlight the included stations. (Figure 5)

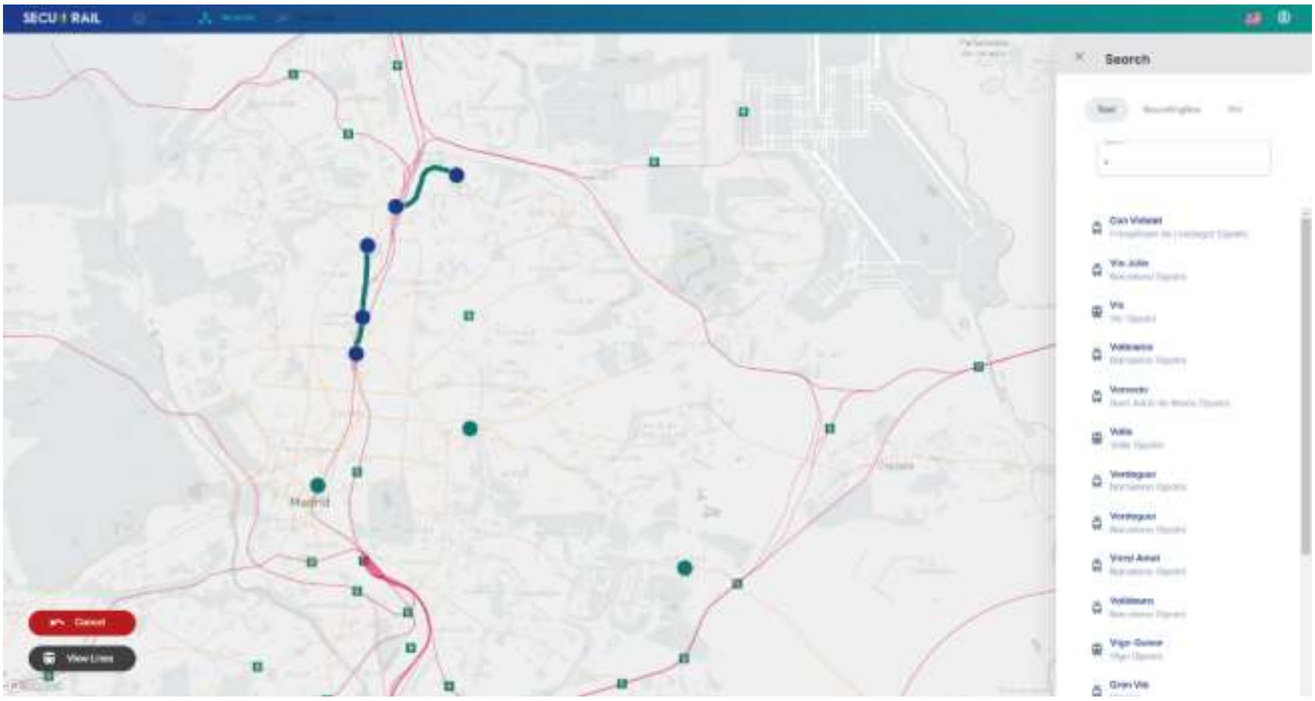


FIGURE 3: SECURAIL 2.0 CREATION OF A STATION (A)

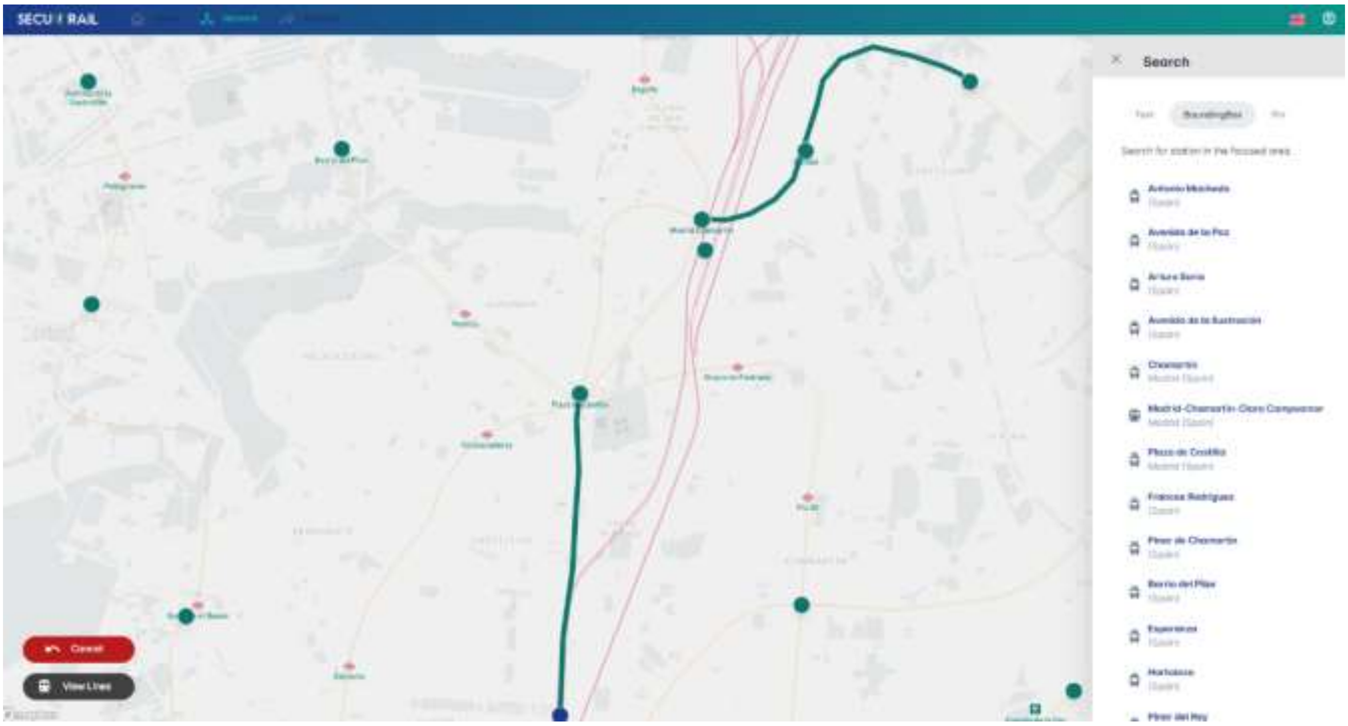


FIGURE 4: SECURAIL 2.0 CREATION OF A STATION (B)

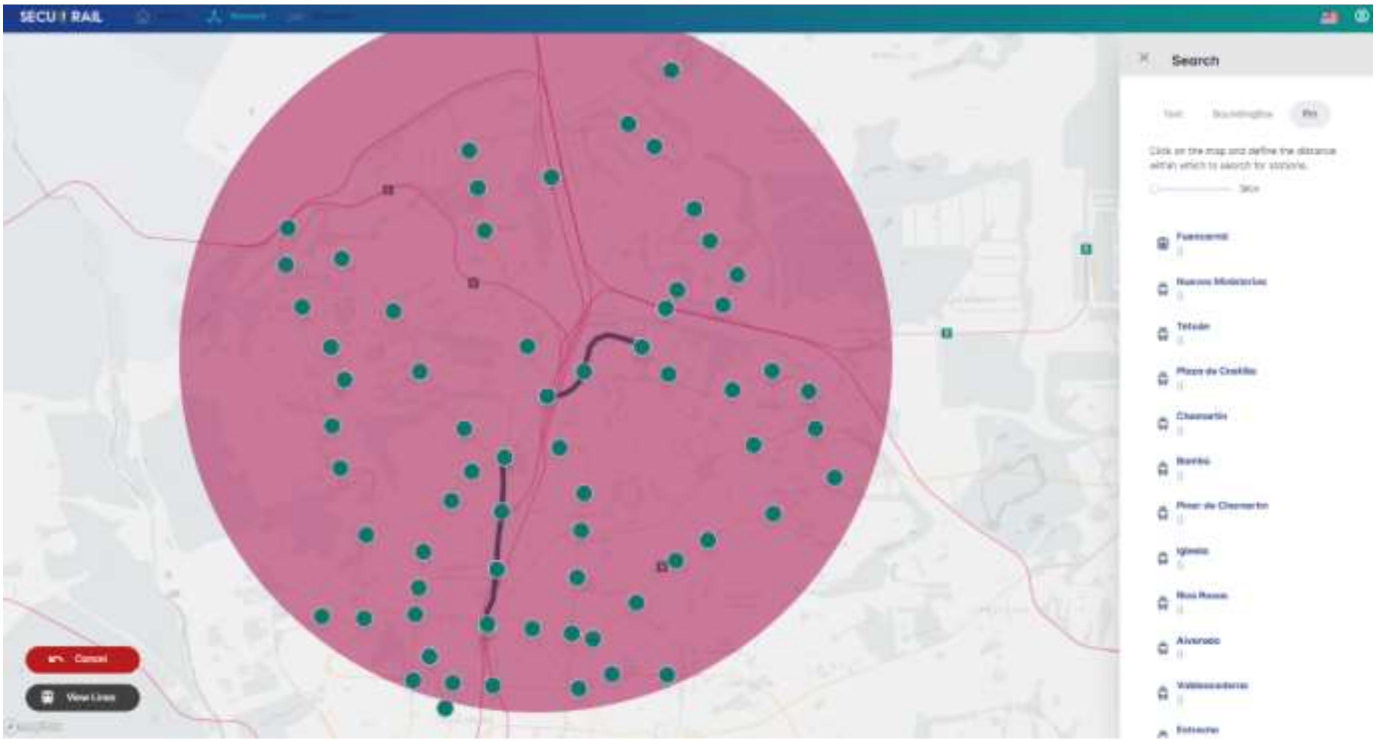


FIGURE 5: SECURAIL 2.0 CREATION OF A STATION (C)

Once the user has found the station that he/she needs to add, he/she can just click on “add station” in the right sidebar to add it to their own railway network. (Figure 6)

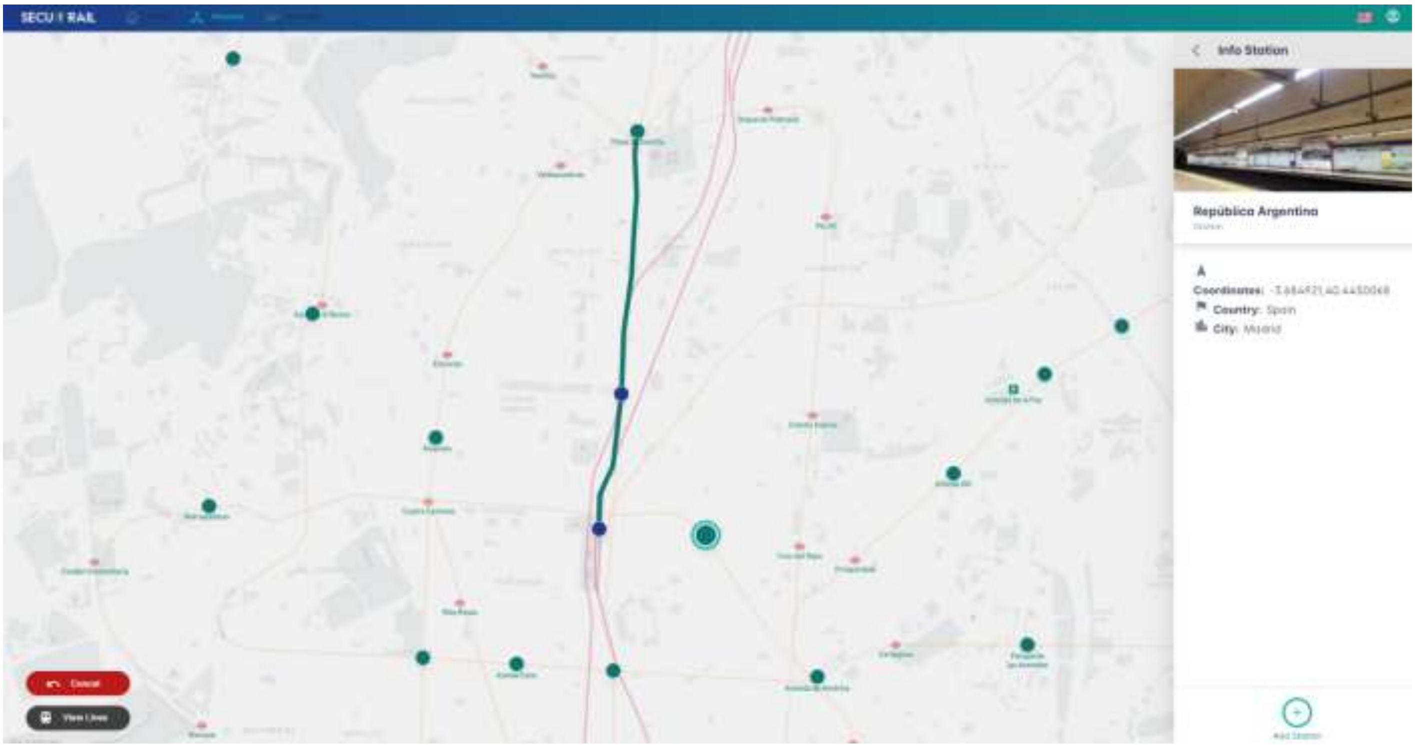


FIGURE 6: SECURAIL 2.0 ADDING A STATION

The procedure to add a new section to the network is straightforward: first the starting station is selected, then the final station needs to be selected. After doing this, the tool automatically creates the new section between the two stations. (Figure 7)

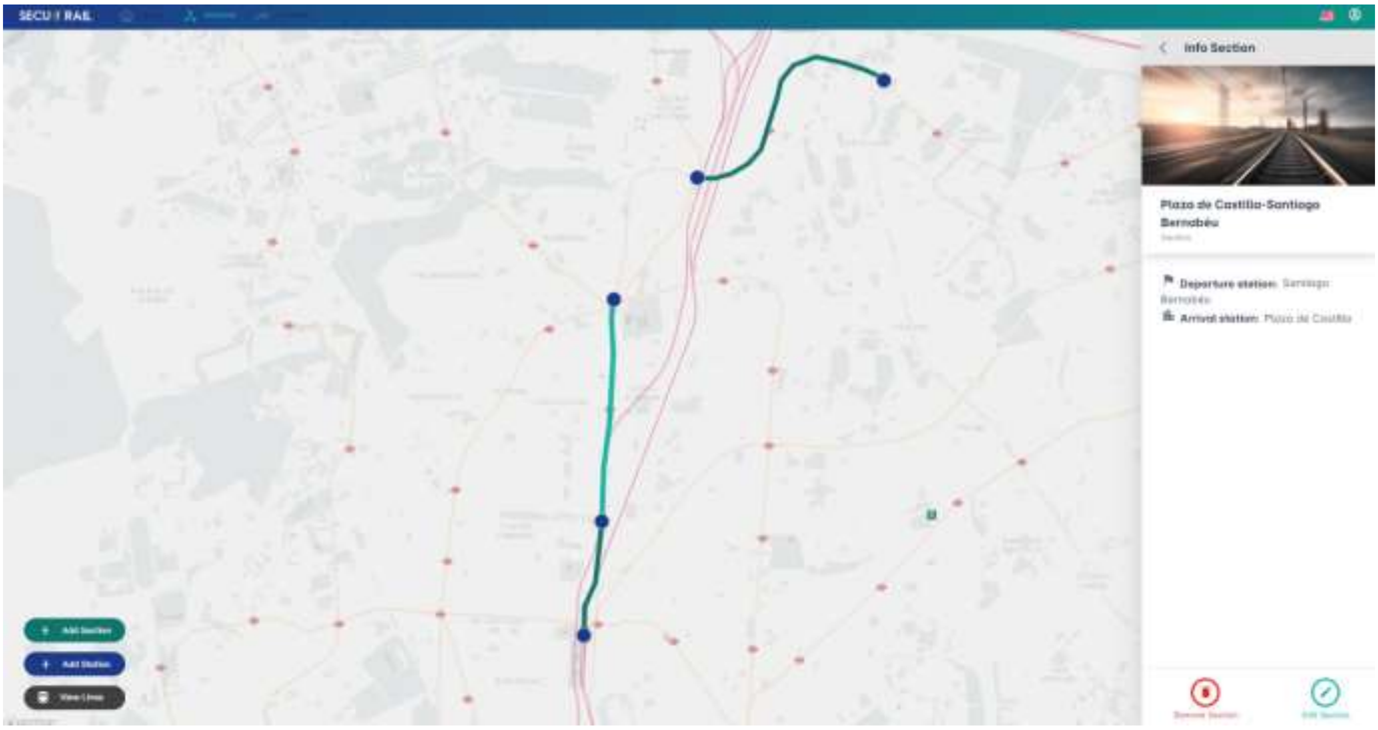


FIGURE 7: SECURAIL 2.0 ADDING A SECTION

Moreover, there is also the possibility to add lines on the network specifying the starting and ending station, the section present on the line, the stops, and the frequency of the trains. (Figure 8)

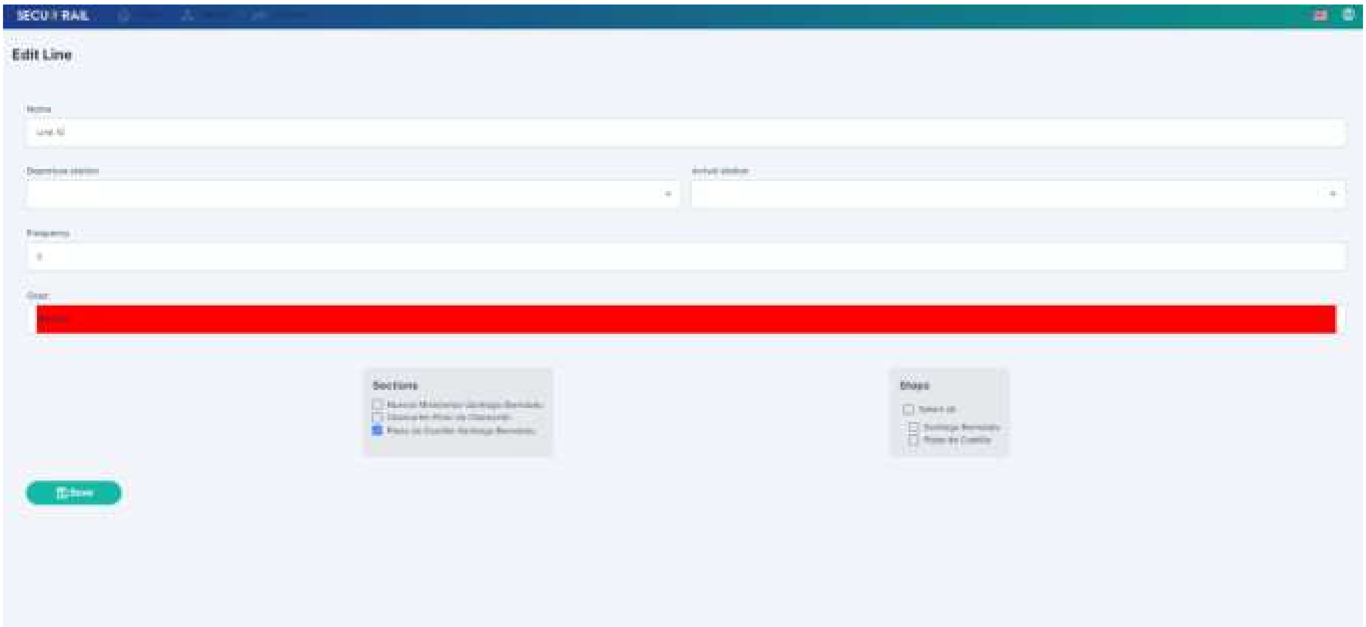


FIGURE 8: SECURAIL 2.0 LINE EDITING

MANAGE COUNTERMEASURES

Form the editing/creation page of the Configuration it also possible to specify the countermeasures active in those specific conditions of the network. Not negligible differences can exist in the activation of countermeasures according to boundary conditions, e.g. the number of security staff is assumed to be higher in the case of an event involving transportation of lots of passengers.

