Optimised budget for a given level of resilience planning

Deliverable 7.5

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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 onrush 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, for example, carry out a threat analysis, maintain situation awareness, establish crisis communication and response, and they must 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.

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Executive summary

This document, deliverable D7.5, has established a guided analysis of Purposes and Contexts underpinning the proposed SAFETY4RAILS optimised budget for a given level of resilience planning and accordingly set out the implicated stakeholder and data types. Accordingly, the budget optimisation under a specific level of resilience is assessed for cyber-physical attacks. Some foundational work on assessing the resilience of infrastructure against natural disasters such as flooding was carried out at RMIT before SAFETY4RAILS was started. In the foundational work (SAFETY4RAILS), a comprehensive resilience assessment model for railway networks was developed, which calculated the optimal investment to achieve a given level of resilience

This defines a localised Investment Assessment model for end-user decision makers so that mitigation and recovery phases can be cost-benefit evaluated, as well as risk-aversive measures to reduce delays in planning specific investment assessments, since it will collect and describe cyber-physical attacks and systems incorporated into the asset assessment. In this context this deliverable used generated outputs from D7.1, D7.3 and D7.4 as required for input to CAMS.

The essential data have been identified, including historical data processing by the CAMS software in SAFETY4RAILS. Therefore, the requisite compliance measures have been budgeted, deployed, and monitored at each stage of the project lifecycle. The results enable related partners and end-users to generate an optimised budget plan, using the necessary information based on incidents or ageing issues. In this context given the evolution of age-related degradation, and more rapidly, the evolution of threats, the maintenance of a target resilience envelope would require dynamic resilience optimisation for which the analysis, by UREAD, of the cyber-physical security-privacy threats, as exemplars, has resulted in a framework for dynamic vulnerabilities and threats based on risk analysis and an intuitively visualised calculus for Threat Severity Ranking and Combinatorial Countermeasures Prioritisation (TSR-CCP). This is to inform CAMS of the dynamic ranking of requisite vulnerability fixes to support an agile resilience engineering eco-system– continuing to remain responsive to the ever-changing threats landscape.

This deliverable is the output of the last task of work package 7. The work package is called Policy planning and investment measures for prevention, detection, and response mitigation, for which RMIT is the lead participant under the SAFETY4RAILS project.

1. Introduction

1.1 Overview

The Central Asset Management System (CAMS) provides deterioration modelling, risk assessment, rehabilitation cost forecasting, and an integrated mobile solution for data collection. As discussed in the first deliverable of this work package (D7.1), budget policies affect resilience, as each recovery plan associated with specific mean budget allocations, lead to specific recovery times and resilience cover. An effective maintenance plan and optimised budget allocation requires insight into the deterioration process of each asset.

As discussed in deliverable 7.1, an effective maintenance plan and optimised budget allocation requires insight into the deterioration process of assets in infrastructures. To maintain high reliability and resilience against ongoing deterioration and potential extreme events, one approach is to ensure rail assets are in good or strengthened condition so that the damage caused by extreme events is minimal and thereby contributing to fast recovery. To achieve this approach, Maintenance and Rehabilitation (M&R) should be regularly carried out. Under the assumption of specific annual budgetary limits. Given a large number of rail assets affected, a budget optimisation scheme is required to select annual M&R actions (including no-action, minor repair, major repair and replacement) on individual rail assets so that the total cost over time is minimised while a specified resilience level is maintained over a planning horizon of 10-20 years. The CAMS software tool is equipped with an optimisation module that helps in determining M&R actions under various budget scenarios and at various resilience levels.

CAMS as the budget planning tool in SAFETY4RAILS, enables the digitisation of this optimal budget for a given level of resilience. Using the CAMS tool, various scenarios of a railway infrastructure incident can be viewed and selected, and the associated budget impacts can be provided.

1.2 Integration process in WP7

A certain process has been followed by the WP7 participants so they could proceed with the integration. The following steps needed to be followed by each participant once they had achieved effective results in WP7.

- Review the results and determine what information is to be shared with other participants from the perspective of their deliverables.
- Communicate with relevant project participants to agree on a specific outcome for another deliverable based on the generated information, data, documents, and technical conclusion during the project period.
- Implement the necessary functionality required, including development for integrating with other involved participants, in order to successfully exchange results and information.
- Verify implementation of functionality by integrating results from each deliverable with other partners and tool(s) (CAMS as the only tool in WP7).

The overall aim was to exchange effective output between each participant in WP7 in accordance with the project scope. In consequence, the D7.5 (not its structure) could be regenerated or updated by each WP7 participant based on real-time data for further development.

- D7.1 Investment assessment model for cost-saving evaluation of risk mitigation and recovery; By using asset classification from ANNEX 3-D3.1 and based on the data table from SecuRail; required data needs for CAMS were categorised and prioritised such as cost of assets maintenance; cost of assets repair; cost of assets renewal; cost of assets replacement; as well as time of assets maintenance; time of assets repair; time of assets renewal; time of assets replacement and components dependency (ANNEX 5&6 D3.1); components priority and risk determination, ranges of cost-saving estimation were discussed and exported to D7.5 for optimising budgets.
- D7.2 Consequence cost model various failure scenarios; Based on the results of D7.2, mitigation actions were established to assist with responding to and recovering from threats (based on the D3.1threats classification), as well as further preventing them in the WP7 deliverables. As a result, D7.2 provided an optimal mitigation strategy based on a model of the risks that can be exposed to the deliverable. Section 4 of D7.2 provided recommendations for identifying weaknesses in asset

management systems, then assisted in improving CAMS fragility analysis through the following methods: experimental fragility functions based on experimental data, empirical fragility curves based on survey data, judgmental functions based on expert judgment, numerical simulations or analytical models. To reduce reopening times after incidents, the results of D7.2 in Annex IV, such as the consequence cost model-mitigation matrix, were also used to create an accurate data table for CAMS regarding the priority of components and their dependencies in the recovery phase. As a result of synergies, T7.2 developed a predictive model of the stochastic process of degradation under normal operating conditions and/or extreme incidents, as described in Section 4.3 of D7.1. Also, the relevant assets were identified in D7.2[1] based on the asset list categorised and prioritised in D7.1 (which were transferred to CAMS). As another result, D7.2 provided complementary functions for CAMS by providing optimal mitigation actions beyond asset maintenance[2].

- D7.3 Budget simulation module of S4RIS; when carrying out the budgetary analysis of a simulated scenario, it is first necessary to establish the severity of the event and the consequences of the scenario which measures the economic impact of these consequences. The budget module provides a basis for CAMS, establishing a broad catalogue of events and indicating the expected effects on assets for each event. This is through a matrix indicating the expected risk and impact for each asset for each phenomenon (See D7.1)[3]. Phenomena can combine with each other, generating complex scenarios. Through the budget simulation module, the different assets that would be affected by the scenario as a whole can be identified. Several data collected in WP7 was also considered, including profiling threats in T7.3 and evaluating the cost implications of response and recovery mitigations in T7.2. Vulnerabilities extracted from WP3 and WP5 toward WP7 were associated with the extended threat taxonomy provided in D7.3 (this requirement is fulfilled by design since this taxonomy extends D3.1). Consequently, this deliverable was prepared based on a list of assets in circulation in WP7 (which is consistent with D7.3), which examines the assets in a typical railway station. Following the concept presented in Figure 1, a relational database containing data categorised in WP7 contributed by D7.3 was developed to estimate the budget optimisation for a particular threat or combination of threats. According to the result, the threat/asset matrix identifies the assets that are affected by each threat and describes the impact and probability of that threat. These matrices were generated based on threat ranking at the asset level, which considers the probability and impact of a threat affecting an asset. In addition, the catalogue of phenomena was also used as an input to identify vulnerabilities, enabling a vulnerability matrix to be generated from the catalogue of events in D7.2. In Deliverable D7.2, the probability scale was transformed into percentage while the impact scale was transformed into quantitative cost, and then considered through the cost per asset provided in CAMS output (See Data for CAMS on D6.4[*Columns N–O*] and D8.2 [*Columns 9–10*])[4&5]. So depending on the number of assets likely to be affected by specific threats, the impact on the asset (damaged, disabled or destroyed) and the priority of the asset for service recovery, each phenomenon was categorised by these matrixes, assisting CAMS in determining the priority [*Column N*] and dependencies of assets [*Column O*] that will be affected by the phenomenon as well as the extent to which they will be affected (See Figure 2 on D7.3)[6]. On the one hand, explosions caused by terrorist attacks at specific locations at specific times would have totally different effects on the railway component than floods at those same locations. On the other hand, each threat can have a different effect on railway component priority and dependencies to achieve minimum recovery time. In the process, CAMS subsequently examined the costs caused by the threats described in D7.3. This enables the intensity

[1]SAFETY4RAILS, Deliverable D7.2- Page 25.

[2]SAFETY4RAILS, Deliverable D7.2-Page 54.

[3]SAFETY4RAILS, Deliverable D7.1- Page 39 and Table 12 [*Columns 9-10*].

[4]SAFETY4RAILS, Deliverable D6.4 - Data for CAMS [*Columns N-O*]- ANNEX III.

[5]SAFETY4RAILS, Deliverable D8.2 - CdM SE [*Columns9-10*].

[6]SAFETY4RAILS, Deliverable D7.3-Figure 2.

of a threat to be graded, and therefore generate concrete simulation scenarios. So, CAMS associated the expected damage to assets for each phenomenon provided by the Budget Simulation Module with other data entered into the system. This includes the number of elements of each type as present in the environment in which the simulation is generated, repair times and repair costs to perform the economic analysis. The generated matrix is therefore an input for the analysis of the costs of a threat that is carried out by the CAMS tool. Due to this synergy between SAFETY4RAILS work packages and their participants, end-users can determine the optimum budget by prioritising mitigations according to the threats they selected. In this way, Asset Management and budgeting strategies can be guided under incidents.

In below diagram (Figure 1)[7], showing the relationships between the Tasks (7.1, 7.2, and 7.3) identified above as part of WP7.

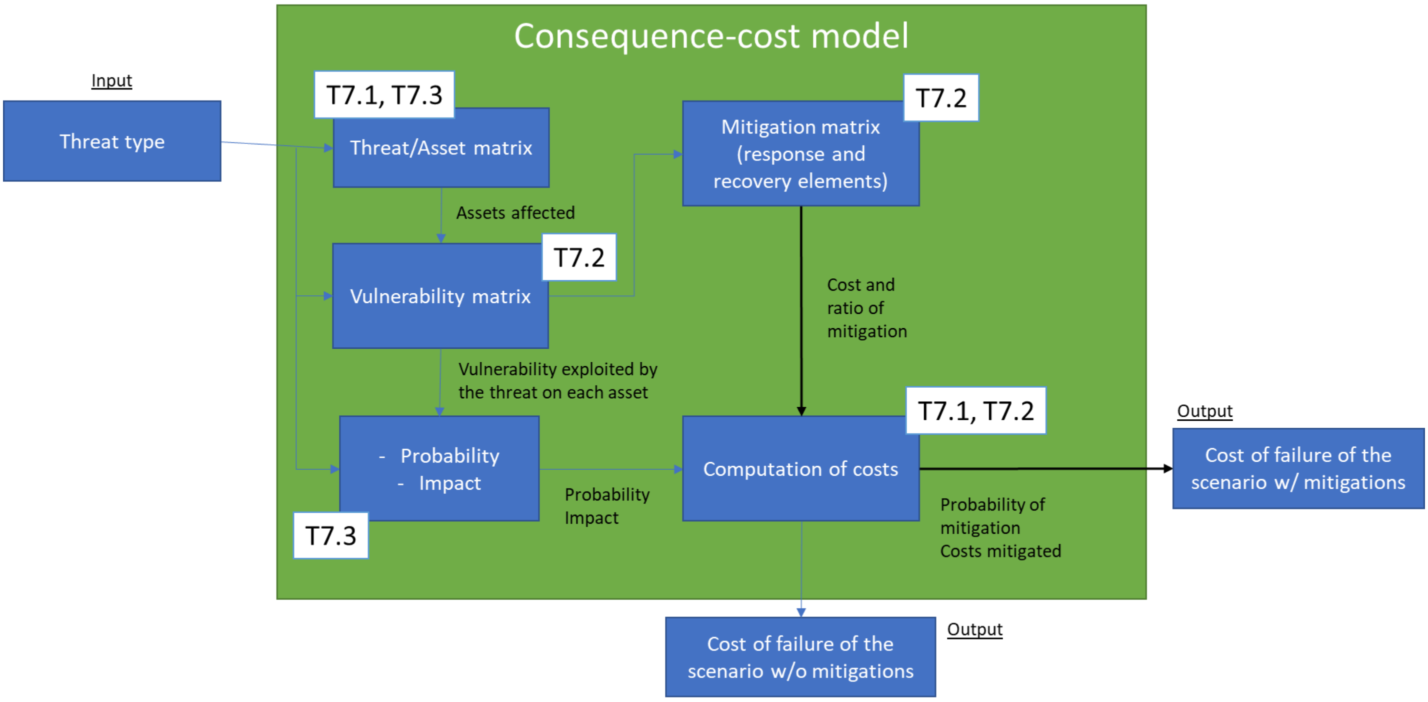

FIGURE 1: TASKS 7.1, 7.2 AND 7.3 RELATIONSHIP - CONSEQUENCE COST MODEL CONCEPT*[4]*

- D7.4 Resilience assessment model of optimised investment; the Fault Tree model maps each node's assets to its infrastructure, which CAMS used to identify interdependencies between railway assets based on flood scenarios that were studied in Sections 2 and 3 of D7.4. In Deliverable D7.4, the mitigation strategy was described in Table 2[8], which was applied to meet CDM scenario requirements in the Milan simulation (a sample of other SAFETY4RAILS simulations). Through the use of the Fault Tree model, CAMS improved its input data fields [*Columns I to M*][9] to reduce recovery time for accurate budget policies derived from D7.4. This means that CAMS uses binary methods (FIGURE 2) for assets condition to reduce recovery time by defining 1 and 0 [*Columns I to M*] of the input data (See ANNEX III). As a result of D7.4, CAMS used binary methods (Good/Faulty) of D7.4 to define asset condition priorities and dependencies in CAMS input data (Figure 3). In the process, Colour Codes[8] classified in D7.4 was used to assist CAMS in identifying flood-affected assets. For CDM, the flooding scenario from D7.4 was presented with CAMS on pages 11-13, which were simulated in

[7]SAFETY4RAILS, Deliverable D7.2– Page 10.

[8]SAFETY4RAILS, Deliverable D7.4 – Page 15.

[9]ANNEX III

Milan. Furthermore, D7.4 demonstrated the proposed scenario and methodology by testing floods in Milan for settings, resilience, and mitigation strategies, and then CAMS used it for numerical analysis of asset condition and performance. (See FIGURE 3 from the CAMS presentation in Milan simulation exercise.)

Elevators=1	Elevators_1	Elevators_2	Elevators_3	Elevators_4	Expert Rule
1	1	1	1	1	If all Elevators are functional then Stairs module is considered fully functional
0,75	1	1	1	0	If one of the Elevators is functional then Elevators are considered functional to the extend depending on amount of functional Elevators.
0,75	1	1	0	1	If one of the Elevators is functional then Elevators are considered functional to the extend depending on amount of functional Elevators.
0,5	1	1	0	0	If one of the Elevators is functional then Elevators are considered functional to the extend depending on amount of functional Elevators.
0,75	1	0	1	1	If one of the Elevators is functional then Elevators are considered functional to the extend depending on amount of functional Elevators.
0,5	1	0	1	0	If one of the Elevators is functional then Elevators are considered functional to the extend depending on amount of functional Elevators.
0,5	1	0	0	1	If one of the Elevators is functional then Elevators are considered functional to the extend depending on amount of functional Elevators.

FIGURE 2: ASSET CONDITION IN D7.4 FORWARDED TO CAMS[10]

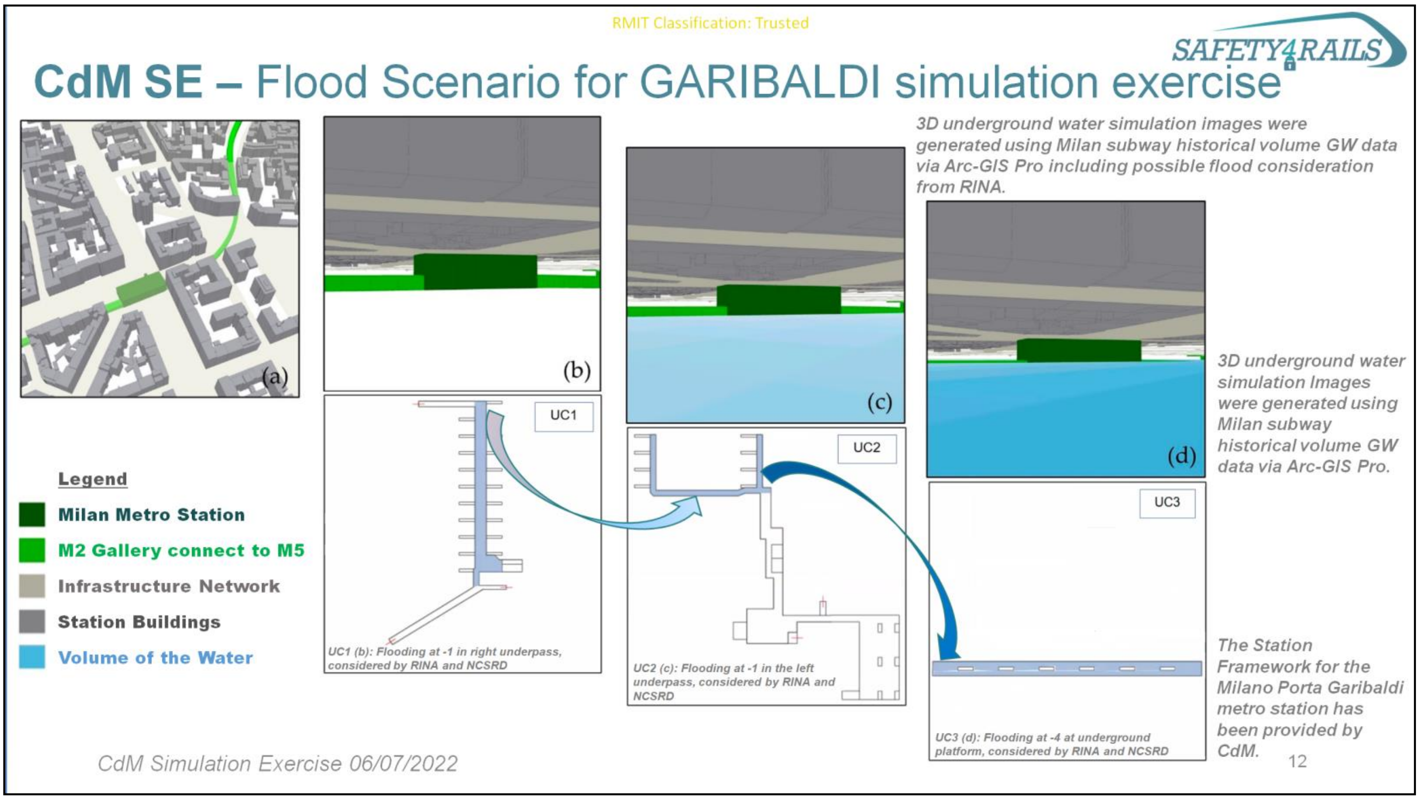

FIGURE 3: THE FLOOD SCENARIO IN D7.4 USED IN THE SIMULATION EXERCISE - CDM[3]

[10]SAFETY4RAILS, Deliverable D6.4 - Data for CAMS [*Columns N-O*].