The countermeasures can be chosen to be applied at a general level of the station or for specific areas of the station, and even for specific assets present in the station. The user can navigate the different elements of the network using the "Network tree" on the left; anytime the user selects an element on the right the applicable countermeasures are visualized.

For each countermeasure, the user can define:

- The Operative Expenditure (OPEX)
- The Capital Expenditure (CAPEX)
- The efficiency of the countermeasure, from 1 to 100, which represents a qualitative evaluation of how well each countermeasure is applied. (Figure 9)

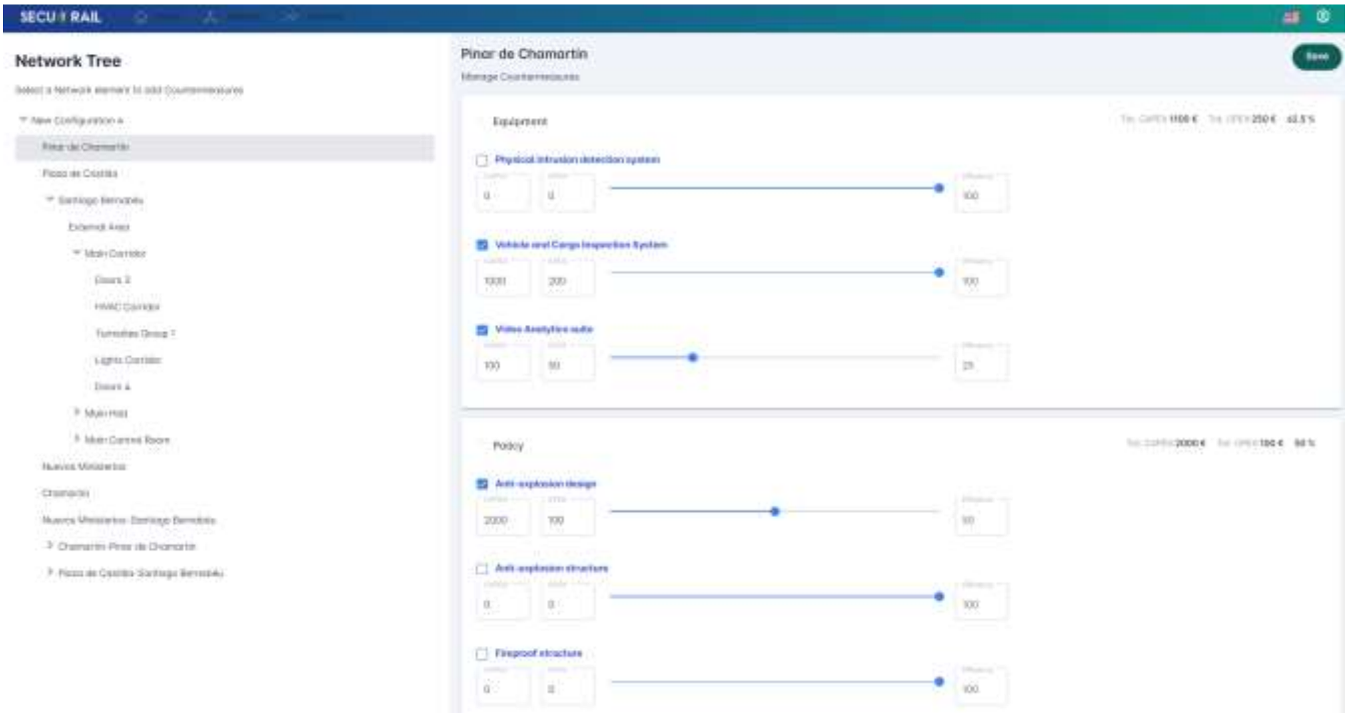


FIGURE 9: SECURAIL 2.0 COUNTERMEASURES SELECTION

EDITING OF A RAILWAY STATION

After adding a station to the railway infrastructure, the user can enter into a dedicated screen where the station can be modelled in detail. (Figure 10)

The user can draw on the map the areas present in the station, indicating their names, and the software can automatically compute their dimensions in m^2. Moreover, in this page is also possible to indicate the expected crowding for each hour from 00:00 to 23:00 and they can be specified for weekdays, Saturday and Sunday.

FIGURE 10: SECURAIL 2.0 STATION EDITING

The user has also the possibility to edit the areas previously created, choosing the economic value and the type that is used by the software to identify the type of area: Control Room, Corridor, Ticket Office, Hall, Wating Room, and Platform. There is also the possibility to create an area and specify its dimension by simply adding a new card.

There is also the possibility to add the assets present in each area by clicking on Details which is present on each card. When clicking on this link the user is redirected to another page where the asset can be added. It can be specified the economic value of each asset, the type of the asset, and the number of assets of that type present in the area. (Figure 11)

FIGURE 11: SECURAIL 2.0 ASSET EDITING

EDITING OF A RAILWAY SECTION

The section of a network can be modified in similar ways of the stations. (Figure 12) After having created the section, the user can specify which assets are present in the selected section assigning them a name, value, and type. Moreover, there is also the possibility to specify the length of the section, the percentage of paths bridges and under tunnels, the number of crossings, and the number of tracks.

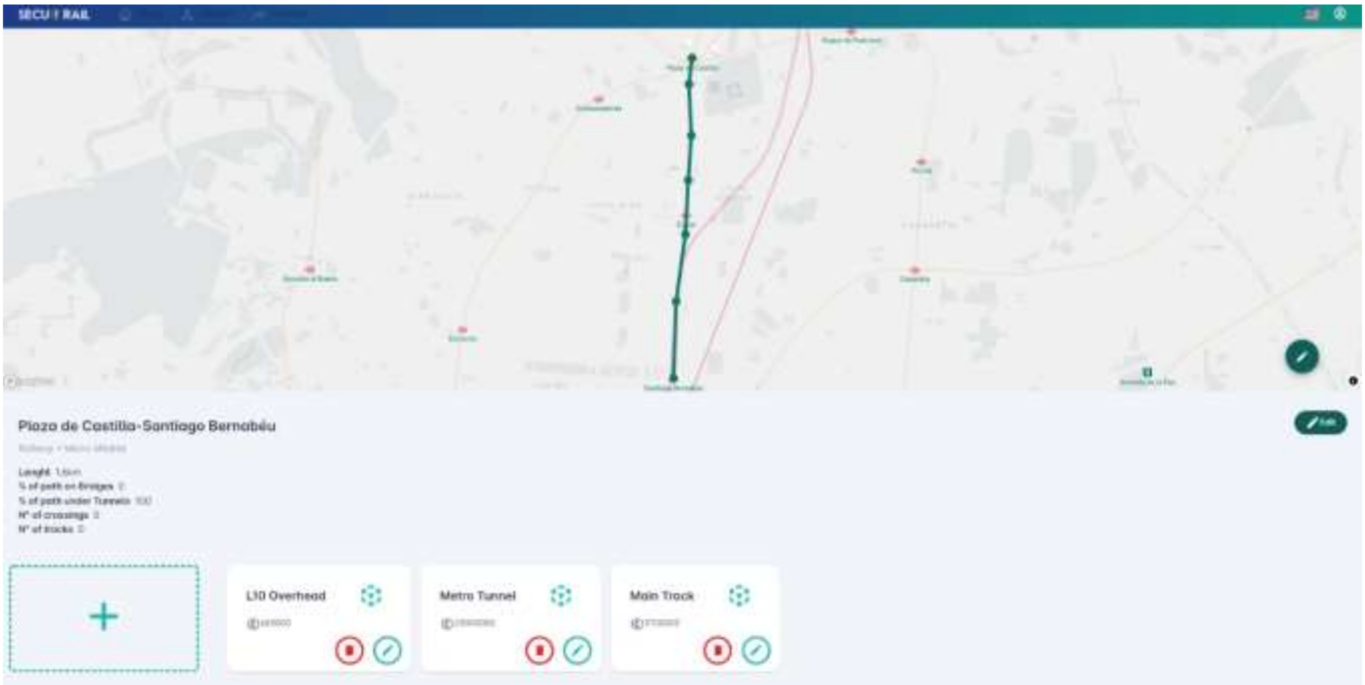


FIGURE 12: SECURAIL 2.0 SECTION EDITING

4. Set up and launch of the risk analysis

This section seeks to explain how the user can create configurations and analyse them and to explain in detail what happens in the risk analysis algorithm, including different steps and formulas. Obviously, the quality of the results provided by the tool is strongly depended on the quality of the data entered by the user.

The algorithm used to compute the risk in SecuRail is capable of handling serval types of data as input and it has already been outlined in deliverable D3.2. [6] The data that the algorithm requires are:

- The structure and features of the railway infrastructures.
- The model of the stations with their areas and respective assets
- The number of people present in the stations at given timeframes
- The countermeasure deployed to the various element presents in the model
- The services provided by the element presents in the model
- The specification of the threats
- The specifications of the impacts and consequences

These data are used by the algorithm to firstly, generate possible scenarios and then to compute the likelihood, the impact and associated risk of the scenario.

The model used by the algorithm implemented in this tool is based on a tree structure. It has been chosen to adopt this type of structure because in such way it is possible to track how every event contributes to the overall risk in a simple way. It is simlar to the approach used in the Event Tree Analysis, which is a standard technique used normally in risk assement and accident analysis.

4.1 Importance of railway structure

The tree model structure used in SecuRail (Figure 13), like the Event Tree Analysis, adopts a top-down approach in which the triggering event is a threat against a certain target present in the network which generates several, even diverse, impacts. The mentioned propagation of impact is strongly dependent on the structure of the network considered, since the impacts are generated and propagated depending on the connection among the elements in the network. The impacts generated are mitigated by the countermeasures present in the network which have the capability to mitigate or eliminate the effects of those impact and contribute to the generation of various outcomes.

One of the main differences compared to classical event tree is the possibility to represent the railway network as a graph. Indeed, the tree approach is used to represent a scenario occurring because of a threat, but within the same network it is possible to have several scenarios (and indeed several trees).

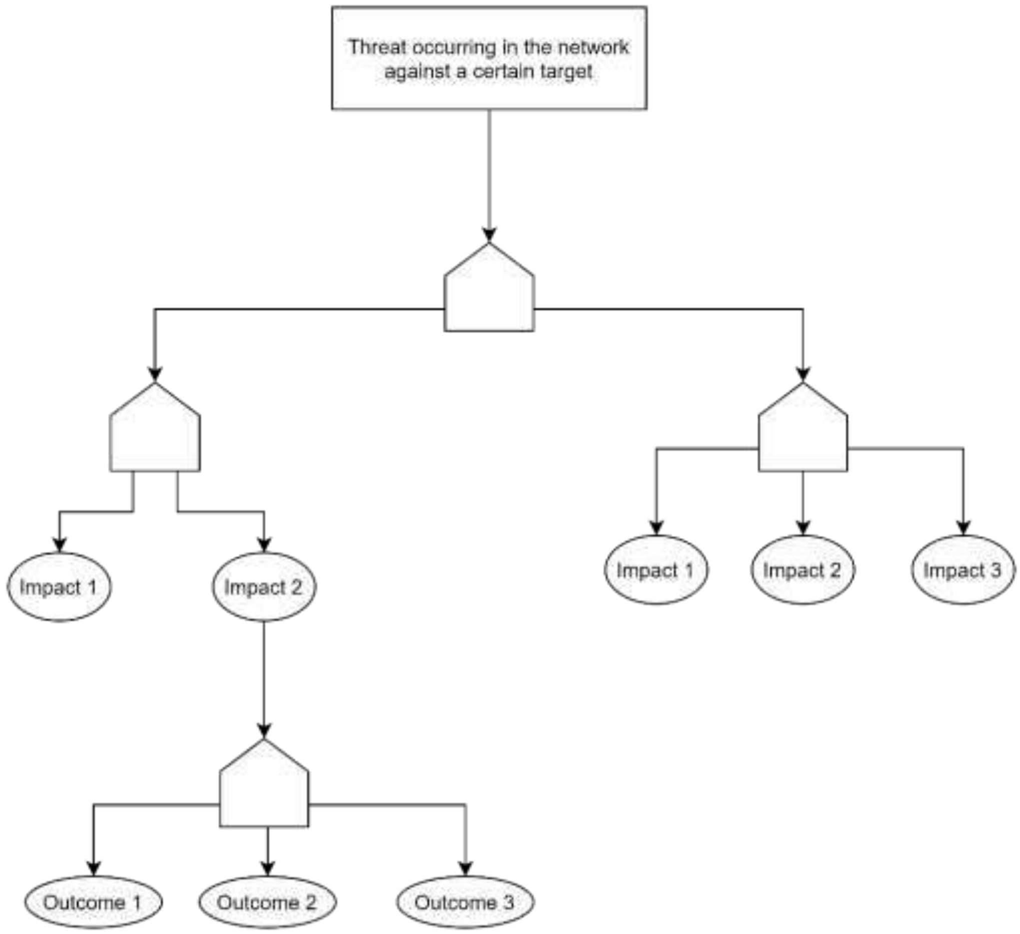


FIGURE 13: TREE MODEL

The algorithm created for this tool (Figure 14) can be subdivided in four steps:

1. **Scenario Generation**: depending on the parameters inserted by the user (network structure, assets, countermeasures, threats, targets, etc.) the scenario is generated.
2. **Scenario Simulation**: the previously generated scenario is simulated, taking into account the applied countermeasures and the cascading effect (which is responsible for the propagation of the threats and generations of the related impacts), and the various outcomes are generated.
3. **Likelihood Calculation**: after the outcomes are generated the corresponding likelihood is computed, starting with the computation of the probabilities related to the triggering event.
4. **Impact Calculation**: the effect of each outcome is computed in monetary terms, taking into account its related fatalities, injuries, physical damages and out of service.

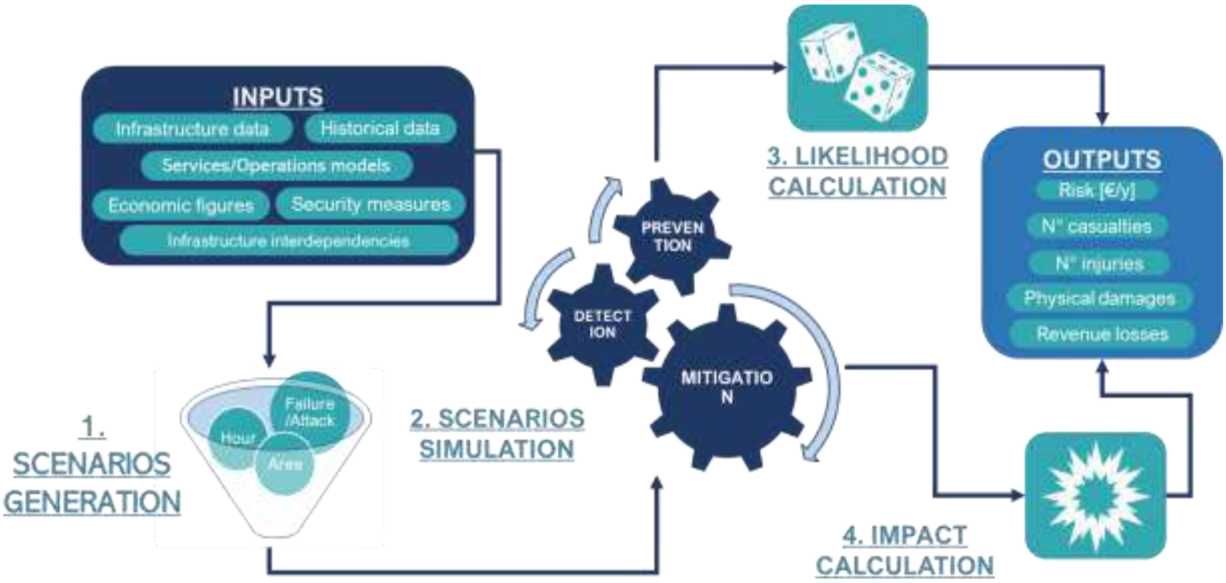


FIGURE 14: SECURAIL 2.0 ALGORITHM

4.2 Cascading Effect, propagation of effects on a network

As previously stated, the algorithm used by SecuRail is based on a tree model structure, this specific structure facilitates the propagation of impacts in the modelled network. As said above, this is fundamental for the cascading effect since when something affects a parent node in the tree model the same will affect the corresponding child nodes. Another important aspect related to this model is that threats are intended to be propagated from the parent node to the children but not vice versa, respecting the hierarchy of the model of the infrastructure presented below. The rationale of this rule is avoiding to incur an infinite loop. However, since disruption of an asset is causing effects also on services, it is considered within the analysis that a damage to a small asset (e.g. a ticket machine) can cause degradation of the service offered by the whole station.