1.3 Structure of the deliverable

In this report, we focused on optimising budgets for a given level of resilience in the chapters that follow.

- Chapter 1: Introduction
- Chapter 2: Central Asset Management System (CAMS)
- Chapter 3: Resilience of Railways Infrastructure
- Chapter 4: Resilience Model
- Chapter 5: Budget Optimisation for Infrastructure Resilience
- Chapter 6: Summary and Conclusion

2. Central Asset Management System

CAMS provides a valuable opportunity to explore the combined effects of cyber-physical disruptions on railway infrastructure. To enhance resilience against cyber-physical attacks, it is necessary to determine when, where, and how to spend money in order to enhance the end-user's ability to effective reaction against cyber-physical attacks.

RMIT developed the CAMS interface for SAFETY4RAILS so that railway end-users can take advantage of this tool. CAMS has been implemented in Madrid, Ankara, Rome, and Milan, and has been tested and debugged successfully. It has enabled the end-users to use the tool's functionalities not only for investment management, but also for interacting with the outcome of the SAFETY4RAILS project by planning the recovery budget and predicting the timeline for reopening railway facilities. Railway end users can plan for incident-based operational expenditures (caused by incidents) and ageing-related capital expenditures (caused by ageing) by using CAMS cost optimisation.

CAMS was accessible through the S4RIS platform not only for end-users for condition monitoring during incidents but also for other tool providers to access and edit the data at any time during the railway life cycle. The CAMS flexibility in using the recommended default settings for railway hierarchy and transition matrices or introducing customised features with the option of importing from Excel worksheets made it appealing to end-users and other SAFETY4RAILS participants.

2.1 CAMS Data

The CAMS data models are categorised and divided into simple stages. In the beginning, data models are very conceptual and not many details are included. As more effort is added, the models can evolve to a more logical or physical level. Also, CAMS simplified the process for different types of models, which included conceptual, logical, and physical stages, in accordance with the sample presented in this deliverable. In this process, CAMS compares the actual data that it receives from end-users with historical data sets, including theoretical as well as logical data sets, in order to make accurate comparisons. Effective budget planning can be designed using conceptual data models generated by CAMS. By representing these concepts in a hierarchy form, end-users can make better informed decisions in case of incidents through CAMS' planning and budgeting optimisation results.

2.2 CAMS Budget Modelling

The CAMS framework organises data in a simple database format. In the CAMS data model, Excel cells are used to represent logical data and their relationships. As a result of the SAFETY4RAILS project, the CAMS asset management system was developed under the framework for managing railway infrastructure. The conceptual infrastructure management framework was adopted for railway assets and some components such as IT components were added during the SAFETY4RAILS project. These components were added to meet the requirements for effective investment management in the event of an incident. The main structure of a railway infrastructure with its essential stages, components and elements is shown in FIGURE 4.

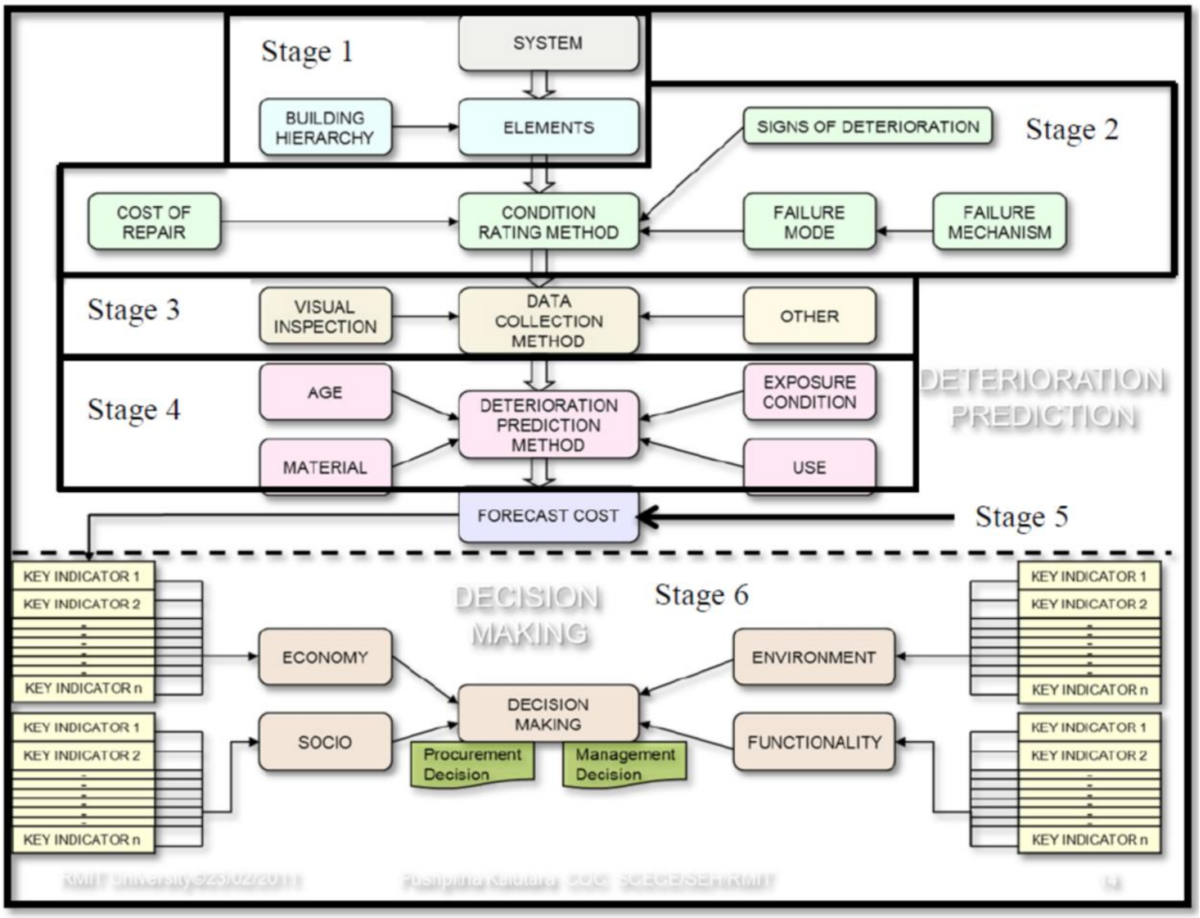

FIGURE 4: CAMS BUDGET MODELLING[8]

2.3 CAMS Workflow

Based on the concept of resilience, the CAMS framework (**FIGURE 5**) was developed by Huu Tran[11] from RMIT University for SAFETY4RAILS. (See CAMS explanation of CAMS related to Deliverables D8.3 and D6.4 for more details.)

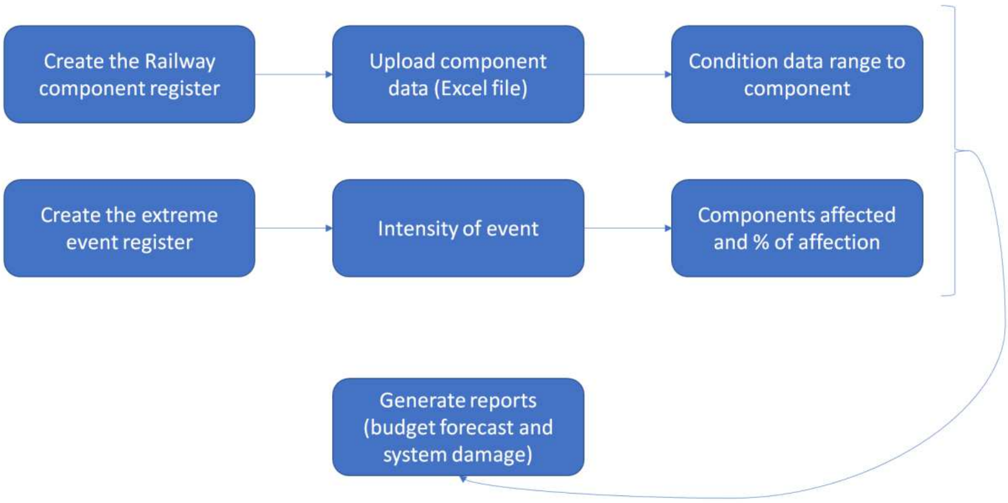

FIGURE 5: CAMS WORKFLOW

[11]As the author of reference 19, in Bibliography - May 2021.

3. Resilience of Railways Infrastructure

CAMS aims to develop a detailed technical and financial plan for the recovery phase of incidents or ageing damage, and to model how recovery can impact the railway infrastructure. The recovery phase involves scheduling a number of recovery activities for both the physical and IT components. It is also imperative to create a CAMS internal matrix that can be easy to understand and useful at different levels of railway asset data. To predict how recovery phases will affect the physical and cyber state of infrastructure, we need historical data and predictive models of how state variables have evolved over time.

CAMS proposes a multistage budgeting approach in terms of the cost of repairing or replacing the damaged components during the recovery phase. CAMS identifies additional features for the rail infrastructure recovery phase, such as reducing costs, partitioning damaged components, and expediting reopening. Railway infrastructure recovery phases can be described through the functional conceptual, logical proximity of railway components, or a combination of different incidents, such as traffic jams caused by terrorist attacks.