The tree model operates a fundamental role in the computation of the risk in the algorithm. (Figure 15) The computation of the risk begins with generation of the first impact on an element of the network. The computation is done for each possible magnitude of the impact, and depending on several parameters, such as the presence and effectiveness of the countermeasures, several outcomes could be generated. The impact on a specific element of the network could be Prevented, Defused, Mitigated, or Not mitigated and diverse outcomes could arise. Finally, the outcomes are propagated to the child nodes and the process is repeated.

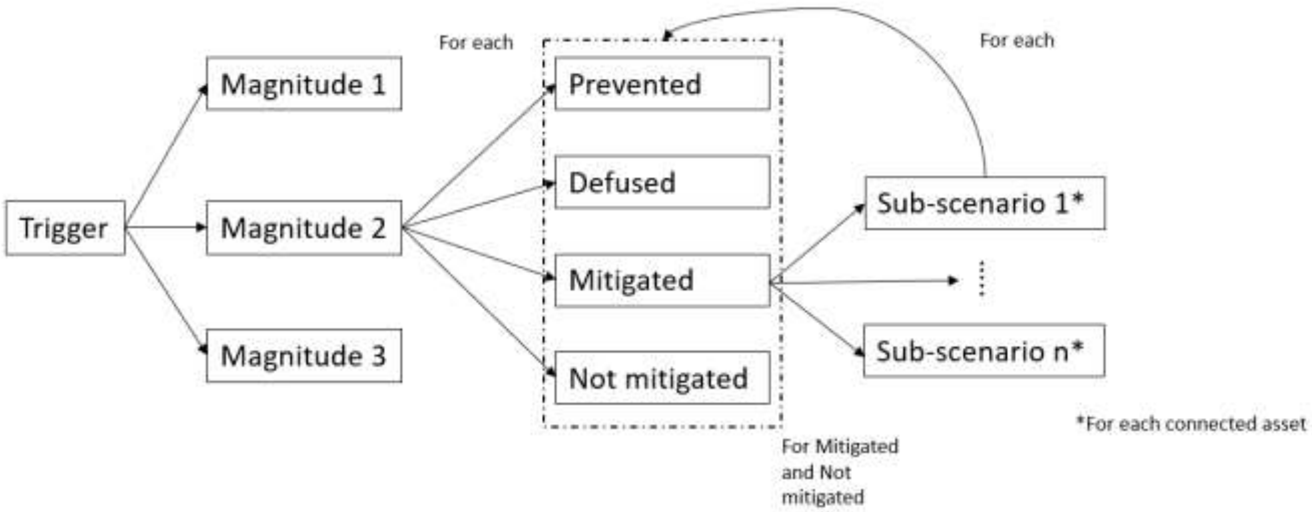


FIGURE 15 : PROCESS IMPLEMENTED

4.3 Inputs & Initial Data

In order to properly work the algorithm for the computation of the risk requires several parameters. The value that the user is required to insert in the tool are:

- List of the areas present in the network $A_i = [a_1, a_2, \ldots, a_i]$
- Time slots that need to be considered $T_i = [t_1, t_2, \ldots, t_j]$
- List of all the possible threats $TH_i = [th_1, th_2, \ldots, th_k]$
- Estimate occupancy of an area in a specific timeslot $EO_{ij}(A_i, T_j) \geq 0$
- The economic value of each area $EVA_i(A_i)$

Other starting parameters and initial computation that are present in the database of the tool are:

- The economic value of a human life VSL
- The tree levels of magnitude $M_z = [m_1\ m_2\ m_3]$, which represents the intensity of a threat
- The probability of a specific attack $0 < POA_{tot} < 1$
- The probability of a certain threat $P(TH_k) = [P(th_1), P(th_2), \ldots, P(th_k)]\ ;\ \sum_{z=1}^{3} P(TH_k) = 1$
- The probability of a certain threat with a certain magnitude $P(TH_k, M_z) = [P(TH_1, M_1), P(TH_k, M_2), P(TH_k, M_3)]\ ;\ \sum_{z=1}^{3} P(TH_k, M_z) = 1$
- The total value of an area $TVA_{ij} = VSL * EO_{ij} + EVA$

4.4 Scenario generation

As previously mentioned, the starting step of the algorithm is the generation of a feasible scenario. A scenario in this case is characterised by three elements: threat, target, and time of occurrence. (1)

$$Scenario(Threat, Target, Time of occurence) \quad (1)$$

Threat and target are fundamental in the identification of a scenario in order to understand the corresponding impacts and their relative propagation on the network elements, the time of occurrence is needed in order to define all the parameters that depends on the time, like for example the occupancy. The scenario is then subdivided in sub-scenarios (2), which, as said before, depend on the type of magnitude and the type of outcome.

$$Sub - scenario(Threat, Magnitude, Target, Timeofoccurence) \quad (2)$$

The value of the magnitude is strongly related to the means of the attacker and the corresponding strength. In this tool three levels are used: Low, Medium, and High. This means that for each scenario, tree sub-scenarios are arranged based on the likelihood of perpetrating the type of attack considered with less or more intensity.

The equation that is used to compute the probability of a specific scenario is:

$$P(S_{ijkz}) = POA_{tot} * \mathrm{P}(TH_k) * \mathrm{P}(TH_k, M_z) * \mathrm{IM}(A_i, T_j) \quad (3)$$

4.5 Scenario simulation

Once an impact hit an element on the network infrastructure, it is expected that the other elements which are linked to the targeted one in the model structure will be also affected by the impact and could even generate a consequent impact. (3)

$$Impact(Sub - scenario, SecondaryTarget) \quad (4)$$

This process is not immediate, there is the need to start taking into account the effects that the countermeasures have on the impacts. Since the countermeasures are directly applied to the element of the network that can be targeted by threats, they can even block the propagation of the impact and reduce the damages.

The application of the countermeasures can generate four diverse outcomes: (Figure 16)

- **Prevented**: when the impact is prevented, there are no impacts on the element targeted and the propagation stops.

  The total efficiency of an area which is in Prevention is:

  $$EP_{tot}^{sec}(A_i) = 1 - [(1 - P_1^{sec}) * (1 - P_2^{sec}) * \dots * (1 - P_m^{sec})] \quad (5)$$

  The probability of outcome in this case is:

  $$P_{SS1}(S_{ijkz}) = \mathrm{P}(S_{ijkz}) * EP_{tot}^{sec}(A_i) \quad (6)$$

- **Defused**: an impact is defused when the countermeasures are effective in not letting it generate any damage.

  The total efficiency of the of an area in Defusion is:

  $$EF_{tot}^{sec}(A_i) = 1 - [(1 - F_1^{sec}) * (1 - F_2^{sec}) * \dots * (1 - F_m^{sec})] \quad (7)$$

  The probability of outcome in this situation is:

  $$P_{SS2}(S_{ijkz}) = \mathrm{P}(S_{ijkz}) * (1 - EP_{tot}^{sec}(A_i)) * (ED_{tot}^{sec}(A_i)) * EF_{tot}^{sec}(A_i) \quad (8)$$

- **Mitigated**: in this situation the impact happens but its effects are mitigated thanks to the countermeasures applied.

  The total efficiency of an area with the impacts Mitigated is:

  $$EM_{tot}^{sec}(A_i) = 1 - [(1 - M_1^{sec}) * (1 - M_2^{sec}) * \dots * (1 - M_m^{sec})] \quad (9)$$

  The probability of outcome in this case depends on the level of Magnitude, with low magnitude the equation is:

$$P_{SS3}(S_{ijk1}) = \mathrm{P}(S_{ijk1}) * (1 - EP_{tot}^{sec}(A_i)) * [(1 - ED_{tot}^{sec}(A_i)) + (ED_{tot}^{sec}(A_i) * (1 - EF_{tot}^{sec}(A_i)))] * EM_{tot}^{sec}(A_i) \quad (10)$$

  The probability of outcome with medium magnitude is:

$$P_{SS5}(S_{ijk2}) = \mathrm{P}(S_{ijk2}) * (1 - EP_{tot}^{sec}(A_i)) * [(1 - ED_{tot}^{sec}(A_i)) + (ED_{tot}^{sec}(A_i) * (1 - EF_{tot}^{sec}(A_i)))] * EM_{tot}^{sec}(A_i) \quad (11)$$

The probability of outcome with high magnitude is:

$$P_{SS7}(S_{ijk3}) = \mathrm{P}(S_{ijk3}) * (1 - EP_{tot}^{sec}(A_i)) * [(1 - ED_{tot}^{sec}(A_i)) + (ED_{tot}^{sec}(A_i) * (1 - EF_{tot}^{sec}(A_i)))] * EM_{tot}^{sec}(A_i) \quad (12)$$

- **Not Mitigated**: when an impact is not mitigated it means that the countermeasures applied have no effect or that there are no countermeasures applied to the targeted element.

  In this case the total efficiency cannot be computed, just the probability of outcome can be calculated.

  For the low magnitude the equation is:

$$P_{SS4}(S_{ijk1}) = \mathrm{P}(S_{ijk1}) * (1 - EP_{tot}^{sec}(A_i)) * [(1 - ED_{tot}^{sec}(A_i)) + (ED_{tot}^{sec}(A_i) * (1 - EF_{tot}^{sec}(A_i)))] * (1 - EM_{tot}^{sec}(A_i)) (13)$$

For the medium magnitude:

$$P_{SS6}(S_{ijk2}) = \mathrm{P}(S_{ijk2}) * (1 - EP_{tot}^{sec}(A_i)) * [(1 - ED_{tot}^{sec}(A_i)) + (ED_{tot}^{sec}(A_i) * (1 - EF_{tot}^{sec}(A_i)))] * (1 - EM_{tot}^{sec}(A_i)) (14)$$

For the high magnitude the equation is:

$$P_{SS8}(S_{ijk3}) = \mathrm{P}(S_{ijk3}) * (1 - EP_{tot}^{sec}(A_i)) * [(1 - ED_{tot}^{sec}(A_i)) + (ED_{tot}^{sec}(A_i) * (1 - EF_{tot}^{sec}(A_i)))] * (1 - EM_{tot}^{sec}(A_i)) (15)$$

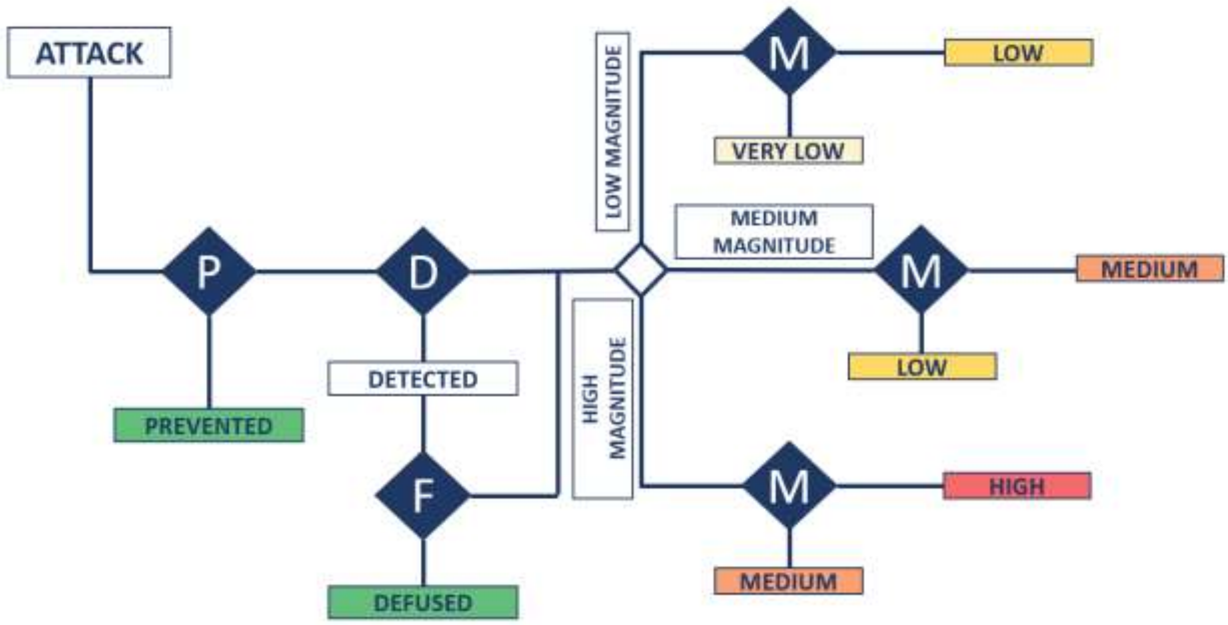


FIGURE 16: POSSIBLE OUTCOMES

The sum of the likelihood of all the outcomes for a possible scenario is equal to one since they cover all the possibilities for a given threat.

In order to estimate the outcomes, each countermeasure is defined by several parameters that define the efficiency of the countermeasures and the reduction of likelihood and damages. These parameters are scores in prevention, detection, defusion and mitigation.

Since one of the main features is the cascading effect, the outcomes Mitigated and Not Mitigated can propagate to the connected element of the model infrastructure generating new impacts.

In order to propagate the impact and generate consequent impacts, a specific mapping is required for the SecuRail algorithm. (Figure 17)

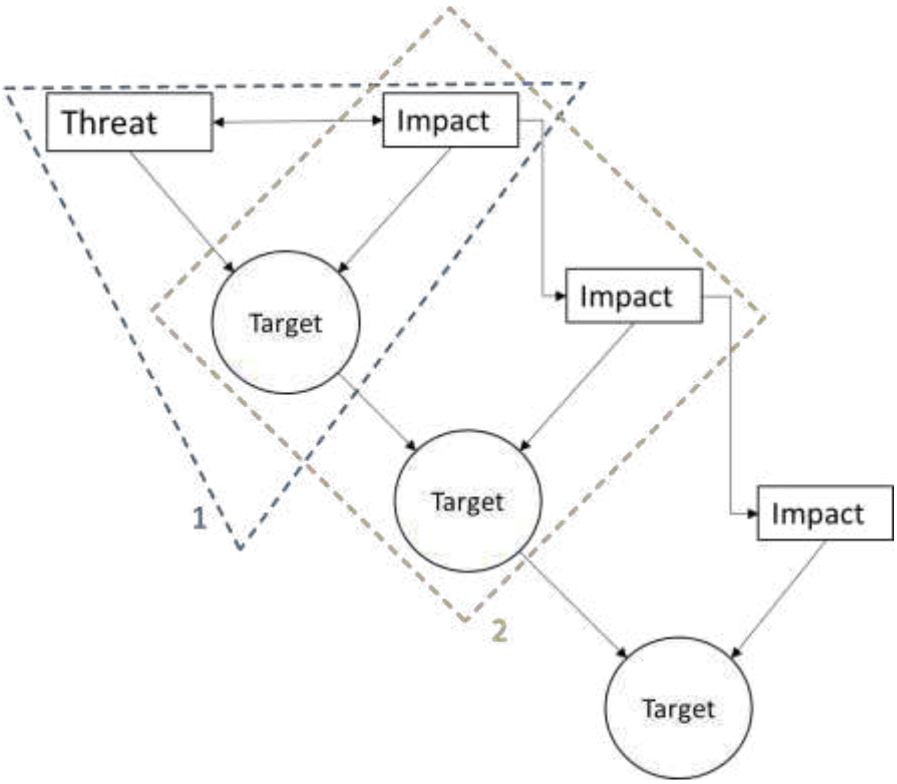


FIGURE 17: MAPPING FOR THE PROPAGATION

In the figure above it can be seen that the mapping can be divided in two parts.

In the first section of the mapping (the blue triangle in the figure), it can be seen that the threat is mapped to a target, and both are mapped to an impact. This is due to the fact that only some targets can be targeted by some threats, and depending on the target and the threat, a specific impact is generated. For example, an asset like the IT network service cannot be considered a primary target of a bombing attack but the platform yes and an asset targeted by a bombing attack will generate an explosion impact. (see Asset-Threats matrix in the appendix of [1])

The second section of the mapping (the orange square) links the starting generated impact to the subsequent one, and the new target to the old one. Depending, on the starting target and impact, new element of the network can become new target and they can even generate new and different impacts.

4.6 Likelihood calculation

As previously stated, for each of the outcomes generated the algorithm computes the likelihood of occurrence.

This kind of computation starts with the POA, which is present in the software and the user does not have to insert it manually. It is a value which is estimated using historical data and with the analysis of the current geopolitical situation, these are values present on the database of the platform. The estimation of POA is done considering geographical position when possible; this is relevant, of course, when likelihood of terroristic attacks is estimated, since it depends on specific pollical situations. It is important to highlight that, diverse threats have diverse probabilities, so the POA is computed using the following equation:

$$POA(TH_k, M_z) = [P(TH_k, M_1)P(TH_k, M_2)P(TH_k, M_3)] = \sum_{z=1}^{3} P(TH_k, M_z) \quad (16)$$

The meaning of this formula is that the percentage for specific threat is subdivided among the three level of magnitude.

The result of such equation is not the finale value of the POA, to compute the finale value a few steps are required:

1. The likelihood is subdivided among the elements of the network. The values are split taking into account that some elements are more critical than others in the supply of services or because they have higher cost, or they are more relevant in ensuring the security.
2. The likelihood is also divided according to the time frame that is being considered, since some threats have more probability of happening when there are more people present.
3. The likelihood can be reduced by the overall protection score that is relative to the target considered.
4. The likelihood is reduced of a predefined percentage each time an impact generates a new threat, since the cascading effect is not deterministic.

The final value of the likelihood is a frequency assigned to each outcome generated by the simulation of the scenario.