3.1 Budget Estimation

The CAMS conceptual data model has been created to show how various entities relate to each other during asset assessment. These relationships have dependent and complicated connections, which are difficult to handle from the end-user's perspective. CAMS has been designed to help decision-makers to establish the hierarchy relationships between the components of the railway infrastructure thereby identifying the importance of individual components with regards to system functioning. If it is considered that the rail system still functions even when the ticketing system is out of service, then the train station and rail track have a more important role than the ticketing system. This importance ranking can be used for the scenario of a limited budget in a prioritised manner such that components with a more important ranking receive the budget before the less important ones.

Budget estimation after the incidents is based on a damage assessment report, which is often carried out right after the incidents. If the budget is unlimited for the repair of critical rail assets such as tracks and train wagon, the repair crew and repair material might be limited, resulting in prioritised repair planning. In this case budget estimation can provide time and costs for repair with prioritised schedules. If the budget is limited, optimisation of repair budget is carried out to maximise system resilience while keeping time and cost at specified levels. In this case, the importance ranking of individual assets and system resilience as demonstrated in D7.1 was used in the optimisation process to provide repair actions (e.g., repair, replace or delayed) for individual assets.

3.2 Investment Model

The CAMS contributed scenarios, calculations and engagement with the railway infrastructure, and investment measures that supported the prevention, detection, response, and mitigation aspects of the main that were addressed in the recovery phase. Data introduced by end-users to CAMS is divided into the following categories:

- Assets inventory (component data)
- Topology
- Type and quantity of elements

In order to determine the overall configuration of a system, first determine the type of element or component group that is needed. Based on the probability of the component, a rehabilitation budget can be calculated. A conceptual model determined by CAMS includes the following recommendations.

- Required Cost

- Available Funding
- Cumulative difference

The investment model in the CAMS tool provides the optimised budget to maintain resilience at a specified level, i.e., to keep rail assets from being in a poor condition due to deterioration and to strengthen these assets against potential extreme events. The optimisation of a budget requires the selection of maintenance actions every year for individual assets based on the deterioration rate of their asset groups and the damage matrix of extreme events. FIGURE 6shows the relationship between the deterioration and rehabilitation cost over planning time. In this figure, the asset condition has five condition states corresponding to the deterioration levels. Condition 1 is a brand-new like condition and condition 5 is the worst or failure condition. As the probability of condition 5 increases over time, the rehabilitation cost also significantly increases as compared to other conditions. This is because condition 5 is often treated with replacement or a major repair, which incurs higher costs than minor repairs as may be deemed appropriate for conditions 2 and 3. The investment model uses this cost-deterioration curve to optimise a network of rail assets so that network resilience is at the specified level.

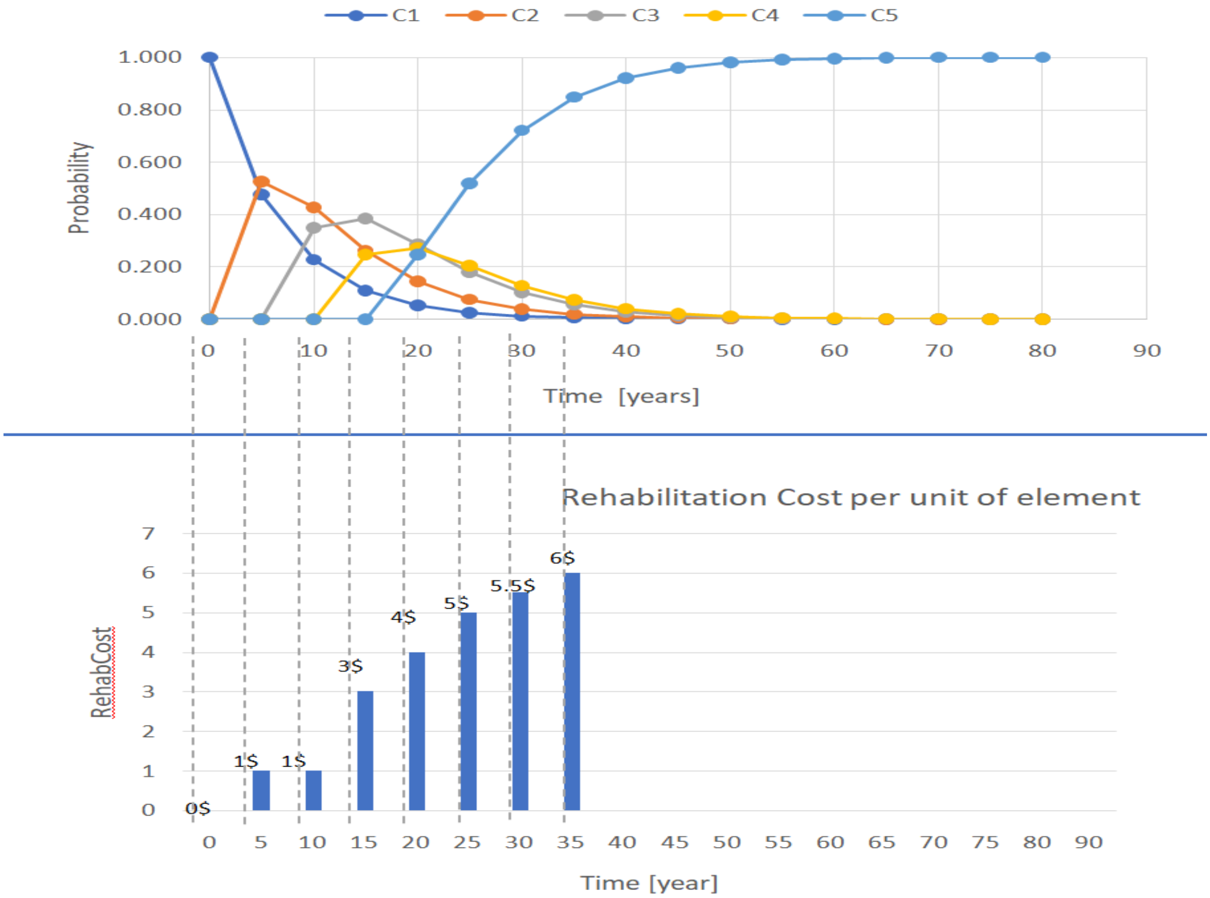

FIGURE 6: FUTURE DETERIORATION PREDICTION AND BUDGET FORECASTING

3.3 Reactive Model

Reactive models reflect the condition states of assets by comparing past and current inspection reports. The model also provides the cost spent on various maintenance activities. The CAMS tool can be used with the reactive models. In Figure 7, the deterioration curve abruptly shifts from current condition to a failure condition C5 after one year. This abrupt change in the deterioration curve is a reflection of the occurrence of an extreme event. The cost associated with the replacement of failed assets is shown in the cost bar below.

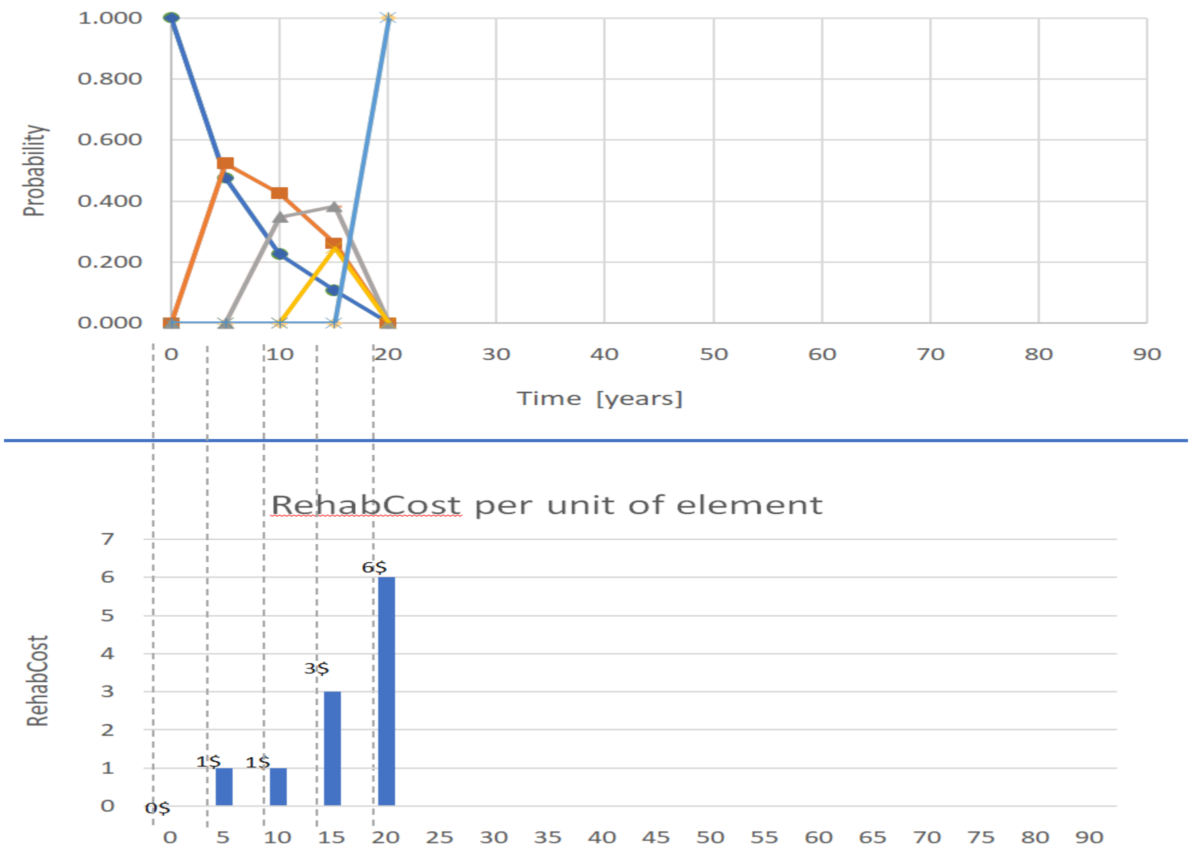

FIGURE 7: DETERIORATION CHANGE DUE TO INCIDENT AND SERVICE RESTORING GRAPH

The CAMS tool takes the rehabilitation cost per unit of element to be the cost of replacing an element when it changes to failure condition C5.