4.7 Impact calculation

The computation of the impact is conducted at the same time of the estimation of the likelihood. For every outcome generated the tool computes:

- Percentage of physical damage of the target
- Average number of injuries
- Average number of fatalities
- Average hour of interruption of services
- Expected economic losses due to physical damage
- Expected economic losses due to injuries
- Expected economic losses due to fatalities
- Expected economic losses due to interruption of service

Also in this case, the estimation of the impact is strongly dependant on the type of threat, target, impact, and magnitude.

The final value of the impact calculation is the estimation of total economic losses, which is computed using the equation below.

$$EL_{tot} = EL_{fatalities} + EL_{injuries} + EL_{physical\_damage} + ELIS_{tot} \tag{17}$$

COMPUTATION OF PHYSICAL DAMAGES

Concerning the physical damages, it is estimated as a percentage that symbolizes how much the integrity and functionality of an element has been affected.

To compute the economic losses at first there is the need to compute the physical damage function, which strongly depends on the type of attack and level of magnitude. But it important to highlight that there are two different types of physical damage functions, which depend on the type of outcome: Mitigated (18) or Not Mitigated. (19)

$$PD_{mitigated}(TH_k, M_z) \tag{18}$$

$$PD_{not\_mitigated}(TH_k, M_z) \tag{19}$$

$$PD(th_k, m_k) = PD_{base} \tag{20}$$

Finally, the equation used to estimate the economic losses related to physical damages is:

$$EL_{physical\_damges} = PD(th_k, m_k) * EVA_i(A_i) \tag{21}$$

NUMBER OF INJURIES AND FATALITIES

Since some threats can affect people, the algorithm has also the capability to estimate the number of injuries and fatalities related to the impacts, also presented as related economic losses.

The first step in the estimation of the number of people involved in an attack depending on the type of attack and type of magnitude, such computation is possible thanks to the use of a hit function which is a value saved in the database of the tool. (22)

$$People_{hit} = EO(a_i, t_j) * HF(th_k, m_z) \tag{22}$$

Then in order to compute the number of injuries a parameter related to the fatality of an attack is required. This parameter is used for a gaussian distribution in order to allocate the number of injuries among the categories of the Abbreviated Injury Scale (AIS) [7], that are used to describe the severity of the injuries:

- **AIS 1**: Minor
- **AIS 2**: Moderate
- **AIS 3**: Serious
- **AIS 4**: Severe
- **AIS 5**: Critical
- **AIS 6**: Lethal

The AIS is computed for each attack and magnitude, but, obviously, only for the outcomes Mitigated (23) and Not Mitigated. (24)

$$AIS_{mitigated}(th_k, m_z) = [AIS_1, AIS_2, AIS_3, AIS_4, AIS_5, AIS_6] \tag{23}$$

$$AIS_{not\_mitigated}(th_k, m_z) = [AIS_1, AIS_2, AIS_3, AIS_4, AIS_5, AIS_6] \tag{24}$$

The AIS distribution has been created by the US Department of Transportation [8]. According to this methodology, the economic losses is estimated as a fraction of the VSL. (Table 9)

TABLE 9: FRACTION OF VSL

AIS 1	AIS 2	AIS 3	AIS 4	AIS 6
0,003	0,047	0,105	0,266	0,593

So, the computation of the number of people involved subdivided into the AIS category is done applying the following equations.

$$People_{AIS1} = People_{hit} * AIS_1 \tag{25}$$
$$People_{AIS2} = People_{hit} * AIS_2 \tag{26}$$
$$People_{AIS3} = People_{hit} * AIS_3 \tag{27}$$
$$People_{AIS4} = People_{hit} * AIS_4 \tag{28}$$
$$People_{AIS5} = People_{hit} * AIS_5 \tag{29}$$
$$People_{AIS6} = People_{hit} * AIS_6 \tag{30}$$
$$N_{fatalities} = People_{AIS6} \tag{31}$$
$$N_{injuries} = \sum_{p=1}^{5} People_{AIS_p} \tag{32}$$

With those values, it is possible to estimate the economic losses related to number of fatalities using the equation (33).

$$ES_{fatalities} = VSL * N_{fatalities} \tag{33}$$

On the other hand, for the computation of the economic losses (34) for the injuries requires to take into account another function called MAIS. (35)

$$MAIS = [MAIS_1, MAIS_2, MAIS_3, MAIS_4, MAIS_5] \tag{34}$$

$$EL_{injuries} = \sum_{p=1}^{5} People_{AIS_p} * MAIS_1 * VSL \tag{35}$$

The value used for VSL in SecuRail is equal to € 3.370.891, which is an average estimated for EU28 [9].

ESTIMATION OF OUT OF SERVICE

The other aspect that is fundamental for the correct estimation of the economic losses is the estimation of the out of service. In this estimation there is the need to take into account the value of the element of the network considered, and the salary of the worker that could be required for the restoration of the functionalities.

It has been chosen to consider those parameters because the time required to repair an asset is proportional to its cost, and also the choice of replacing or fixing an asset is strongly related to the corresponding costs.

Taking all of this in consideration, the formula used to compute the time of out of service is:

$$Toos(Value, Damage, Type) = \begin{cases} T_{fix}, & C_{fix} < C_{rep} \\ T_{rep}, & C_{rep} \geq C_{fix} \end{cases} \tag{36}$$

Where T_{fix}(37) is the estimation of the time required to fix the asset, T_{rep} (38) is the time required to replace the asset, C_{fix} (39) is the cost of repairing the asset, and C_{rep} (40) is the cost of replacing the asset.

$$T_{fix}(Damage, Type) = Type_{RepairRate} * Damage + 0.5 \tag{37}$$

$$T_{rep}(Value) = 6 * 10^{-16} * Value^3 + 8 * 10^{-10} * Value^2 + 0.0004 * Value + 1 \tag{38}$$

$$C_{fix}(Damage, Type) = Type_{RepairCost} * People_{Needed}(Damage) * T_{fix}(Damage, Type) \tag{39}$$

$$C_{rep}(Value) = Value \tag{40}$$

$$People_{Needed}(Damage) = -1 * 10^{-10} * Damage^2 + 0.0002 * Damage + 1 \tag{41}$$

Where $Type_{RepairCost}$ and $Type_{RepairRate}$ are respectively the salary of one day of work for the people required to repair an asset and the time required to repair one euro of damage on the considered asset.

So, the estimation of the economic losses for the out of service depend on either if it chosen to repair the asset or to substitute it.

$$ELIS_{tot} = \begin{cases} C_{fix}, & C_{fix} < Threshold \\ C_{rep}, & C_{rep} < Threshold \end{cases} \tag{42}$$

The value of the threshold is predetermined for each type of asset present in the network and saved on the database.

4.8 Risk computation

After conducting all the previous steps, it is possible to compute the overall risk score, which is computed for each possible outcome of the scenario. The formula usually used to estimate the risk score:

$$Risk = Likelihood \; x \; Expected \; damages \tag{43}$$

This equation in SecuRail becomes:

$$RiskLevel_i = P_{SSi} * \; EL_{tot} \tag{44}$$

The risk score is expressed in monetary terms (€/year) since the likelihood is expressed in number of expected events per year and the expected damages in euros. The risk score of a scenario is considering the threat set by the user as the trigger of the scenario (e.g. the bombing attack), as well as all the consequent impacts caused by the initial threat.

4.9 Real-time risk assessment

SecuRail is expected to be able to perform the estimation of the risk in almost real-time. This process can be triggered by an alert/notification generated by sensors or software that monitor the current state of the network.

The computation of the risk is fast in order to be able to provide immediately the user with useful information. This is fundamental in order to be able to analyse the potential scenario that could be generated by the imminent threat or suspicious activity.

The algorithm applied for this type of application is almost identical to the one described above. The information generated by the sensors become the initial data that is required by the algorithm. The data fundamental for the generation of the scenario is like the one requires previously:

- The type of threat detected (or that can be generated by the suspicious phenomena/anomalies detected)
- The target
- Date and time of occurrence
- The device that has detected the threat

One of the main differences from the algorithm used before in the static case is in the computation of the likelihood. In this case since the alert is generated when something is happening the likelihood is very high, almost close to one. It is estimated based on the type of alert received, if the threat is occurred the likelihood is obviously set to one, otherwise if the alert is generated by a suspicious activity the likelihood is set with a value lower than one since there is not the absolute certainty that the threat will happen. Since these threats are generated by a monitoring tool there is also the need to take into account the possibility that a false alarm is generated. So, when a threat is detected, the likelihood is not set exactly to one since it also considered the possibility of having received a false alarm.

The precision of the device used to generate the alert is computed using the equation (44).

$$Precision = \frac{True \; Positive}{True \; Positive + False \; Negative} = \frac{True \; Positive}{Total \; Predicted \; Positive} \tag{45}$$

The equation used for the computation of the likelihood, in this case, is defined as:

$$Estimated\ Likelihood = Threat\ Likelihood * Precision \tag{46}$$

$$Threat\ likelihood = \begin{cases} = 1\ if\ the\ threat\ is\ detected \\ > 0\ \&\ < 1\ if\ a\ suspicious\ phenomena\ is\ detected \end{cases} \tag{47}$$

There is also the possibility that an alert could generate more than one malicious event, in this case the software computes all the possible scenarios and provides results for every possible scenario.

4.10 Algorithm implementation

The functionalities of the algorithms are implemented in the backend of the SecuRail tool. The backend can be seen subdivided in two parts one responsible for the computation of the risk and one responsible to manage all the specific elements related to railway sector. All these functionalities were already presented at a higher level in the deliverable D3.3. [10]

The Risk backend is responsible for modelling and keeping track of the relation between threats and their response. In this part of the backend are modelled the countermeasures, threats, targets, services, and other elements fundamental for the computation of the risk but not directly related to the rail infrastructure.

Concerning the Rail backend, it is the part responsible for managing everything specific to the railway environment. Here all the elements of the infrastructures: sections, lines, areas, etc. are managed.

4.11 Risk Analysis UI

The risk analysis can be executed in two ways, by clicking on the run button present on the card of the configuration or by selecting the tab "Scenario" present on the top of the page. In both cases the user is presented by the web page represented in Figure 18.

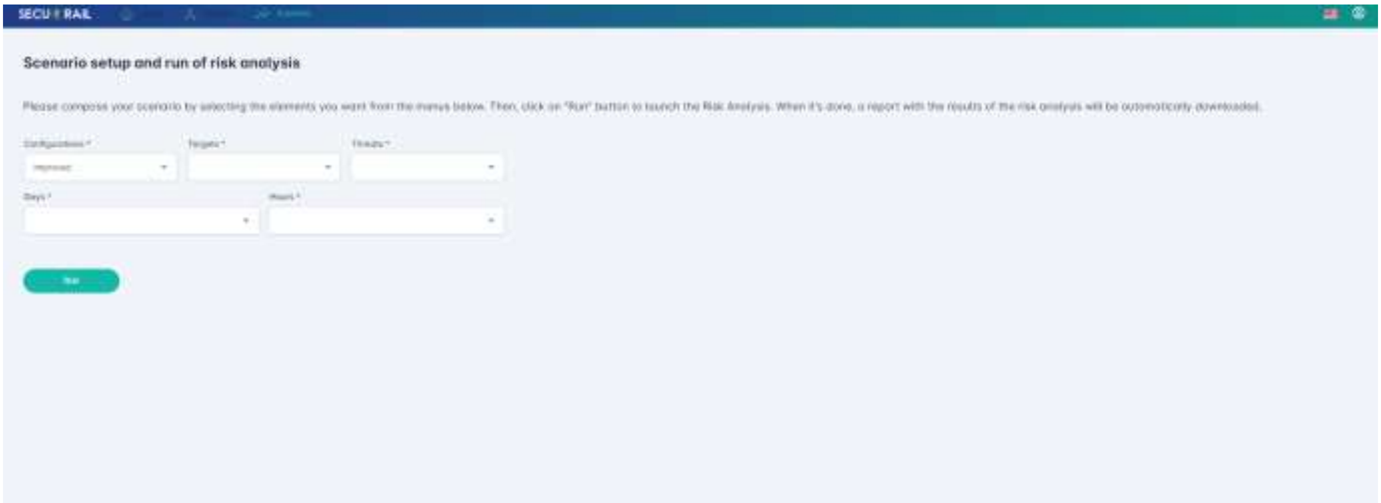
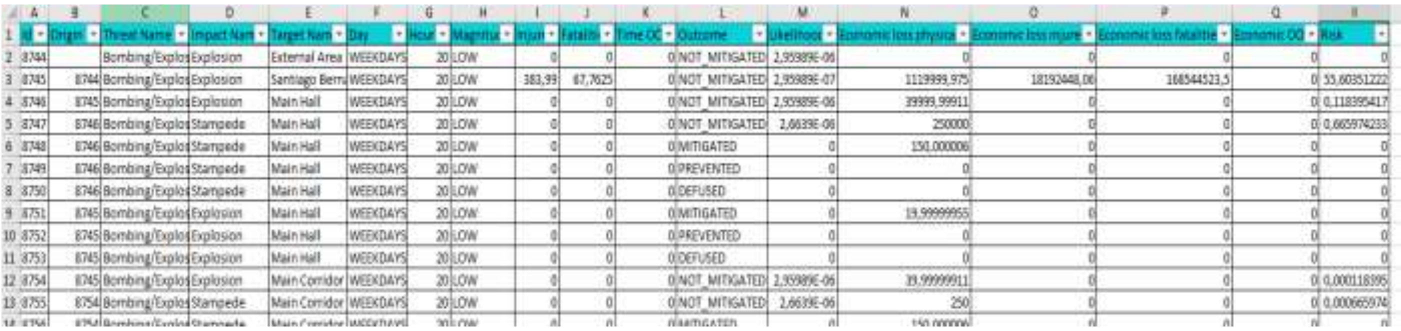


FIGURE 18: SECURAIL 2.0 SCENARIO SELECTION

In this page it possible to select the configuration of which it is wanted to perform the risk analysis, the threats the user want to analyse and the target(s). It is also possible to specify the date and the hours. After inserting all of the aforementioned values the computation of the risk can be performed. The result of the analysis is provided in two ways, with a dashboard and with an excel file.

The excel file, which is automatically downloaded after finishing the computation, provides the result in the most detailed way possible by listing in detail all the impacts generated by the triggering event, and the risk computed by all the possible outcomes and level of magnitude of the impact. (Figure 19)



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Id	Origin	Threat Name	Impact Nam	Target Nam	Day	Hour	Magnitu	Injuri	Fataliti	Time OC	Outcome	Likelihood	Economic loss physica	Economic loss injurie	Economic loss fatalitie	Economic OO	Risk
2	8744		Bombing/Explos	Explosion	External Area	WEEKDAYS	20	LOW	0	0	0	NOT_MITIGATED	2,959989E-06	0	0	0	0	0
3	8745	8744	Bombing/Explos	Explosion	Santiago Bern	WEEKDAYS	20	LOW	383,99	67,7625	0	NOT_MITIGATED	2,959989E-07	1119999,975	18192448,06	168544523,5	0	55,60351222
4	8746	8745	Bombing/Explos	Explosion	Main Hall	WEEKDAYS	20	LOW	0	0	0	NOT_MITIGATED	2,959989E-06	39999,99911	0	0	0	0,118395417
5	8747	8746	Bombing/Explos	Stampede	Main Hall	WEEKDAYS	20	LOW	0	0	0	NOT_MITIGATED	2,6639E-06	250000	0	0	0	0,665974233
6	8748	8746	Bombing/Explos	Stampede	Main Hall	WEEKDAYS	20	LOW	0	0	0	MITIGATED	0	150,000006	0	0	0	0
7	8749	8746	Bombing/Explos	Stampede	Main Hall	WEEKDAYS	20	LOW	0	0	0	PREVENTED	0	0	0	0	0	0
8	8750	8746	Bombing/Explos	Stampede	Main Hall	WEEKDAYS	20	LOW	0	0	0	DEFUSED	0	0	0	0	0	0
9	8751	8745	Bombing/Explos	Explosion	Main Hall	WEEKDAYS	20	LOW	0	0	0	MITIGATED	0	19,99999955	0	0	0	0
10	8752	8745	Bombing/Explos	Explosion	Main Hall	WEEKDAYS	20	LOW	0	0	0	PREVENTED	0	0	0	0	0	0
11	8753	8745	Bombing/Explos	Explosion	Main Hall	WEEKDAYS	20	LOW	0	0	0	DEFUSED	0	0	0	0	0	0
12	8754	8745	Bombing/Explos	Explosion	Main Corridor	WEEKDAYS	20	LOW	0	0	0	NOT_MITIGATED	2,959989E-06	39,99999911	0	0	0	0,000118395
13	8755	8754	Bombing/Explos	Stampede	Main Corridor	WEEKDAYS	20	LOW	0	0	0	NOT_MITIGATED	2,6639E-06	250	0	0	0	0,000665974
14	8756	8754	Bombing/Explos	Stampede	Main Corridor	WEEKDAYS	20	LOW	0	0	0	MITIGATED	0	150,000006	0	0	0	0

FIGURE 19: EXCEL REPORT

The other way in which the results are provided is through a dashboard which presents the results in an aggregated way in order to be more easily understandable by the user. (Figure 20) The values which are reported on this page are:

- The value of the risk
- The value of the risk corresponding to the diverse threats
- The breakdown of the risk according to the different threats
- The worst risk scenario presented with its corresponding impacts
- The map where the worst risk scenarios are geographically positioned

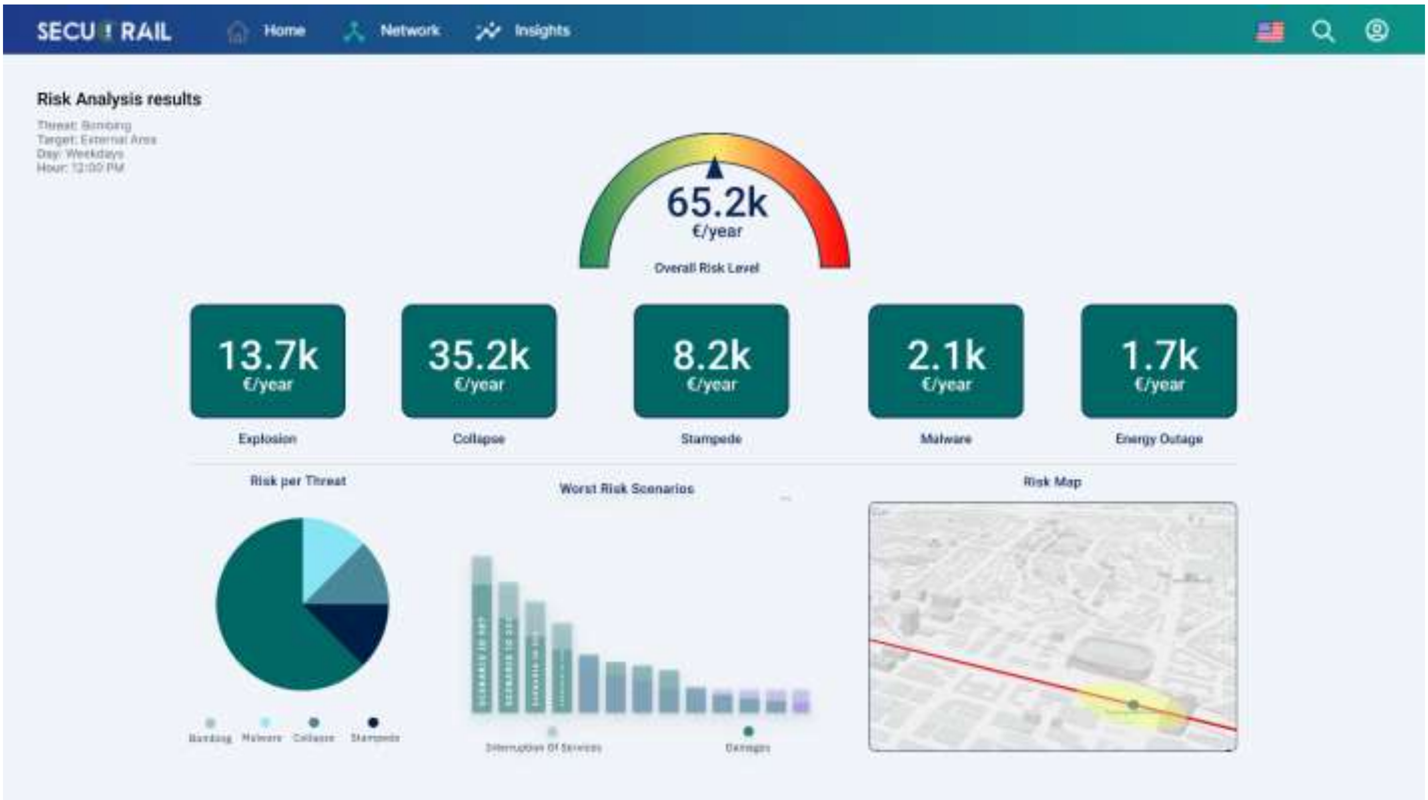


FIGURE 20: SECURAIL 2.0 DASHBOARD

REAL-TIME ALERT

As stated before, the risk analysis can be triggered both manually (by the user through the UI) or automatically if the tool receives an alert from the monitoring tools (see Chapter 6). The user can be indeed notified by events which are registered by sensor deployed on the network infrastructures and receive the results of real time risk computation based on the values received by the sensors. The alert is visualized as a notification appearing on the header of the app; in this notification, the user can confirm to run the risk analysis associated to the event which has been detected by the monitoring tools (to visualize results as usual) or to discard the alert. (see Figure 21)

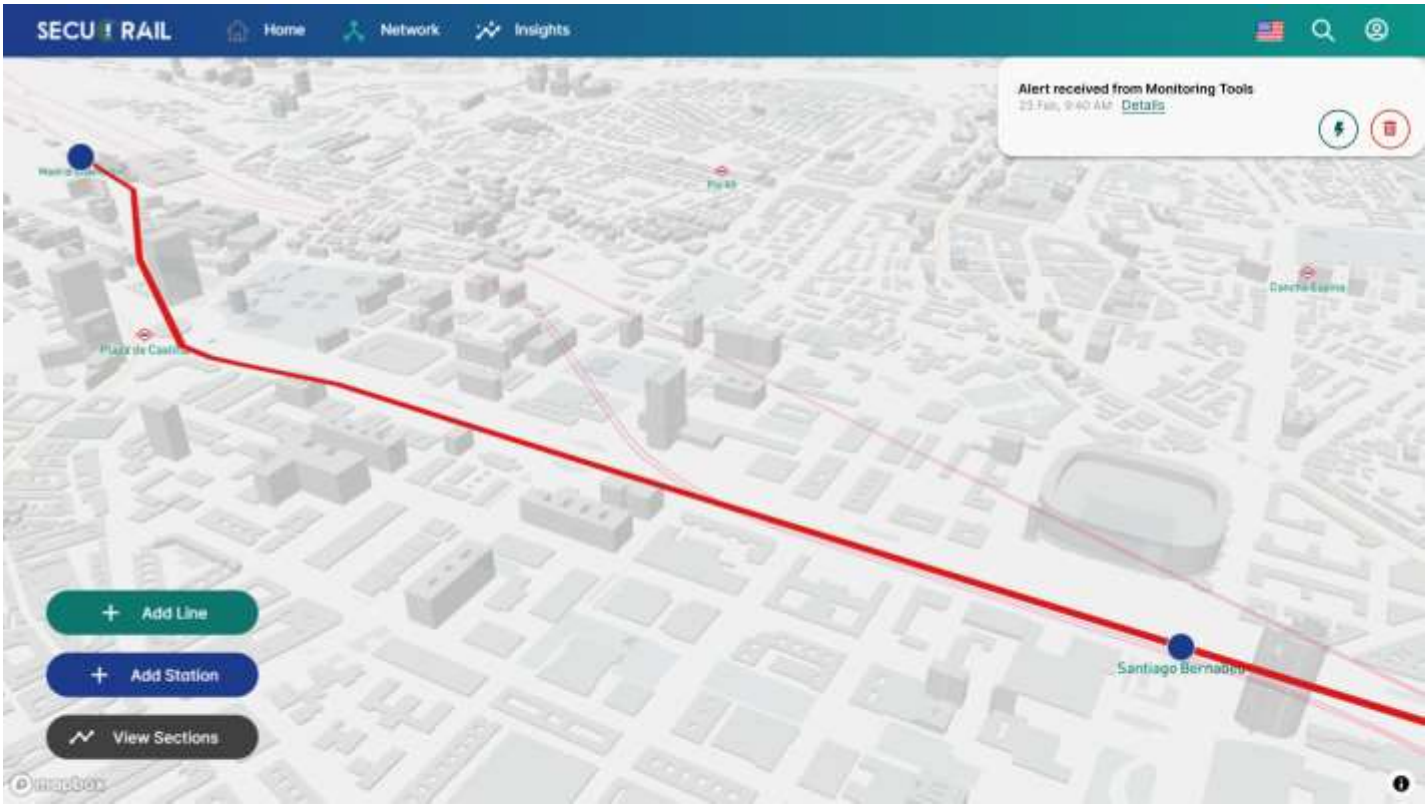


FIGURE 21: SECURAIL 2.0 REAL-TIME ALERT RECEIVED BY THE USER

5. Analysis of results

As described in the Chapter 2, there are two main ways in which the results of the risk computation are provided to the user. An analysis of the results was provided in a Confidential deliverable based on a use case scenario with security sensitive information, and some the following figures are taken from there and provided with a generic level of detail.

5.1 Excel document

As said previously, when the software completes the computation of the risk an excel file is immediately downloaded on the computer of the user.

The file generated consists of 18 columns and several rows (Figure 19), the number of rows depends on how many impacts are generated from the starting threat. The columns represent the parameters that are used to characterize all the impacts, these parameters are:

- ID of the event
- Origin, meaning the Id of the event (an initial threat or an impact) which have generated the event in the row
- Name of the threat
- Name of the impact
- Name of the target
- Day of occurrence
- Hour of occurrence
- Magnitude of the impact
- Number of injuries
- Number of fatalities
- Time of out of service

- Outcome of the impact
- Likelihood of the impact
- Value of the economic loss related to injuries
- Value of the economic loss related to fatalities
- Value of the economic loss related to out of service
- Risk level

One of the most important values that characterize each impact is the one in the column called Origin. All the rows have this value a part form the starting event. This value corresponds to the ID of an event, so this means that, when in a row is present a number in the Origin column, the corresponding event is the consequence of a previous impact. This value is fundamental in order to be able to track the history of the event and to see the propagation thanks to the cascading effect.

One of the advantages of having the results provided in such way is that it is easy to see the how the risk is shared among all the diverse threats, how easy it is to see how the events propagate on the network, and they can be processed easily using all the tools present in Excel.

Thanks to the functionalities present in Excel it is possible to visualize the data in an easy way thanks to the plots and it is possible to aggregate data in order to see the value of the risk subdivided by the type of threat, type of impact (Figure 22), level of magnitude (Figure 23), outcome (Figure 24), and type of economic loss (Figure 25). The data taken for the figure below is taken form the Metro de Madrid use case.

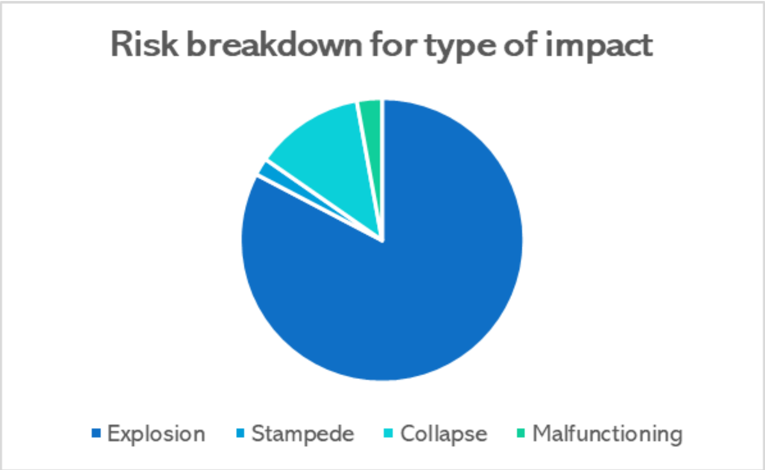


FIGURE 22: RISK VALUE BY TYPE OF IMPACT

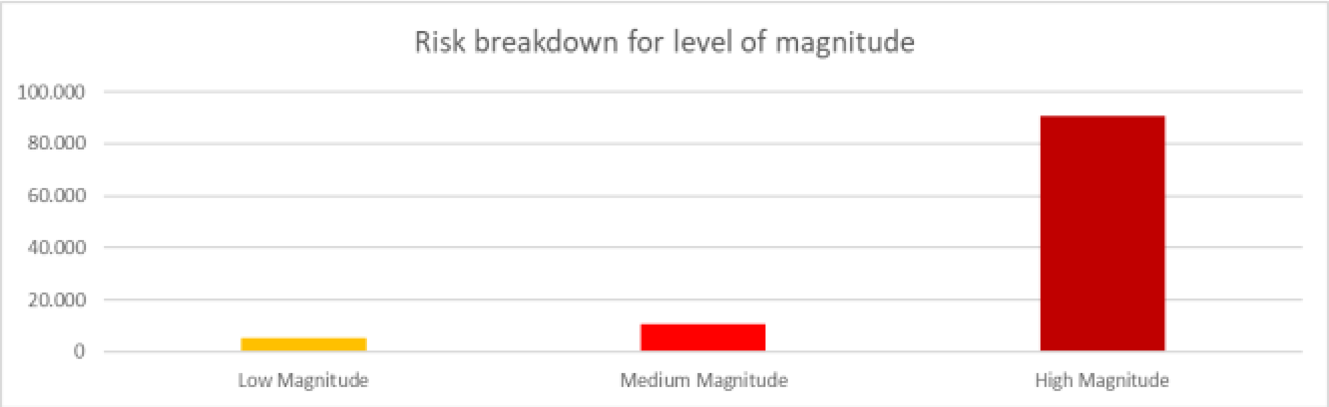


FIGURE 23: RISK BY LEVEL OF MAGNITUDE

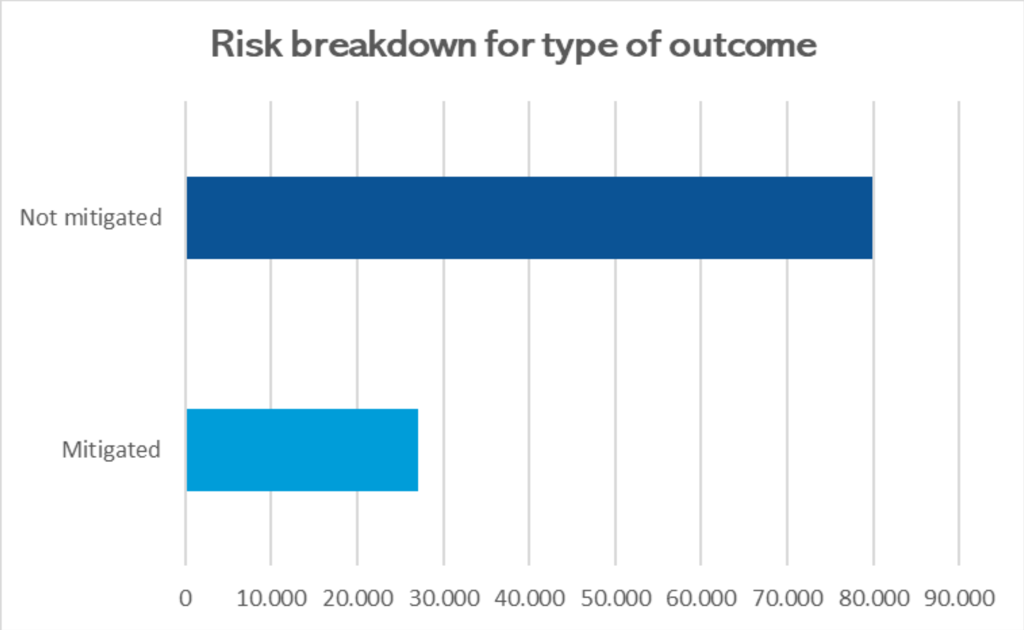


FIGURE 24: RISK VALUE BY TYPE OF OUTCOME

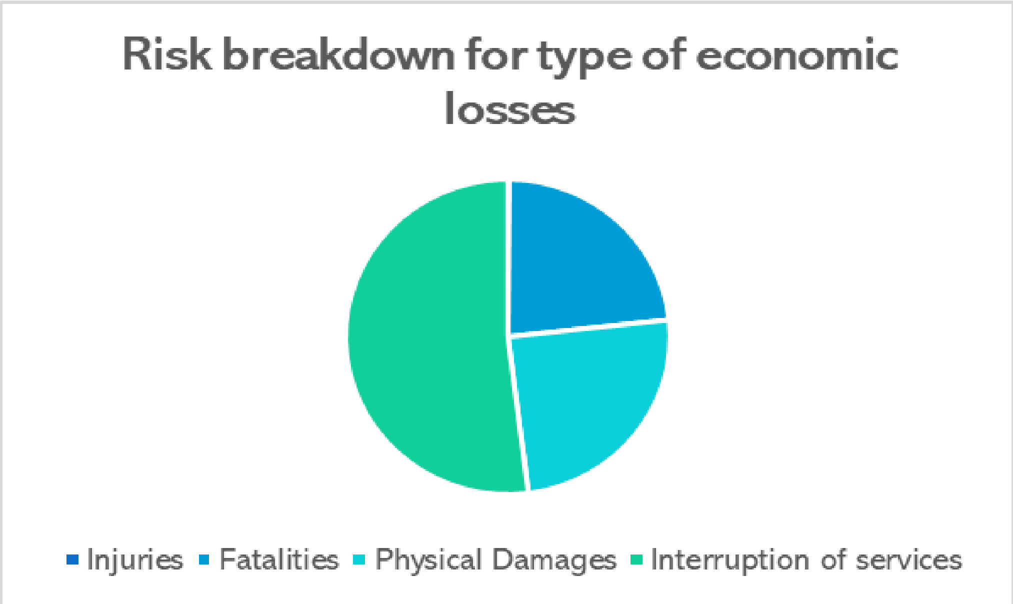


FIGURE 25: RISK BY TYPE OF ECONOMIC LOSSES

Another advantage of the data provided using an excel file is that the data generated by different configurations can be easily compared and the user can immediately see how, with the application of diverse countermeasures, the risk is modified.

5.2 Dashboard

Upon completing the risk analysis, the results are not only downloadable but also deployed on a dashboard. (Figure 20)

The dashboard provides to the user the most relevant information in an easy and aggregated way. The data displayed is the same that can be derived from the Excel file, so the overall risk score and the risk subdivided into type of threat, type of impact, level of magnitude, outcome, and type of economic loss.

Moreover, there is also a map in which there are displayed risk areas coloured by increasing shades of red depending on the gravity of the risk.

6. Integration with S4RIS platform

The SecuRail tool, as part of S4RIS platform, should be operationally integrated with relevant other tools in order to favour the data exchange and to increase its own capabilities. Furthermore, interoperability is a fundamental requirement to be met by such tools. This section addresses the main integration steps that have been performed during the development, i.e.:

- The integration with the main S4RIS platform, which enables the user to access to SecuRail tool.
- The integration with the monitoring tools, which enables the reception of real-time alerts to trigger automatic risk analysis
- The integration with BB3D tool, which enables a final estimation of the risk of explosive attack outside the railway station

6.1 Integration with S4RIS platform

This is the main integration at platform level, since it enables to access SecuRail tool from the S4RIS website. The workflow for this is simply that the user should enter into S4RIS website and select SecuRail tool by clicking on the logo. The user will then be re-directed to the SecuRail webapp or, alternatively, he/she can remain on S4RIS website and visualize SecuRail through an Iframe integration.

The integration currently requires the user to be authenticated only when accessing to SecuRail (using the SecuRail URL or through the Iframe, but SecuRail authentication provider can be prepared to implement single sign-on mechanism. In this option, the user can do the login to the S4RIS platform and then it can access to every tool included in the platform without re-entering again credentials.

The Json message that SecuRail sends to the other tools through the DMS contains information regarding station and lines present in the network, assets implemented, areas inside the stations, and service provided by the elements of the network. (all of these information can be seen in the forthcoming Deliverable D4.6).