3.4 Damage and Performance

Based on the condition of the element before the event, its intensity, and the intensity of the event, we have some way of estimating the actual condition of the element after an extreme event.

For the budget reactive module (after an extreme event occurs), CAMS assumes that it will all end up in the C5 condition after the event occurs. In reality, some elements may not be functional, and some will experience failures or outages concurrently.

Ideally, the CAMS generated module will serve as a budget planning tool (for proactively identifying system weaknesses) during extreme events.

- Expected condition C
- Damage index D=(C-1)/4
- Performance Q=1-D

FIGURE 8 shows the prediction of final condition by the CAMS tool after an extreme event based on the current condition and intensity of the extreme event. It can be seen that if the current condition of assets is in good state, it requires extreme event with large intensity to change the good condition into very poor or failure condition. For example, the lower part of Figure 6 shows that if an asset is in condition 4 (yellow line) before the extreme event, then the event with intensity measure of 2 can bring the asset to the final failure condition 5. On the other hand, if the asset is in initial condition 1 (blue line), it requires an intensity measure of 5 to bring asset to final failure condition. The upper part of Figure 6 shows an example of condition, damage and performance of an asset before and after the extreme event. The intensity of extreme event can be obtained from past data or scenarios-based analysis. For example, fire intensity is defined in fire science as the rate of heat transfer per unit length of the fire front. The intensity is more related to the process of the event and might be difficult to be measured in some cases. Alternatively, event severity can be used to assess its damage or impact on the surroundings. In this case, event severity can be used to replace event intensity in damage assessment and estimation. Based on this damage performance model, it is recommended to maintain assets in a good condition to mitigate the impacts of extreme events.

Before Event		Event	After Event	
Year	5	IM	C	2.524
C	1.524	2.00	D	0.381
D	0.131		Q	0.619
Q	0.869			

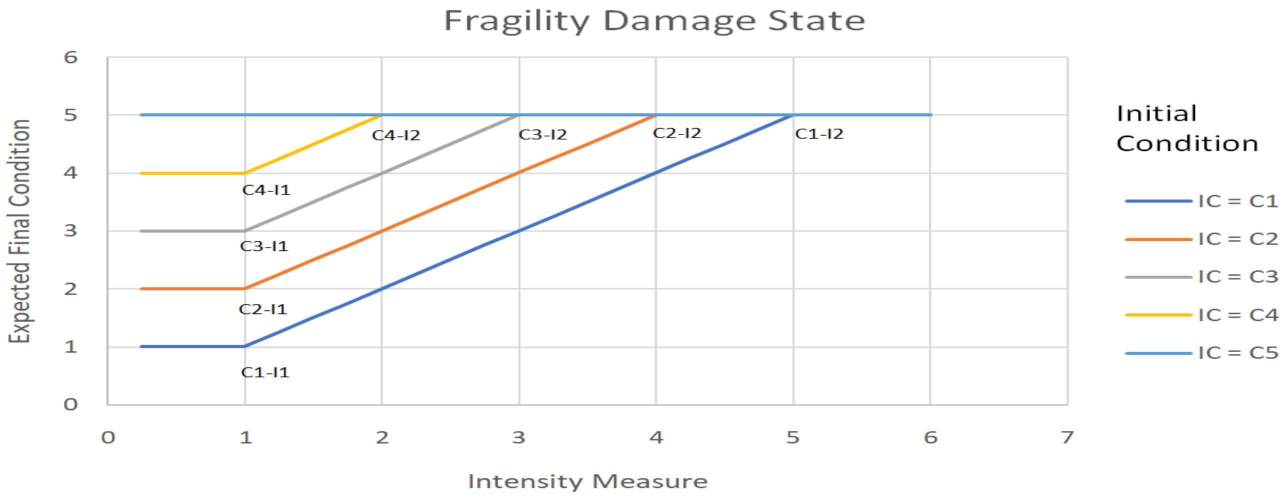

FIGURE 8: FRAGILITY DAMAGE STATE[3]

4. Resilience Model (quantitatively and qualitatively)

The damage condition of all components for a mixed-type incident can be assessed as a whole. CAMS can determine the future performance of the infrastructure based on the assessment of damage, including the budget and recovery time. FIGURE 9 shows two methods that can be used to assess the resilience of a component. To quantify railway resilience, CAMS uses the condition states of rail assets as an indicator of resilience instead of the framework of resilience shown in FIGURE 9 and FIGURE 10due to a lack of complete historical data. The first method is a quantitative method that uses an integration formula to calculate the resilience. Alternatively, the second method is a qualitative method that considers many factors contributing to the recovery rate as shown in FIGURE 9. These factors can be arranged in a hierarchy structure that enables calculation of their scores to arrive at the resilience index. Each contributing factor is given a qualitative score based on expert opinion. FIGURE 10 shows the comparison between the Australian framework on contributing factors to the resilience of the infrastructure asset and the simplified framework adopted for CAMS to estimate the resilience of a rail component.

FIGURE 11 shows the integration formula that consider how performance Q(t) of the component returns to its normal level over a recovery period of time t after a damage event. The resilience becomes the area of the curve Q(t) and the larger the area the higher the resilience. FIGURE 11 also shows the calculation of resilience with regards to performance Q(t) and resource C. The resource C and recovery time T often has some correlation as shown in FIGURE 11. However, this method requires the data on the performance Q(t) after a damage event, which might not always be available and the contribution of many factors (e.g., the capacity of emergency service and social support) to the recovery rate is difficult to measure.

Reducing recovery budgets for disruptions in infrastructure functionality is crucial to railway operations. In particular, effective strategies for enhancing railway resilience need to:

- Develop tools for the recovery of infrastructure, such as the CAMS mathematical environment
- Quantify resilience associated with quick recovery facilities after incidents.

- Develop a computationally manageable approach for resilience optimisation.

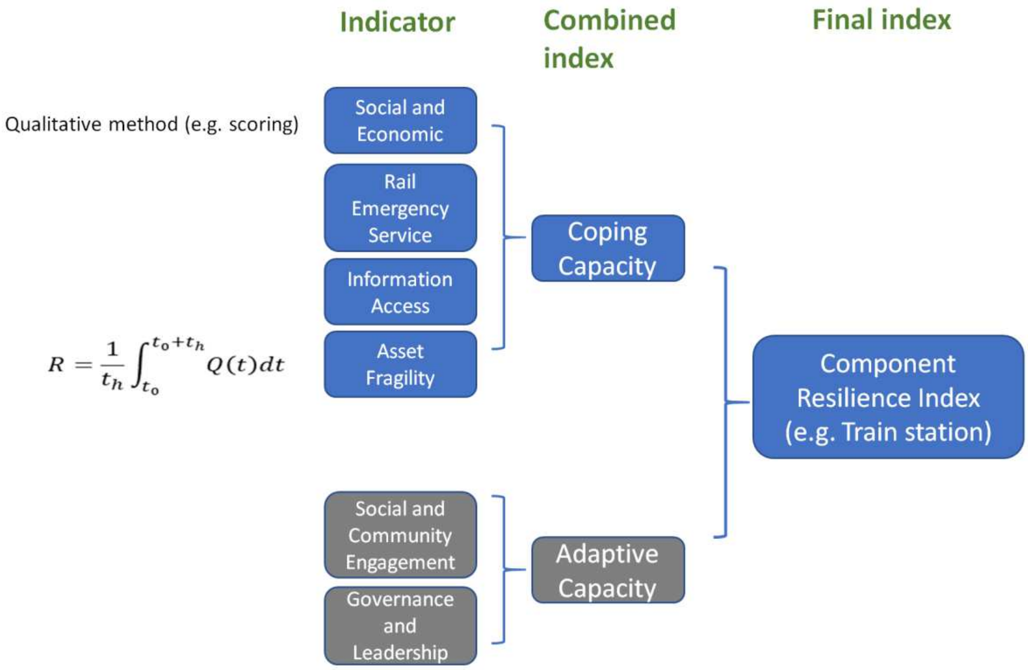

FIGURE 9: THE COMPONENT LEVEL OF THE RESILIENCE MODEL[3]

CAMS propose a simple mathematical formulation to model recovery phases, assess resilience, and optimise the resilience of infrastructure through reducing repair and replacement budgets. The CAMS multistage curves are designed to reduce computation costs and make recovery plans more manageable and practical.

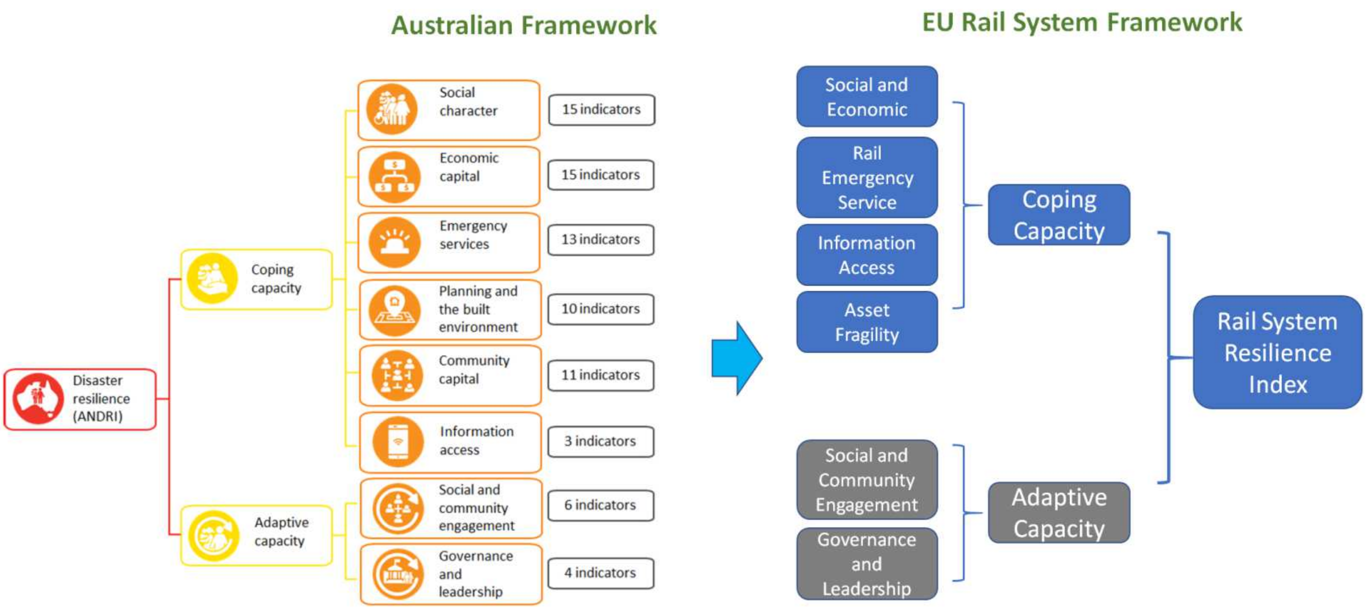

FIGURE 10: COMPARISON OF THE RESILIENCE INFRASTRUCTURE IN AUSTRALIA AND THE EU (AS A SAMPLE)[14]

For instance, if an asset is in good condition 1, then resilience is 4 and if the asset is in failure condition 5, its resilience is zero (0) because this condition state requires replacement or major repair, which often takes long time and high cost. However, for some IT assets, the replacement might take a short time if the replacement part is readily available. As the condition state becomes poorer due to deterioration or extreme events, the resilience gets smaller. In this example, the range of resilience is between 0 and 4. A smaller or larger scale can be used. This is a simplified approach since data to calculate resilience using the quantification method is not yet available. CAMS then formulates a multi-feature optimisation budget plan that aims to increase the resilience of the metrics while minimising the recovery cost and increasing the accuracy of the results. The outcomes of the optimisation are maintenance actions that can keep the rail assets in good condition, thereby maintaining the specified level of resilience. The objective of the optimisation is the cost minimisation over a planning time while keeping the resilience or asset condition at the specified level. For example, Table 1 shows an example of 4 rail assets and their area (m2), conditions and corresponding resilience in a particular year. As explained above, condition 1 is brand-new and condition 5 is the worst or failure condition. The asset condition is obtained from inspection at the current year or predicted by deterioration model in the future year. Table 2 shows five maintenance actions and unit costs that can be taken in a year for a rail asset. Table 3 shows the optimisation solution for maintaining resilience and minimising total cost over a period of 2 years for a given annual budget. As can be seen from Table 3, the annual maintenance cost is below the annual budget. The resilience of rail assets is kept at 3 or above and the total cost over 2 years is minimised taking into consideration the annual rate of deterioration

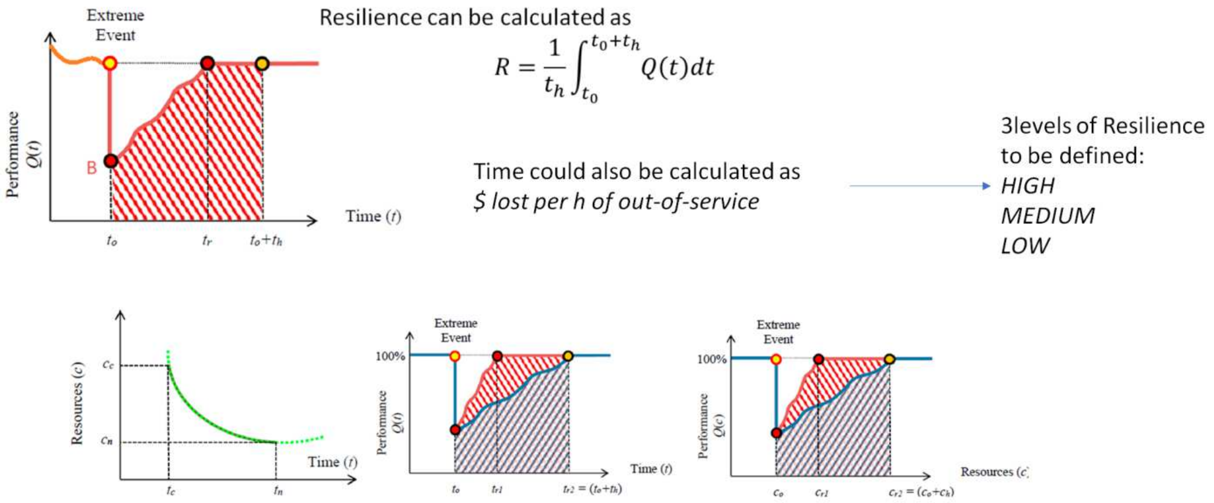

FIGURE 11: QUANTIFICATION OF THE RESILIENCE INFRASTRUCTURE IN CAMS[14]

Four basic railway assets and their resilience are shown in Table 1 and Table 2. Additionally, Table 3 presents an estimation of how to maintain resilience while minimising costs over the next two years. In section 6 and Annex II, detailed cost calculations are presented for the simulation exercises.

No.	Class	Length(m)	Width(m)	Area(m2)	Condition	Resilience
1	Track	92	7.1	656	2	2
2	RollingStock	243	7.1	1725	2	2
3	Station	172	7.1	1221	5	0
4	Info. System	449	8	3592	1	4

TABLE 1: FOUR BASIC RAIL ASSETS

Do-nothing	Minor repair	Medium repair	Major repair	Replace
Cost-M0	Cost-M1	Cost-M2	Cost-M3	Cost-M4
€0	€0.6/m2	€1.08/m2	€2.09/m2	€3/m2

TABLE 2: FOUR BASIC RAIL ASSETS AND THEIR RESILIENCE

€ 10,000	**Budget**			**€ 10,000**	**Budget**	
						3
Total Cost	**€ 5,123**			**Total Cost**	**€ 732.60**	**12**
Year1-Action	**Yr1-Cost**	**Resilience after repair**	**Deterioration**	**Yr2-Action**	**Yr2-Cost**	**Resilience after repair**
2	708.48	4	3	0	0	3
2	1863	4	3	0	0	3
3	2551.89	3	2	1	732.6	3
0	0	4	3	0	0	3
	Ave.	3.75			Ave.	3
	Sum	15			Sum	12
	RAIL SYSTEM Resilience	**3**			**RAIL SYSTEM Resilience**	**3**

TABLE 3: AN ESTIMATION OF OPTIMISATION SOLUTION FOR MAINTAINING RESILIENCE AND MINIMISING COST OVER 2 YEARS

4.1 Resilience Quantification

CAMS aims to model the effects of a cyber-physical attack on infrastructure and determine a schedule for the recovery of Quantification budgets due to incidents. There are several components that have to be scheduled in a recovery facility to make data easier to manage for decision makers at different levels. CAMS uses historical and predictive data on the state variables that describe the components' time evolution to prepare inputs for recovery and estimation budgets for reopening damaged facilities under attack. SAFETY4RAILS exercise simulation uses imaginary scenarios to identify critical members, component priorities and state variables. CAMS creates a realistic budget plan for the repair or replacement of broken components through simulation exercises. In CAMS, some newly added features define recovery times and costs for the damaged components along the railway infrastructure.

5.Budget Optimisation for Infrastructure Resilience

5.1 Predicted Cost by CAMS

According to D7.1, CAMS tool has the capacity to optimise infrastructure investment across multiple locations. For example, rail lines can be divided into metro lines and suburb lines. For multiple asset groups and a limited budget, the optimisation solution focuses on minimising the total cost while keeping critical assets at a specified level of resilience. Figure 12 shows a collective view of the asset portfolio and its functional spaces. The colour of the boxes represents the average condition of the spaces, and the sizes represent the number of components.

The model within CAMS consists of deterioration matrices that have been developed using historical condition data gathered from multiple sites in Australia. Due to limited condition data of rail assets at the current stage, those deterioration matrices using Australian data are used as the substitute until more condition data of rail assets become available. These matrices can then be converted into deterioration curves which are used to predict the life of assets over time.