Here is reported an example of Json message sent by the SecuRail tool:


```
{
   "network":{
      "id":"b80edfcc-5294-423f-ba03-da93af94e123",
      "name":"XXXX XXXX",
      "owner":"XXXXXXX",
      "country":"XX",
      "type":"RAILWAY",
```


In this first part of the message is specified the name, the owner and the country of the network contained in the Json and also the type of network.


```
      "stations":[
         {
            "id":"cebbc0ba-9239-4f7d-80d6-4976e4c03a6e",
            "name":"XXXXXXX XXXXXX",
```

```
"city":"XXXXX",
"economic_value":0,
"location":{
   "type":"Point",
   "coordinates":[
      -X.XXXXXX,
      XX.XXXXXX
   ]
},
```

Here the station of the network is identified specifying its name, the city and the coordinates.

```
"areas":[
   {
      "name":"Main Hall",
      "type":"HALL",
      "location":{
         "type":"Polygon",
         "coordinates":[
            [
               [
                  -X.XXXXXX,
                  XX.XXXXXX
               ],
               [
                  -X.XXXXXX,
                  XX.XXXXXX
               ],
               [
                  -X.XXXXXX,
```

```
            XX.XXXXXX
         ],
         [
            -X.XXXXXX,
            XX.XXXXXX
         ],
         [
            -X.XXXXXX,
            XX.XXXXXX
         ],
         [
            -X.XXXXXX,
            XX.XXXXXX
         ],
         [
            -X.XXXXXX,
            XX.XXXXXX
         ]
      ]
   ]
},
```


In this part of the Json message an area is defined and identified by the coordinates of the points that represent the vertexes of the polygon in which the area is located.


```
"economic_value":0,
"size":573,
"area_assets":[
   {
      "id":"00773371-c69e-448c-9f2c-319d99cc8afb",
      "name":"Ticket Machine",
```

"type":"GENERIC",
"economic_value":12000
},

Here an asset is defined specifying its name, type, and economic value.

{
"id":"5c3abdb5-7bf1-4199-b6c7-13b9cbb9ae47",
"name":"Main Electronic Timetable",
"type":"GENERIC",
"economic_value":23200
}
]
},
{
"name":"Main Control Room",
"type":"CONTROL_ROOM",
"location":{
"type":"Polygon",
"coordinates":[
[
[
-X.XXXXXX,
XX.XXXXXX
],
[
-X.XXXXXX,
XX.XXXXXX
],
[

```
-X.XXXXXX,
XX.XXXXXX
],
[
-X.XXXXXX,
XX.XXXXXX
],
[
-X.XXXXXX,
XX.XXXXXX
]
]
]
},
"economic_value":0,
"size":74,
"area_assets":[
{
"id":"156e8fc4-5c30-4265-8608-9a8dcd4e3756",
"name":"Backup Server",
"type":"GENERIC",
"economic_value":2500
},
{
"id":"21bb49bf-8fdc-401b-be57-c54cec00e560",
"name":"Doors Control Unit",
"type":"GENERIC",
"economic_value":1500
```

```
                },
                {
                   "id":"ffd35586-a172-4ffc-abd6-fd47655996b4",
                   "name":"Main Server",
                   "type":"GENERIC",
                   "economic_value":3400
                }
             ]
          }
       ],
       "crowding":[
          {
             "weekday":"WEEKDAYS",
             "occupation":"[{\"time\": 0, \"people\": XX}, {\"time\": 1, \"people\": xx}, {\"time\": 2, \"people\": XX }, {\"time\": 3, \"people\": XX }, {\"time\": 4, \"people\": XX }, {\"time\": 5, \"people\": XX }, {\"time\": 6, \"people\": XX }, {\"time\": 7, \"people\": XX }, {\"time\": 8, \"people\": XX }, {\"time\": 9, \"people\": XX }, {\"time\": 10, \"people\": XX }, {\"time\": 11, \"people\": XX }, {\"time\": 12, \"people\": XX }, {\"time\": 13, \"people\": XX }, {\"time\": 14, \"people\": XX }, {\"time\": 15, \"people\": XX }, {\"time\": 16, \"people\": XX }, {\"time\": 17, \"people\": XX }, {\"time\": 18, \"people\": XX }, {\"time\": 19, \"people\": XX }, {\"time\": 20, \"people\": XX }, {\"time\": 21, \"people\": XX }, {\"time\": 22, \"people\": XX }, {\"time\": 23, \"people\": XX }]"
          },
          {
             "weekday":"SATURDAY",
             "occupation":"[{\"time\": 0, \"people\": XX}, {\"time\": 1, \"people\": xx}, {\"time\": 2, \"people\": XX }, {\"time\": 3, \"people\": XX }, {\"time\": 4, \"people\": XX }, {\"time\": 5, \"people\": XX }, {\"time\": 6, \"people\": XX }, {\"time\": 7, \"people\": XX }, {\"time\": 8, \"people\": XX }, {\"time\": 9, \"people\": XX }, {\"time\": 10, \"people\": XX }, {\"time\": 11, \"people\": XX }, {\"time\": 12, \"people\": XX }, {\"time\": 13, \"people\": XX }, {\"time\": 14, \"people\": XX }, {\"time\": 15, \"people\": XX }, {\"time\": 16, \"people\": XX }, {\"time\": 17, \"people\": XX }, {\"time\": 18, \"people\": XX }, {\"time\": 19, \"people\": XX }, {\"time\": 20, \"people\": XX }, {\"time\": 21, \"people\": XX }, {\"time\": 22, \"people\": XX }, {\"time\": 23, \"people\": XX }]"
          },
```

```
        {
            "weekday":"SUNDAY",
            "occupation":"[{\"time\": 0, \"people\": XX}, {\"time\": 1, \"people\": xx}, {\"time\": 2, \"people\": XX }, {\"time\": 3, \"people\": XX }, {\"time\": 4, \"people\": XX }, {\"time\": 5, \"people\": XX }, {\"time\": 6, \"people\": XX }, {\"time\": 7, \"people\": XX }, {\"time\": 8, \"people\": XX }, {\"time\": 9, \"people\": XX }, {\"time\": 10, \"people\": XX }, {\"time\": 11, \"people\": XX }, {\"time\": 12, \"people\": XX }, {\"time\": 13, \"people\": XX }, {\"time\": 14, \"people\": XX }, {\"time\": 15, \"people\": XX }, {\"time\": 16, \"people\": XX }, {\"time\": 17, \"people\": XX }, {\"time\": 18, \"people\": XX }, {\"time\": 19, \"people\": XX }, {\"time\": 20, \"people\": XX }, {\"time\": 21, \"people\": XX }, {\"time\": 22, \"people\": XX }, {\"time\": 23, \"people\": XX }]"
        }
    ]
},
```

Finally, here is presented the occupancy for each timeslot considered and defined for Weekdays, Saturdays and Sundays.

```
{
    "id":"e6ac27e1-0c0e-4461-b393-d054aeee9a41",
    "name":"XXXXX",
    "city":"XXXXX",
    "economic_value":0,
    "location":{
        "type":"Point",
        "coordinates":[
            -X.XXXXXX,
            XX.XXXXXX
        ]
    },
    "areas":[
        {
            "name":"Metro Hall G1",
            "type":"GENERIC",
```

```
"location":{
   "type":"Polygon",
   "coordinates":[
      [
         [
            -X.XXXXXX,
            XX.XXXXXX
         ],
         [
            -X.XXXXXX,
            XX.XXXXXX
         ],
         [
            -X.XXXXXX,
            XX.XXXXXX
         ],
         [
            -X.XXXXXX,
            XX.XXXXXX
         ],
         [
            -X.XXXXXX,
            XX.XXXXXX
         ],
         [
            -X.XXXXXX,
            XX.XXXXXX
         ],
```

```
                [
                    -X.XXXXXX,
                    XX.XXXXXX
                ],
                [
                    -X.XXXXXX,
                    XX.XXXXXX
                ]
            ]
        ]
    },
    "economic_value":0,
    "size":1710,
    "area_assets":[
        {
            "id":"b0278150-7614-47da-9524-ca7fd8776309",
            "name":"Ticket Machine",
            "type":"GENERIC",
            "economic_value":14000
        },
        {
            "id":"c137d880-7aba-4f2d-8f55-910491e673b4",
            "name":"Electronic Timetable",
            "type":"GENERIC",
            "economic_value":5600
        }
    ]
},
```

```
{
   "name":"Main Corridor",
   "type":"CORRIDOR",
   "location":{
      "type":"Polygon",
      "coordinates":[
         [
            [
               -X.XXXXXX,
               XX.XXXXXX
            ],
            [
               -X.XXXXXX,
               XX.XXXXXX
            ],
            [
               -X.XXXXXX,
               XX.XXXXXX
            ],
            [
               -X.XXXXXX,
               XX.XXXXXX
            ],
            [
               -X.XXXXXX,
               XX.XXXXXX
            ],
            [
```

```
                -X.XXXXXX,
                XX.XXXXXX
             ],
             [
                -X.XXXXXX,
                XX.XXXXXX
             ],
             [
                -X.XXXXXX,
                XX.XXXXXX
             ],
             [
                -X.XXXXXX,
                XX.XXXXXX
             ],
             [
                -X.XXXXXX,
                XX.XXXXXX
             ]
          ]
       ]
    },
    "economic_value":0,
    "size":2716,
    "area_assets":[

    ]
}
```

```
        ],

        "crowding":[

            {

                "weekday":"SATURDAY",

                "occupation":"[{\"time\":  0,  \"people\":  XX},  {\"time\":  1,
\"people\": xx}, {\"time\": 2, \"people\": XX }, {\"time\": 3, \"people\": XX },
{\"time\":  4,  \"people\":  XX  },  {\"time\":  5,  \"people\":  XX  },  {\"time\":  6,
\"people\": XX }, {\"time\": 7, \"people\": XX }, {\"time\": 8, \"people\": XX },
{\"time\":  9,  \"people\":  XX  },  {\"time\":  10,  \"people\":  XX  },  {\"time\":  11,
\"people\":  XX  },  {\"time\":  12,  \"people\":  XX  },  {\"time\":  13,  \"people\":  XX
},  {\"time\":  14,  \"people\":  XX  },  {\"time\":  15,  \"people\":  XX  },  {\"time\":
16,  \"people\":  XX  },  {\"time\":  17,  \"people\":  XX  },  {\"time\":  18,  \"people\":
XX  },  {\"time\":  19,  \"people\":  XX  },  {\"time\":  20,  \"people\":  XX  },  {\"time\":
21,  \"people\":  XX  },  {\"time\":  22,  \"people\":  XX  },  {\"time\":  23,  \"people\":
XX }]"

            },

            {

                "weekday":"SUNDAY",

                "occupation":"[{\"time\":  0,  \"people\":  XX},  {\"time\":  1,
\"people\": xx}, {\"time\": 2, \"people\": XX }, {\"time\": 3, \"people\": XX },
{\"time\":  4,  \"people\":  XX  },  {\"time\":  5,  \"people\":  XX  },  {\"time\":  6,
\"people\": XX }, {\"time\": 7, \"people\": XX }, {\"time\": 8, \"people\": XX },
{\"time\":  9,  \"people\":  XX  },  {\"time\":  10,  \"people\":  XX  },  {\"time\":  11,
\"people\":  XX  },  {\"time\":  12,  \"people\":  XX  },  {\"time\":  13,  \"people\":  XX
},  {\"time\":  14,  \"people\":  XX  },  {\"time\":  15,  \"people\":  XX  },  {\"time\":
16,  \"people\":  XX  },  {\"time\":  17,  \"people\":  XX  },  {\"time\":  18,  \"people\":
XX  },  {\"time\":  19,  \"people\":  XX  },  {\"time\":  20,  \"people\":  XX  },  {\"time\":
21,  \"people\":  XX  },  {\"time\":  22,  \"people\":  XX  },  {\"time\":  23,  \"people\":
XX }]"

            },

            {

                "weekday":"WEEKDAYS",

                ""occupation":"[{\"time\":  0,  \"people\":  XX},  {\"time\":  1,
\"people\": xx}, {\"time\": 2, \"people\": XX }, {\"time\": 3, \"people\": XX },
{\"time\":  4,  \"people\":  XX  },  {\"time\":  5,  \"people\":  XX  },  {\"time\":  6,
\"people\": XX }, {\"time\": 7, \"people\": XX }, {\"time\": 8, \"people\": XX },
{\"time\":  9,  \"people\":  XX  },  {\"time\":  10,  \"people\":  XX  },  {\"time\":  11,
\"people\":  XX  },  {\"time\":  12,  \"people\":  XX  },  {\"time\":  13,  \"people\":  XX
},  {\"time\":  14,  \"people\":  XX  },  {\"time\":  15,  \"people\":  XX  },  {\"time\":
16,  \"people\":  XX  },  {\"time\":  17,  \"people\":  XX  },  {\"time\":  18,  \"people\":
XX  },  {\"time\":  19,  \"people\":  XX  },  {\"time\":  20,  \"people\":  XX  },  {\"time\":
21,  \"people\":  XX  },  {\"time\":  22,  \"people\":  XX  },  {\"time\":  23,  \"people\":
XX }]"

            }
```

```
        ]
      },
      {
        "id":"f8b0c0df-ce0a-4f18-ab23-e508042a845d",
        "name":"XXXXXX",
        "city":"XXXXX",
        "economic_value":0,
        "location":{
          "type":"Point",
          "coordinates":[
            -X.XXXXXX,
            XX.XXXXXX
          ]
        },
        "areas":[

        ],
        "crowding":[
          {
            "weekday":"SATURDAY",
            "occupation":"[{\"time\": 0, \"people\": XX}, {\"time\": 1, \"people\": xx}, {\"time\": 2, \"people\": XX }, {\"time\": 3, \"people\": XX }, {\"time\": 4, \"people\": XX }, {\"time\": 5, \"people\": XX }, {\"time\": 6, \"people\": XX }, {\"time\": 7, \"people\": XX }, {\"time\": 8, \"people\": XX }, {\"time\": 9, \"people\": XX }, {\"time\": 10, \"people\": XX }, {\"time\": 11, \"people\": XX }, {\"time\": 12, \"people\": XX }, {\"time\": 13, \"people\": XX }, {\"time\": 14, \"people\": XX }, {\"time\": 15, \"people\": XX }, {\"time\": 16, \"people\": XX }, {\"time\": 17, \"people\": XX }, {\"time\": 18, \"people\": XX }, {\"time\": 19, \"people\": XX }, {\"time\": 20, \"people\": XX }, {\"time\": 21, \"people\": XX }, {\"time\": 22, \"people\": XX }, {\"time\": 23, \"people\": XX }]"
          },
          {
```

"weekday":"SUNDAY",

"occupation":"[{\"time\": 0, \"people\": XX}, {\"time\": 1, \"people\": xx}, {\"time\": 2, \"people\": XX }, {\"time\": 3, \"people\": XX }, {\"time\": 4, \"people\": XX }, {\"time\": 5, \"people\": XX }, {\"time\": 6, \"people\": XX }, {\"time\": 7, \"people\": XX }, {\"time\": 8, \"people\": XX }, {\"time\": 9, \"people\": XX }, {\"time\": 10, \"people\": XX }, {\"time\": 11, \"people\": XX }, {\"time\": 12, \"people\": XX }, {\"time\": 13, \"people\": XX }, {\"time\": 14, \"people\": XX }, {\"time\": 15, \"people\": XX }, {\"time\": 16, \"people\": XX }, {\"time\": 17, \"people\": XX }, {\"time\": 18, \"people\": XX }, {\"time\": 19, \"people\": XX }, {\"time\": 20, \"people\": XX }, {\"time\": 21, \"people\": XX }, {\"time\": 22, \"people\": XX }, {\"time\": 23, \"people\": XX }]"

},

{

"weekday":"WEEKDAYS",

"occupation":"[{\"time\": 0, \"people\": XX}, {\"time\": 1, \"people\": xx}, {\"time\": 2, \"people\": XX }, {\"time\": 3, \"people\": XX }, {\"time\": 4, \"people\": XX }, {\"time\": 5, \"people\": XX }, {\"time\": 6, \"people\": XX }, {\"time\": 7, \"people\": XX }, {\"time\": 8, \"people\": XX }, {\"time\": 9, \"people\": XX }, {\"time\": 10, \"people\": XX }, {\"time\": 11, \"people\": XX }, {\"time\": 12, \"people\": XX }, {\"time\": 13, \"people\": XX }, {\"time\": 14, \"people\": XX }, {\"time\": 15, \"people\": XX }, {\"time\": 16, \"people\": XX }, {\"time\": 17, \"people\": XX }, {\"time\": 18, \"people\": XX }, {\"time\": 19, \"people\": XX }, {\"time\": 20, \"people\": XX }, {\"time\": 21, \"people\": XX }, {\"time\": 22, \"people\": XX }, {\"time\": 23, \"people\": XX }]"

}

]

}

],

"sections":[

{

"id":"2198b35b-fb6b-4f82-bd45-b5cde014fd93",

"name":"XXXXXXXXXXXXXXXXX",

"economic_value":0,

"location":{

"type":"LineString",

"coordinates":[

[

```
            -X.XXXXXX,
            XX.XXXXXX
         ],
         [
            -X.XXXXXX,
            XX.XXXXXX
         ],
         [
            -X.XXXXXX,
            XX.XXXXXX
         ],
         [
            -X.XXXXXX,
            XX.XXXXXX
         ],
         [
            -X.XXXXXX,
            XX.XXXXXX
         ],
         [
            -X.XXXXXX,
            XX.XXXXXX
         ]
      ]
   },
   "departure_station_id":"f8b0c0df-ce0a-4f18-ab23-e508042a845d",
   "arrival_station_id":"cebbc0ba-9239-4f7d-80d6-4976e4c03a6e",
   "length":0.8,
```

```
"n_of_tracks":0,
"max_speed":null,
"bridge_percentage":0.0,
"tunnel_percentage":0.0,
"number_of_crossings":0,
"section_assets":[

]
},
```

In this part of the Json message are defined the sections present among the stations, they are identified by a name, an economic value, the coordinates, the ID corresponding to the departure and arrival station, the max speed, its length, and the percentage of it covered by bridged, tunnels and crossings. Also, the number of assets present in the section is reported here.

```
{
"id":"714bed18-58b5-49d8-8932-ba34278ee0be",
"name":"XXXXXXXXXXXXXX",
"economic_value":0,
"location":{
"type":"LineString",
"coordinates":[
[
-X.XXXXXX,
XX.XXXXXX
],
[
-X.XXXXXX,
XX.XXXXXX
],
[
-X.XXXXXX,
```

```
            XX.XXXXXX
        ],
        [
            -X.XXXXXX,
            XX.XXXXXX
        ],
        [
            -X.XXXXXX,
            XX.XXXXXX
        ],
        [
            -X.XXXXXX,
            XX.XXXXXX
        ],
        [
            -X.XXXXXX,
            XX.XXXXXX
        ],
        [
            -X.XXXXXX,
            XX.XXXXXX
        ],
        [
            -X.XXXXXX,
            XX.XXXXXX
        ]
    ]
},
```

```
        "departure_station_id":"e6ac27e1-0c0e-4461-b393-d054aeee9a41",
        "arrival_station_id":"cebbc0ba-9239-4f7d-80d6-4976e4c03a6e",
        "length":2.6,
        "n_of_tracks":0,
        "max_speed":null,
        "bridge_percentage":0.0,
        "tunnel_percentage":95.0,
        "number_of_crossings":0,
        "section_assets":[
           {
              "id":"0b9500b8-285b-4dca-b626-c9649f5b5905",
              "name":"New Section Asset 2",
              "economic_value":0,
              "location":null,
              "horizontal":null,
              "spacing":null
           },
           {
              "id":"5008b05b-4812-438c-9352-cdb757766da0",
              "name":"Rail",
              "economic_value":0,
              "location":null,
              "horizontal":null,
              "spacing":null
           }
        ]
     }
  ],
  "lines":[
  ]
```

```
    }
}
```

6.2 Integration with monitoring tools

Integration with the monitoring tools of the S4RIS platform (specifically, those developed in WP4) was foreseen to enable real-time risk assessment functionalities of SecuRail tool. Specifically, it is foreseen to use alerts from monitoring tools as a trigger for starting the risk assessment process within SecuRail, unlike the offline risk assessment which needs intervention by user to set up the scenario.