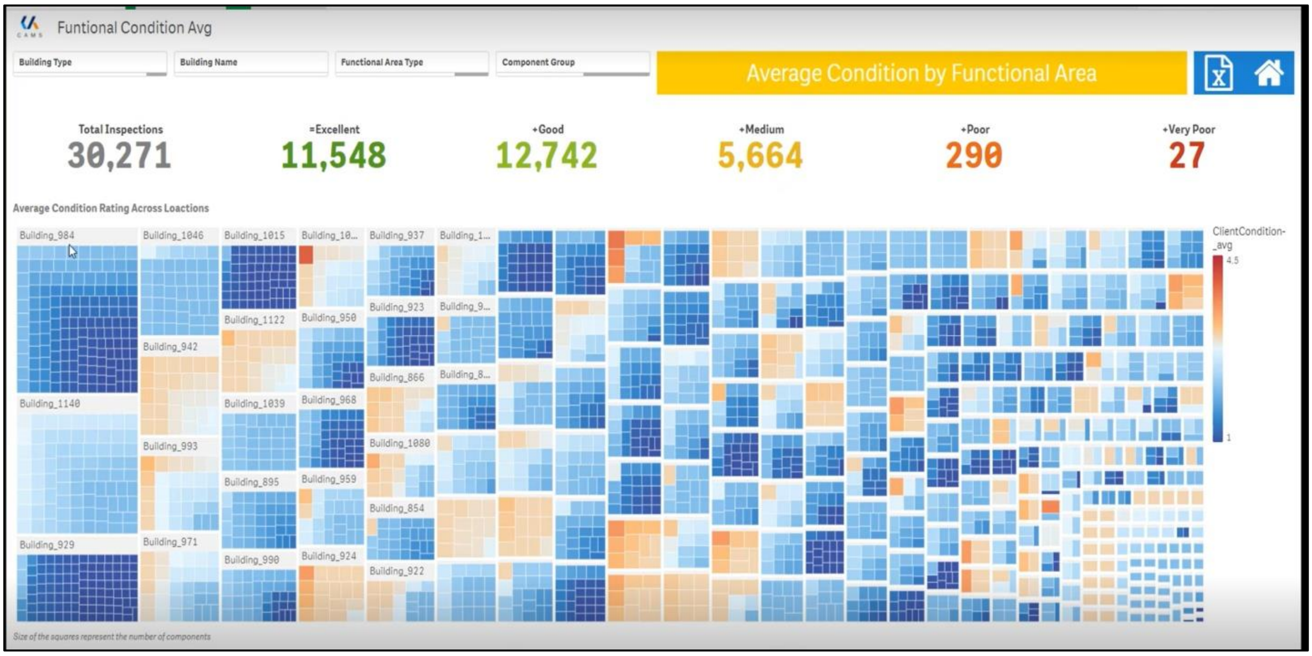

FIGURE 12: CAMS CONDITION DISTRIBUTION

Unlike standard deterioration curves which are linear or simple deterministic curves, the probabilistic nature of these curves provides a distribution of condition rather than a definite condition of an asset. At any given point in time, the condition rating of an individual asset is a probability distribution instead of a specific condition rating. Each curve consists of five individual curves for condition 1 to condition 5, where 1is best condition 5 is worst condition. The total value of all these curves adds up to 100% at any given point in time. Using this probability, an intervention can be applied, and replacement of the asset can be carried out when a certain probability threshold point is met. FIGURE 13 shows an example of the outcome which is generated by CAMS. Replacement costs are uploaded for each asset. When the threshold point is reached, each of these assets will be replaced which shows as a single peak in the cost chart. The analysis is run for all of the components in the system and the result is aggregated to determine the portfolio. FIGURE 13 component count is 30271. For these components the total required cost for 42.5 million over the next 40 years. On the bottom right corner of the dashboard a distribution of risk cost is represented. The size of the blocks represents the intensity of the cost. An array of scenarios can be generated by varying the replacement probability threshold. The scenarios can be selected based on a variety of factors including risk, criticality, component group location etc. The outcome information can be displayed in different tabs.

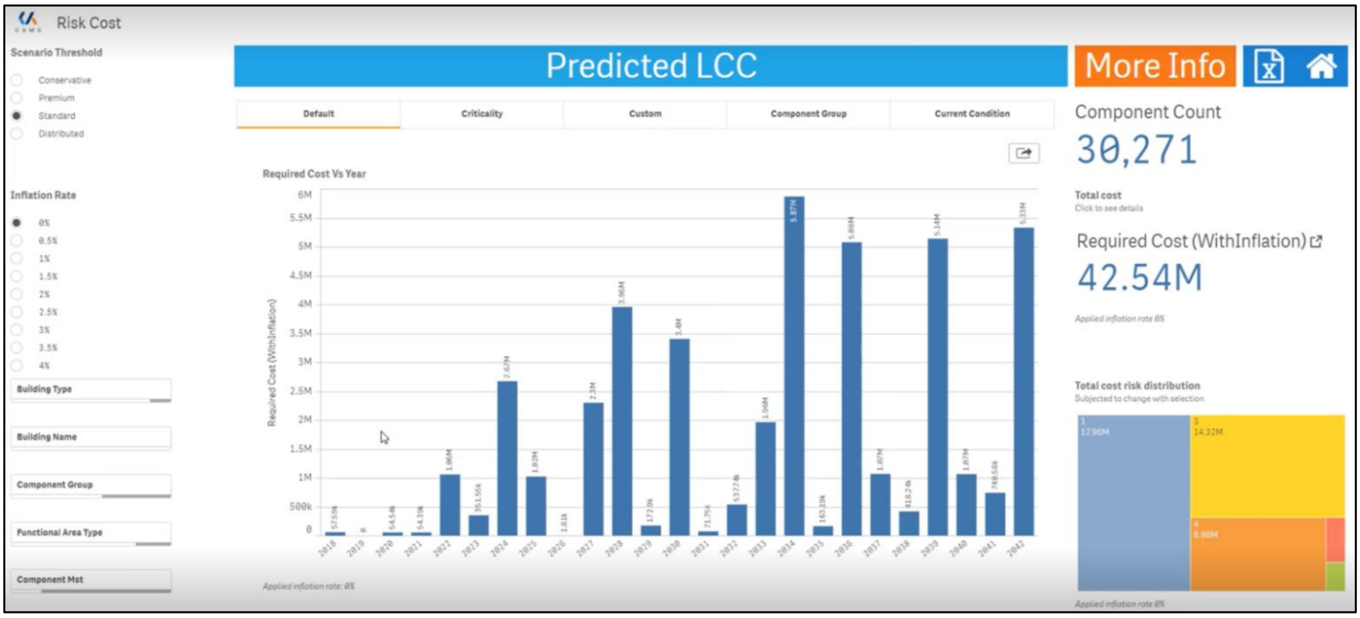

FIGURE 13: CAMS PREDICTED COST

CAMS also develops financial modelling and simulation techniques to evaluate the effectiveness of investments and lack of investments in railway infrastructures physically, digitally, as well as operationally, determining whether there is a cascade of effects on the railroad industry in the case of an event or attack.

FIGURE 14 represents the cost profile distributed by criticality. Each colour represents a different criticality; red: High criticality and blue: Low criticality. Criticality can be based on many factors and will be different from one station to the next. Each element may have a criticality based on their location, function, contribution to safety etc. (Distributing criticality as shown helps.)

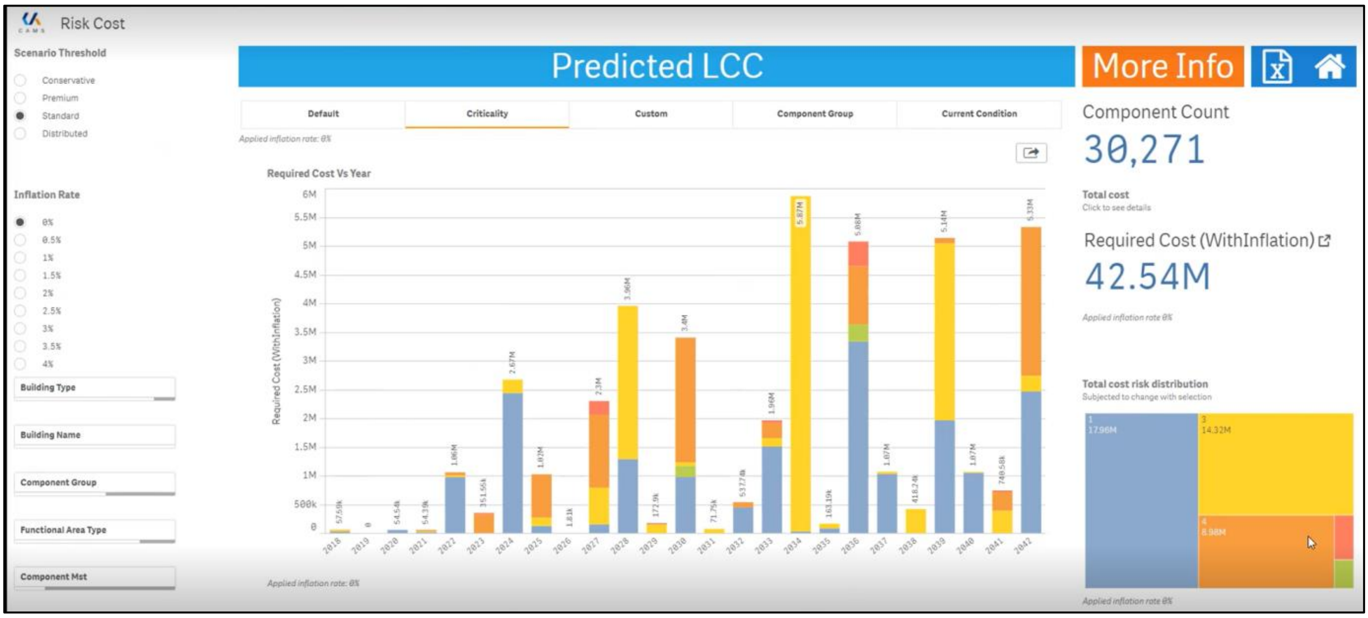

FIGURE 14: CAMS COST DISTRIBUTED BY CRITICALITY

Cost related to different criticality ratings can be isolated and analysed. This feature enables the user to identify and plan for budgeting with limited resources. As seen in FIGURE 15 only criticality 4 has been selected and the number of components has now decreased to 4550 and the cost has changed to 8,98 million. This means if there was limited budget; the priority can be applied for the high criticality/risk assets.