Indeed, integration mainly consists of data exchange between SecuRail and monitoring tools. The data exchange is performed through the Distributed Messaging System (DMS) which has been set up to support communications about different components of S4RIS platform. Monitoring tools send messages containing alerts about threats (or anomalies) occurring to SecuRail endpoint. Then, SecuRail translates the message received in as input for its own risk computation engine, in order to set up the scenario to be analysed.

At an information level, the message sent by monitoring tools should contain:

- The type of threat occurring (or the anomaly detected)
- The target suffering the threat
- The timestamp, i.e., when the threat/anomaly has been detected.

Monitoring tools are indeed devoted to immediately pushing this information through the DMS at any time when a new threat/anomaly is discovered. The message, in JSON format, is structured as follows:

```
{
      "threat": "threat_id",
   "anomaly": "anomaly_id",
   "target": "asset_id",
   "timestamp": "DD/MM/YYYY, HH:MM:SS"
}
```

Starting from this information, SecuRail creates the starting scenario for the risk analysis. To do this, a specific mapping has been created to translate anomalies into a narrow set of potential threats occurring (e.g., a loud sound detected could stand for the occurrence of an explosive attack) for the threats and target IDs corresponding to those already instantiated in SecuRail.

6.3 Integration with BB3D tool

5.3.1 Objective of the study

The objective of the present section is to describe the coupling of SecuRail with BomBlast3d (hereinafter referred to as BB3d), two of the tools developed and used in the SAFETY4RAILS project. This coupling was performed to enable that some results gained through BB3d, which concern structural and people damage consequent to a bomb attack, were passed to SecuRail as input to evaluate the risk level and the damages (estimated in monetary terms) they cause.

The following sections respectively report the description of the models specifically implemented during the project to calculate structural and people damage, the creation of the geometrical model of the reference blast scenario analysed that is suitable for BB3d computing, and the results gained.

It is worth to mention that BB3d results are reported and visualized in a qualitative manner (e.g. without indicating the quantitative values of blast parameters and casualties / people injured) because they are sensitive, and that the technical details of the implemented models, as well as the sensitive data, are reported in further confidential deliverables of the SAFETY4RAILS project.

5.3.2 Structural and people damage models

OUTDOOR PEOPLE DAMAGE MODEL

To supply an estimate of the amount of damage of people invested by blast wave for out-door blast scenarios, the curves reporting people response to fast rise pressure of short duration were used and implemented in the BB3d tool [11]. These profiles are illustrated in Figure 26 for different values of the percentage of survival, in a bi-logarithmic chart with the scaled impulse (scaled through the quantity W_h, namely the average weight of a human being measured in lbs) on the abscissa axis and the overpressure on the ordinate axis [12]. The percentage of survival refers to lung damage since, as far as people mortality is concerned, this is the most critical organ in blast pressure injuries.

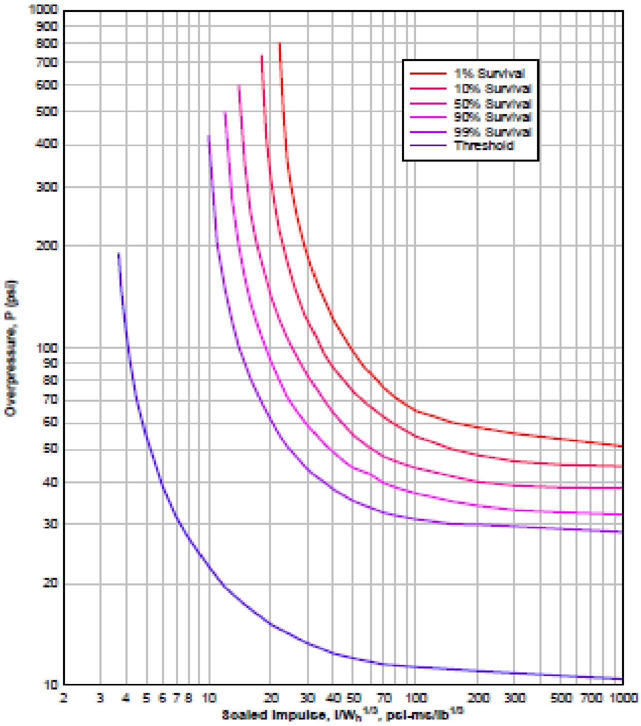


FIGURE 26. SURVIVAL CURVES FOR LUNG DAMAGE [12]

Enabling the generation of the fluid mesh, which is one of the advanced features of the BB3d tool, it is possible to enable the out-door people survival model that calculates, for each node of the fluid mesh, the survival probability of standing people because of lung haemorrhage. The fluid mesh consists of a hexahedral structured mesh (i.e. computational grid) enveloping a box-shaped volume virtually filled by air, that is generated to compute and visualize the blast quantities of interest in air. The data needed to be assigned in an ASCII input file for BB3d computing are the average mass of people, the average height above the ground of people lungs and the average density of people nearby the explosion point.

By calculating the area over a horizontal plane cutting the fluid mesh at the average height of people lungs where survival percentage is below a predefined threshold, the number of dead people (casualties) is determined using the average density of people set. The number of people injured is calculated using a relationship correlating the area for casualty's evaluation with the area characterised by a survival percentage varying in a predefined range of survival percentage.

BUILDING AND IN-DOOR PEOPLE DAMAGE MODEL AND IMPLEMENTATION

The prediction of blast loading effects on structures is a complex matter because there are many variables involved that have an impact on the structural response. These variables include (i) structure type, (ii) structure material strength, elasticity and ductility, (iii) structural response to blast loading (iv) diffraction loading effects,

(v) drag loading effects, (vi) building orientation to blast loading and (vii) local topography to name the most relevant ones.

Studies performed in the past considered accidents, trials and war damage data to identify categories for structural damage due to air blast loading [13] [14]. These studies led to the definition of categories for the potential severity of the effects of an undesirable explosion. Considering those categories, empirically derived relationships were proposed to enable those interested in studying blast consequences to fast estimate the damage level. The model proposed by Gilbert [15] was selected and implemented in the BB3d tool.

Gilbert's model was improved with the probability values for building occupants suffering fatal, serious or light injuries. The table collecting the just described probability values in function of damage category (or level) is shown in Figure 27. Gilbert's model calculates for the low level of structural damage number of people injured larger than that referring to casualties.

The adoption of Gilbert's model enables on one hand the visualization of the structural damage level over the solid surfaces of the Computer-Aided design (CAD) model of the asset of interest (i.e. building(s) of interest) and, on the other hand, the evaluation of the number of casualties and seriously or lightly injured people present in the buildings when the bomb attack happens. These figures are hereinafter referred to as in-door people damage.

Damage Category	Damage Definition	Probability (Fatality)	Probability (Fatality or Serious Injury)	Probability (Fatality, Serious Injury or Light Injury)
		P(K)	P (K + I)	P (K + SI + LI)
A_a	Houses totally demolished.	0.96	1.0	1.0
A_b	Houses almost completely demolished.	0.57	0.66	0.82
A	Houses demolished.	0.62	0.71	0.84
B	Houses so badly damaged they are beyond repair and require demolition.	0.096	0.15	0.38
C_b	Houses rendered uninhabitable but can be repaired with extensive work.	0.009	0.043	0.13
C_a	Houses rendered uninhabitable but can be repaired reasonably quickly.	0	0.002	0.006
D	Houses requiring repairs to remedy serious inconvenience but remain habitable.	0	0	0

FIGURE 27. PEOPLE IN COLLAPSING BUILDINGS

Gilbert's model was modified to also consider the area directly impinged by the blast wave. Using the value given in input by the user which specifies the (total) area of the lateral facades of the building, BB3d computes both structural and in-door people damage according to the standard Gilbert's model if the ratio between the visible area and the lateral area of the building is larger than a predefined threshold, otherwise the in-door damage data is decreased using the ratio of such areas. The data to be set in the BB3d's input file are:

- The number of buildings to consider;
- Name of each building (i.e. the name of the solid zone specified in the discretised geometry) with the number of people present in the building when the bomb attack happens and the value of the lateral area of the building expressed in meters.

The in-door people damage data is collected in a specific output file detailing the average level of structural damage, number of casualties and seriously or lightly injured people for each building set (in this case the total figures is provided as well). It is worth mentioning that the selection and use of Gilbert's model fit with the BB3d development rationale, which is based on two main pillars: the easiness of use, and fast and stable computing.

The area of interest and the bomb attack point of the blast scenario taken as reference to showcase the coupling between SecuRail and BB3d is shown in Figure 28. The reference blast scenario consists of the courtyard of an urban area surrounded by four buildings: the main building, which is the target of the bomb attack, and other three buildings respectively named building1, building2 and building3. Such an areas is supposed to be normally closed to traffic and access is permitted only to authorized vehicles. A midsize hatchback carrying a certain amount of explosive is supposed to force the entrance gate and reach the courtyard in front of the main building. Casualties, injured people and damage effects are evaluated for the main building and nearby buildings.

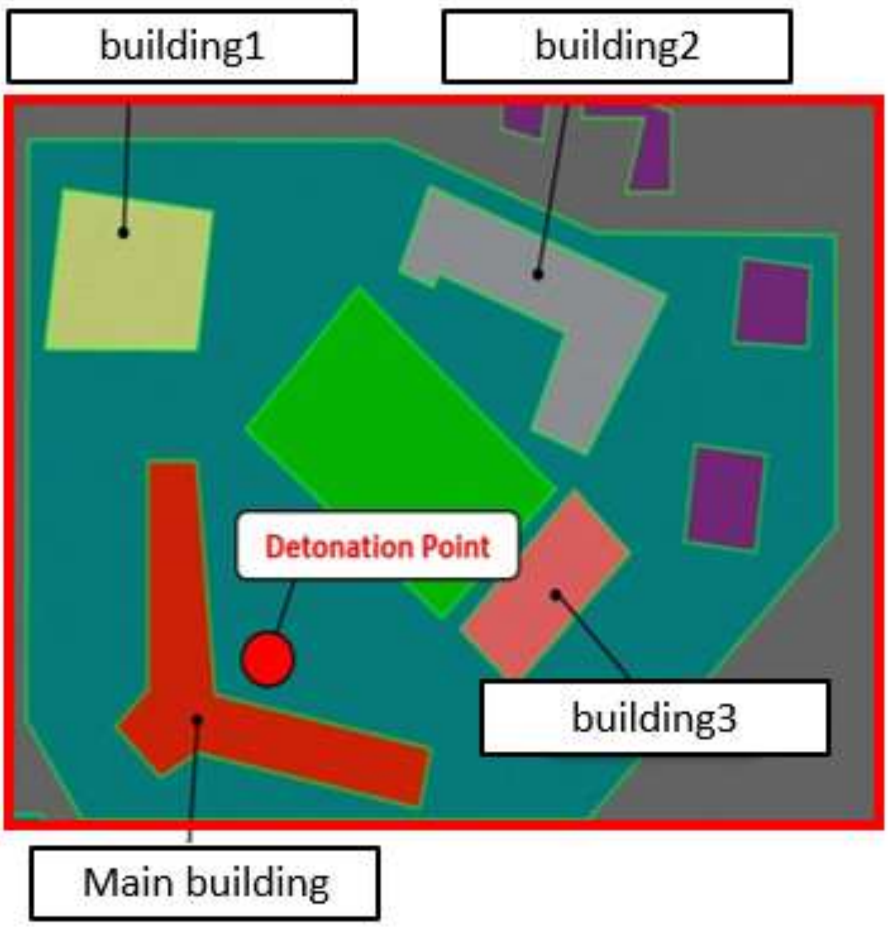


FIGURE 28. BS1: DETONATION POINT AND BUILDINGS OF INTEREST OF THE REFERENCE CASE (TOP VIEW)

In the setup of the test case, such an area was reproduced in a detailed 3D CAD (Computer-Aided Design) model. That CAD model was created starting from scratch, taking the requirements of BB3d into account (i.e. the international system of units and z axis of the global system of coordinates toward the top) and simplifying the real geometry of buildings thus avoiding losing the significance of BB3d processing.

The CAD model was then exported using a CAD neutral format (i.e. STEP file) for enabling the successive creation of the surface mesh (i.e. discretised geometry). To generate the surface mesh comprised of triangular elements only (i.e. BB3d requirement), the free meshing algorithm of the tool was adopted imposing a proper dimension of the average length of surface elements.

To the buildings of interest supposed to be analysed in the blast scenario identified (see the following section), a specific ID (Identification Number) was assigned so that BB3d computing can process them separately. Once the complete CAD model was discretised, its surface mesh was exported using the ASCII STL (STereoLithography) file format satisfying the requirements of BB3d.

The reference blast scenario is set on BB3d tool enabling structural damage model, fluid mesh and outdoor people damage. The main building is the most crowded building at the attack moment. The near buildings have instead a few people inside. Using 200 m as processing distance, the total time to evaluate blast outputs, buildings damage and casualties is just below one minute.

Figure 29 shows the distribution of the structural damage over the surface of interest which are visible from the detonation point and the detonation point. The structural damage level has medium values and all the surface of the frontal facades of the main building is covered.

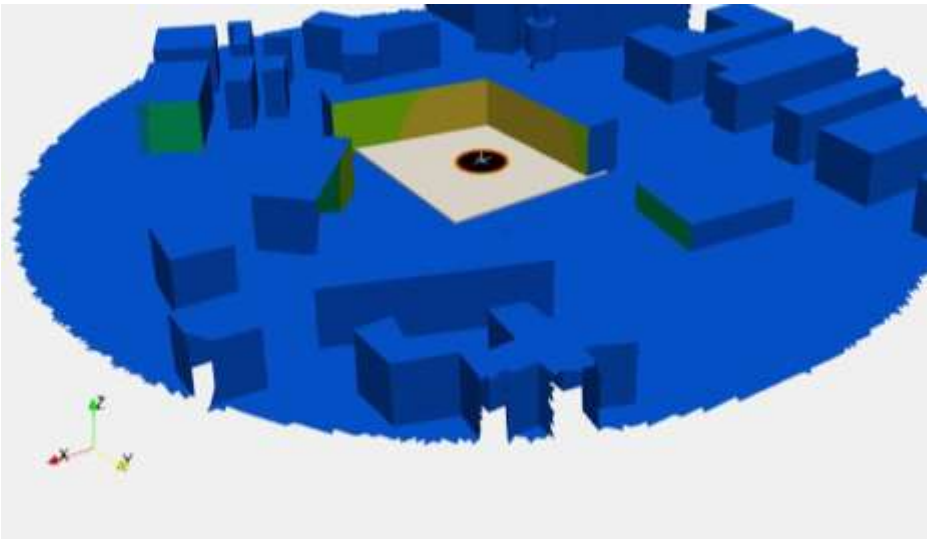


FIGURE 29. BS1: STRUCTURAL DAMAGE LEVEL DISTRIBUTION OVER THE MAIN BUILDING'S FACADES

The peak reflected overpressure (expressed in kPa) distribution over the solid surfaces (i.e. walls) is shown in Figure 30, which is characterised by the maximum value on the right facade as expected.

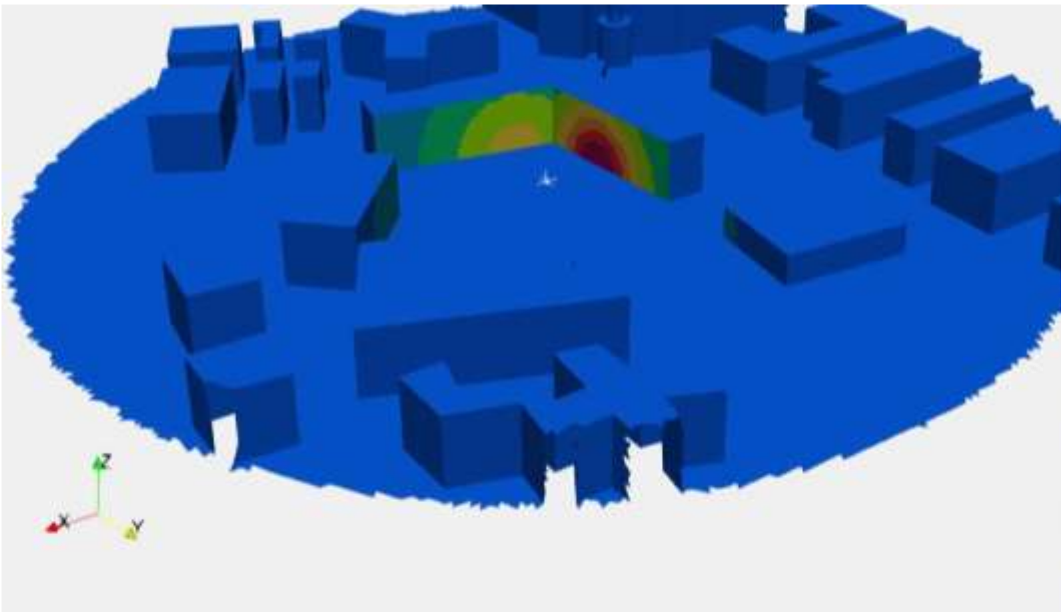


FIGURE 30. BS1: PEAK OF REFLECTED OVERPRESSURE DISTRIBUTION

BB3d processing also provides data referring to people and structural damage. The results show that the main building has the highest number of indoor casualties and injured people and is also subjected to a structural damage level of a major intensity. The outdoor casualties are low in this case but could be much higher in case of a crowded open area.

5.3.3 Risk Analysis using BB3D outputs

As already explained, integration between SecuRail and BB3D has been performed mainly to enable SecuRail to evaluate attack scenarios also outside the railway environment. The integration has been initially done manually and then BB3D has been connected to the Distributed Messaging System of SAFETY4RAILS in order to transmit output of the tool through the broker. An example of the JSON message shared by BB3D tool is provided below:


```
{"records":[
  {"value":
    {
      "ts":      XXX.00,
      "nextTs":    0.00,

      "results": [
        {
          "bombName":       "XXX",
          "bombCoords": [  XXX.00,   XXX.00,   XXX.00],
          "bombType":       "XXX",
          "bombCharge":      XXX.00,
          "bombChargeEqu":   XXX.00,

          "solidWallResults": [
            {
              "centrCoords": [  157.56,  269.61,    1.04],
              "calcTri":                    1,
              "peakIncOverpr":          39.81,
              "peakRefOverpr":          99.52,
              "arrivTime":              63.88,
              "posPhasTime":            27.80,
              "vel":                   393.41,
              "dynPres"    :            92.86,
              "incSpecImp":            409.61,
              "refSpecImp":            911.44,
              "damageLev":                  4
            },
            {
              "centrCoords": [  158.93,  269.31,    1.97],
              "calcTri":                    1,
              "peakIncOverpr":          40.78,
              "peakRefOverpr":         101.95,
              "arrivTime":              62.57,
              "posPhasTime":            27.65,
              "vel":                   394.64,
              "dynPres"    :            93.44,
              "incSpecImp":            414.73,
              "refSpecImp":            921.80,
              "damageLev":                  4
            },
```

```
  ...

  {
    "centrCoords": [  305.79,  220.32,    0.00],
    "calcTri":                  1,
    "peakIncOverpr":         5.83,
    "peakRefOverpr":         0.00,
    "arrivTime":           373.17,
    "posPhasTime":          43.18,
    "vel":                 348.42,
    "dynPres"    :          72.84,
    "incSpecImp":          110.19,
    "refSpecImp":            0.00,
    "damageLev":                0
  },
],

"fluidMeshResults": [
  {
    "nodeCoords": [  162.02,  282.02,    0.15],
    "peakIncOverpr":        83.11,
    "specIncImp":          579.70,
    "survProb":            100.00
  },
  {
    "nodeCoords": [  165.63,  282.02,    0.15],
    "peakIncOverpr":       101.74,
    "specIncImp":          631.94,
    "survProb":            100.00
  },

  ...

  {
    "nodeCoords": [  198.08,  318.08,    2.30],
    "peakIncOverpr":        81.51,
    "specIncImp":          574.92,
    "survProb":            100.00
  }
],

"outdoorPeopleDamage": [
  {
    "peopleAvMass":         60.00,
    "peopleAvHeigLung":      1.00,
    "peopleAvDensity":       0.02,
    "TotOutDead":             XXX,
```

```
        "TotOutInj" :            XXX
      }
    ],

    "crowd": [
      {
        "AgentID":  1,
        "AgentPos": [  155.00,  300.00,    1.80],
        "SurvProb" : 100.00
      },
      {
        "AgentID":  2,
        "AgentPos": [  180.00,  300.00,    1.80],
        "SurvProb" :   0.00
      },
      {
        "AgentID":  3,
        "AgentPos": [  190.00,  300.00,    1.80],
        "SurvProb" :  40.13
      }
    ],

    "buildIndoorPeopleDamage": [
      {
        "BuildName": "MainBuilding",
        "TotPeopleIn":        XXX,
        "LatArea":        9360.00,
        "VisArea":        3600.13,
        "AreaRatio":         0.38,
        "AverDamLev":        3.68,
        "Dead":               XXX,
        "Inj":                XXX,
        "DeadSerInj":         XXX,
        "DeadSerLigInj":      XXX
      },
      {
        "BuildName": "Building1",
        "TotPeopleIn":       XXX,
        "LatArea":        2350.00,
        "VisArea":         820.31,
        "AreaRatio":         0.35,
        "AverDamLev":        2.00,
        "Dead":               XXX,
        "Inj":                XXX,
        "DeadSerInj":         XXX,
        "DeadSerLigInj":      XXX
      },
      {
```

```
            "BuildName": "Building2",
            "TotPeopleIn":       XXX,
            "LatArea":       7060.00,
            "VisArea":       2748.51,
            "AreaRatio":        0.39,
            "AverDamLev":       2.00,
            "Dead":              XXX,
            "Inj":               XXX,
            "DeadSerInj":        XXX,
            "DeadSerLigInj":     XXX
          },
          {
            "BuildName": "Building3",
            "TotPeopleIn":       XXX,
            "LatArea":       4100.00,
            "VisArea":       2044.97,
            "AreaRatio":        0.50,
            "AverDamLev":       2.46,
            "Dead":              XXX,
            "Inj":               XXX,
            "DeadSerInj":        XXX,
            "DeadSerLigInj":     XXX
          }
        ],

        "indoorPeopleDamage": [
          {
            "TotInDead":      XXX,
            "TotInInj":       XXX
          }
        ]

      }
    ]

  }
 }
]}
```


The data needed by SecuRail from BB3D to carry out the Risk Assessment are mainly three:

- Number of people involved in the explosion
- Number of injured people
- Number of dead people

These figures are essential for SecuRail computation engine to calculate the expected damage expressed in monetary terms. The step-by-step workflow is the following:

- Figures are received by SecuRail Computation engine
- Lethality is calculated considering number of people involved and total number of deaths

- According to lethality calculated, injured people are distributed into the different AIS categories (as happen in the risk analysis algorithm)
- The number of injured for each AIS category is converted into economic losses using the conversion factors (see Table 9)
- The number of dead people is multiplied by VSL to obtain economic losses from deaths
- The total economic losses from injuries and death are multiplied by the likelihood of occurrence (estimated using SecuRail engine) to obtain the overall risk level.

The possible results that the risk analysis could produce are reported in the following table:

TABLE 10 RISK ANALYSIS RESULTS OF AN HYPOTHETICAL SCENARIO

Example Scenario Results	
Economic losses from fatalities	59.861.025 €
Economic losses from injuries	39.353.126 €
Likelihood	2,96978E-06
Risk Indicator (€/year)	408

The output of the exercise shows that there is a mutual benefit in the integration of BB3D and SecuRail, that is:

Having the results provided in such way is fundamental in order to be able to include such computation in the estimation of the overall risk score. The outputs of the demos conducted up to this point have demonstrated that there is a mutual benefit in the integration of BB3D and SecuRail:

- SecuRail can extend the analysis to the outside environment and can receive accurate data about number of injuries and fatalities thanks to advanced models of BB3D;
- BB3D can enhance the results produced by adding economic losses from injuries and fatalities and the risk level.

6.4 Integration with GANIMEDE tool

5.4.1 Objective of the study

The objective of the present section is to describe the coupling of SecuRail with the GANIMEDE tool. In order to enable that, some results gained through GANIMEDE, which concern the detection of anomalous sound in railway station and the detection of an abandoned baggage, were passed to SecuRail as input to evaluate the risk level and the damages (estimated in monetary terms) they cause.

GANIMEDE is the Leonardo platform for the large-scale analysis of live and recorded data streams based on Deep Learning. It provides a Video Content Analysis platform that enhances situational awareness and transform threat detections from a manual, resource-intensive operation into an efficient and automated process.

Some new algorithms have been developed in GANIMEDE for Safety4rails; two of these are briefly described below:

Audio pattern detection: AI models have been developed for audio pattern detection in a real scenario such railway platform, of events like as a screaming of a person in danger or the sound of a gunshot.

This functionality will be tested in a use case within the Termini Station in Rome, which is a particularly challenging environment due to the high amount of background noise.

The aim is to identify more efficiently a security threat that is strictly related to a specific sound (i.e. gunshot, broken glass, screaming, etc.) within a distance and time frame that will be extracted from the case study at Roma Termini. This functionality will be useful for early-warning activities and will provide further information if integrated with CCTV system.

Enhanced abandoned baggage detection: The aim is to detect an abandoned baggage and its owner in a lesser time; then the early-warning activities and the countermeasures (in case of possible threat connected to the abandoned baggage which defined as such in conjunction with authorities) can be performed in a more efficient way.

This functionality will allow to recognize specific behavioural pattern through AI models robust against a very crowded environment, such in a railway station. An abandoned object is defined as an object that is not at a distance of less than 1 m for at least 20 seconds from the same person.

5.4.2 Integration details

The S4RIS platform provides a Distributed Messaging System (DMS) based on Kafka protocol for exchanging messages between tools.

Following Kafka protocol, the following two specific Json messages related to the above-described functionalities have been developed to be sent over DMS:

Audio pattern detection Json message:


```
{
"asset_ID": "25bdaa8f-b1d54bf1-89df-3309da492d88",
“data_source”: “Ganimede”,
"event_type": "Audio pattern detection",
"event_subtype": "Gunshot",
"event_category": "Railway Station",
“event_severity”: “SEVERE”,
“source_event_time”: 1544908900,
"source_event_id": "9fe73e9-75ff-48ec-b453-2ba953e6894a"
 }
```


Abandoned baggage detection Json message:


```
{
"asset_ID": "25bdaa8f-b1d54bf1-89df-3309da492d89",
“data_source”: “Ganimede”,
"event_type": "Abandoned Object ",
"event_subtype": " Abandoned bag",
"event_category": "Railway Station",
“event_severity”: “SEVERE”,
“source_event_time”: 1643908977,
"source_event_id": "9fe73e9-75ff-48ec-b453-2ba953e6894b"
 }
```

These Json messages constitute an input SecuRail to evaluate the risk level and the damages they can cause.

5.4.3 Risk analysis using GANIMEDE outputs

Data generated by GANIMEDE are then used by SecuRail to perform the real-time risk analysis. To this extent, SecuRail has implemented a mechanism to translate information contained in the JSON message into the data needed to initialize a scenario of the risk analysis.

Indeed, a specific mapping has been created and stored in the database to enable the correct translation. The values of the asset_ID is used by the platform to identify the type of target that have been identified at by GANIMEDE. Then the values of the event_type and event_subtype are used to identify the type of threat. Sometimes, the event_type could correspond to different possible threats; in this case, a multiple mapping (with one input and severable output) can be considered. The likelihood of the threat is specified by a parameter; the likelihood parameter should take care of the accuracy of the sensor generating the alert (in order to consider false positive), but also of the uncertainty that the phenomena detected should be connected to an occurring threat. For example, it is highly probable that the detection of a gunshot corresponds to an armed attack; while the detection of an abandoned luggage does not mean for sure that there is an explosive attack occurring, but it could be a mistake of a passenger. Indeed, likelihood parameter should be calibrated considering these issues. The structure of the mapping is reported in Table 11

TABLE 11: MAPPING BETWEEN EVENT FROM GANIMEDE AND THREAT IN SECURAIL

Event_type (from GANIMEDE)	Threat (according to SecuRail taxonomy)	Likelihood
Event1	Threat1	0.3
Event2	Threat1	0.5
Event3	Threat2	0.9
Event4	Threat3	0.85

Thanks to information previously gathered are then used automatically to create the starting scenario, which is then elaborated, also automatically, to provide the user the risk analysis of what is happening in the exact moment or to what is likely to happen.

7. Conclusion

This document has described in detail technical and functional aspects of SecuRail tool. Specifically, interfaces and commands of the web application has been explained in order to give an overview of what the end-user, i.e. the railway infrastructure manager, can do through the tool and what results can be gathered. Algorithms underlying SecuRail risk analysis engine are reported to make the risk assessment process transparent to stakeholders involved.

This improved version of SecuRail, coming from the previous one developed within RAMPART project, has laid the foundation for a forefront tool capable to carry out tailored quantitative analysis of threat scenarios occurring in railway and metro network. The tool is endowed with scalability, since it can analyse a station but also a large portion of the network, as well as flexibility, since several threats and impacts could be included in the analysis. Furthermore, brand new real-time functionalities allow to carry out near real-time evaluation about current scenarios and support security staff to take right decisions in the most critical situations.

Finally, also integration with the rest of S4RIS platform is described. Besides the coupling with the actual project platform, which acts as a single-entry point, three main integrations have been implemented. The first, in which SecuRail shares with other tools a complete structure of the railway network as a main basis for further data input according to other tools providers models. The second, with BB3D tool, allows to extend SecuRail analysis to areas external to railway infrastructure and to have detailed information for estimating economic losses from injuries and fatalities. The third, with GANIMEDE, is essential to receive real-time information about occurring threats and automatically trigger a fast and targeted risk analysis. The mutual benefits are indeed evident, since coupling of the different tools enable new data exchange and consequently increase the potential and usefulness of the platform.

End Notes

[1] SAFETY4RAILS, “D3.1 Identification and characterization of cyber(-physical) systems and threats in railway environment,” February 2022.

[2] SAFETY4RAILS, “D1.4 Specification of the overall technical architecture,” October 2021.

[3] SAFETY4RAILS, “D2.3 System's specification,” September 2021.

[4] Figma, “Figma,” FIgma, 2016. [Online]. Available: https://www.figma.com/.

[5] Mapbox, “Mapbox,” 2010. [Online]. Available: https://www.mapbox.com/.

[6] SAFETY4RAILS, “D3.2 Description fo the S4RIS tool functionalities,” February 2022.

[7] Agency for Clinical Innovation, “Abbreviated injury scale,” 03 2014. [Online]. Available: https://aci.health.nsw.gov.au/networks/institute-of-trauma-and-injury-management/data/injury-scoring/abbreviated_injury_scale. [Accessed 02 2022].

[8] U.S. Department of Transportation, Office of the Secretary of Transportation, “Guidance on Treatment of the Economic Value of a Statistical Life (VSL) in U.S. Department of Transportation Analyses - 2015 Adjustment,” 7 2015. [Online]. Available: https://www.transportation.gov/sites/dot.gov/files/docs/VSL2015_0.pdf. [Accessed 2 2022].

[9] World Health Organization, Regional Office Europe, “Health Economic Assessment Tool - Value of statistical life,” 2014. [Online]. Available: http://old.heatwalkingcycling.org/index.php?pg=requirements&act=vsl&b=1. [Accessed 2 2022].

[10] SAFETY4RAILS, “D3.3 Definition of the interface between RA tools and S4RIS,” February 2022.

[11] E. Costa, Implementation of an empirical tool for fast prediction of bomb airblast loading, vol. 10, Journal of Protective Structures, SAGE Publications Inc., 2018.

[12] United States Deparment of Defence, Strucuture to Resist the Effects of Accidental Explosion, United Facilities Criteria (UFC) 3-340-02, 2008.

[13] S. N. F. a. H. W. G., “The blast effect of explosion,” Vols. 5, Loss prevention and safety promotion, 1986.

[14] J. D. E., *Derivation of the british Explosives Safety Distancves,* vol. 152, 1968.

[15] G. S. M., L. F. P. and S. N. F., “A Model Hazard Assessment of the Explosion of an Explosive Vehicle in a Built-Up Area,” in *Minutes of the 26th US Department of Defense Explosives Safety Board Seminar*, Miami, USA, 1994.

[16] A. G. N. M. a. C. P. F. Flammini, “Quantitative Security Risk Assessment and Management for Railway Transportation Infrastructures,” in *Critical Information Infrastructure Security*, Rome, 2008.

[17] ANSYS Inc., “ANSYS SpaceClaim software,” [Online]. Available: https://www.ansys.com/products/3d-design/ansys-spaceclaim. [Accessed January 2022].

[18] BETA-CAE System, “ANSA Preprocessor software,” [Online]. Available: https://www.beta-cae.com/ansa.htm. [Accessed January 2022].

[19] G. Earth, “Google Earth,” Google, [Online]. Available: https://earth.google.com/web/. [Accessed January 2022].

[20] SAFETY4RAILS, “D4.5 Model for cascading effects,” April 2022.

[16]

ANNEXES

ANNEX I. GLOSSARY AND ACRONYMS

TABLE A.0-1: GLOSSARY AND ACRONYMS

Term	Definition/description
CAPEX	Capital expenditure
DMS	Distributed Messaging System
UI	User Interface
ID	Identifier
IT	Information Technology
N.A.	Not Applicable
OPEX	Operating expense
OT	Operational Technology
RA	Risk Assessment
REST API	Representational State Transfer Application Programming Interface
S4RIS	SAFETY4RAILS Information System
DoA	Description of Action
AIS	Abbreviated Injury Scale
CAD	Computer-Aided Design
ANFO	Ammonium Nitrate Fuel Oil
TNT	Trinitrotoluene
EGDN	Ethylene glycol dinitrate
JSON	JavaScript Object Notation

Partners:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 883532.