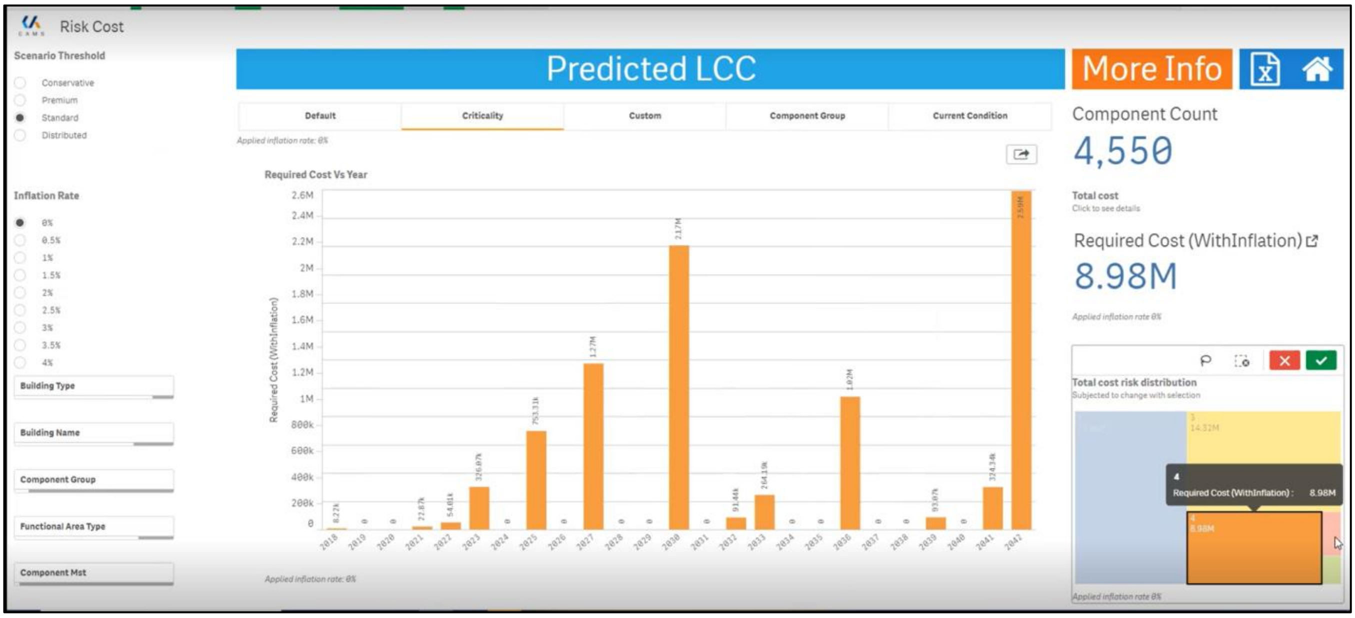

FIGURE 15: CRITICALITY 4 COST

FIGURE 16 shows the selected criticality profiles are 4 and 5 and the required budget over the 40 years is 24.08 million. Thus, if there was a limited budget, the propriety criteria could be applied to these assets and the low criticality assets left to be dealt with later as requested.

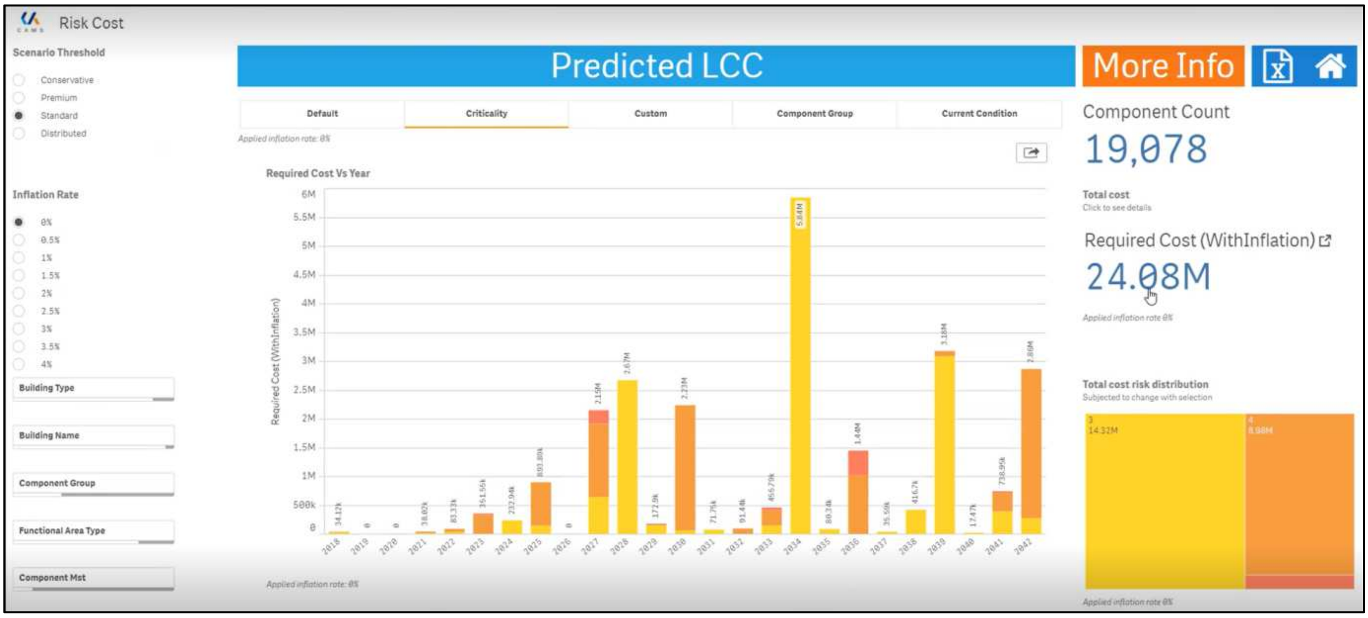

FIGURE 16: CRITICALITY 4 AND 5 COST

5.2 Budget Optimisation by CAMS

CAMS suggests a budget that is required to maintain the facility according to the scenario that is applied to the assets. This is the ideal budget if unlimited resources are available. However, this is not the case in most situations and there are always limited resources. When limited resources are available, a restrictive budget can be applied to the report which then will provide a cumulative difference profile. This can be used to estimate the required budget and adjust the requirement according to the risk profile.

FIGURE 17 shows the required cost in blue bars and the yellow dots represents the applied budget per annum, in this case 2.25 million. This provides the red line graph which shows the cumulative difference between the suggested cost and the available budget over time. In a situation where the budget is not sustainable enough for the upkeep of the selected scenario, higher risk assets can be focused on rather than all of the assets.

This will ensure that all the critical assets are maintained at the required level of resilience (resilience is described in Section 4 of this document). CAMS has a data field to specify risk/importance ranking of individual assets which can be defined by the end user. The data field can be filled manually or can also be filled using a batch excel file uploaded into CAMS. The risk ranking or priority level of individual assets is used as a constraint in the budget optimisation under limited budget. If the budget is not limited, the risk ranking of assets is not used.

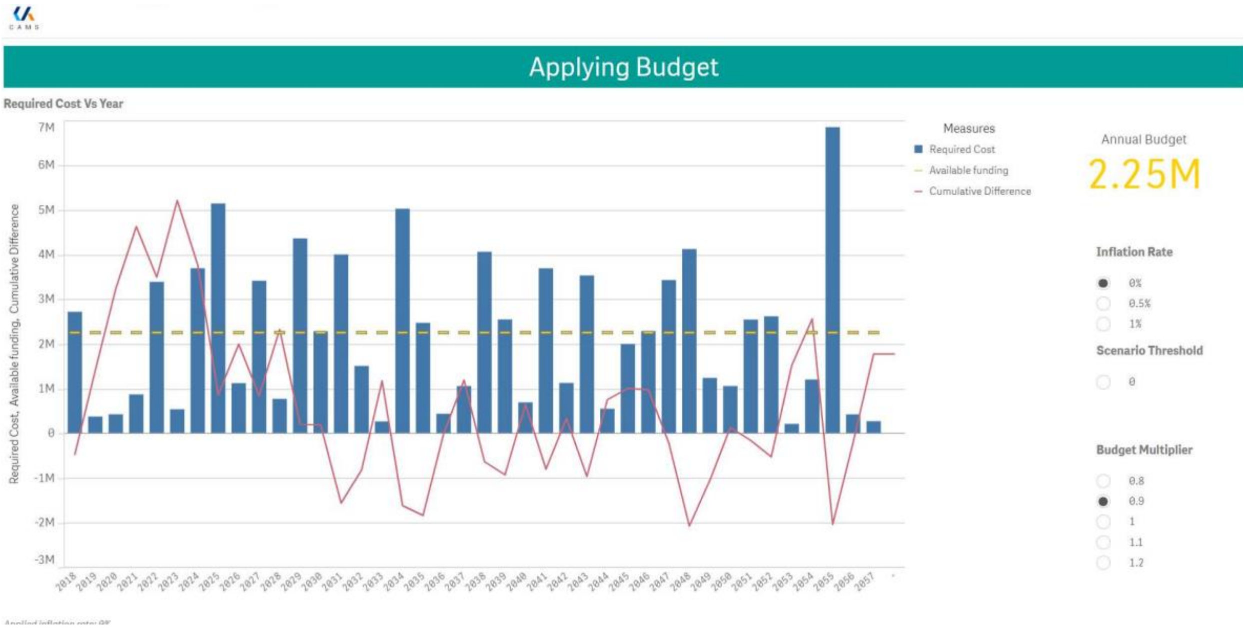

FIGURE 17: CAMS WORKFLOW

FIGURE 18 shows the three levels of budgets provided by CAMS. The difference comes from the different levels of resilience threshold applied to the train network. As mentioned above, it is unlikely that unlimited repair/replacement budget is available for improvement of all damaged assets. Therefore, using the resilience index discussed in section 4, an optimised budget can be provided. This provides a lower cost at the expense of some assets not being in peak condition, however, satisfying the minimum level of resilience required for normal operation of the station.

In this report, the overall budget over a set time period (i.e., 10 years) is looked at. The objective of the optimisation is to have the least budget required over a period of time while ensuring the correct function of the asset.

Additional Inputs that are required for this model to work are as follows

- Maximum available budget per year
- Resilience index before and after incident (Condition Rating is proportional to resilience index. See Table 4)
- Minimum resilience index threshold (This will enable the user to choose which the level of resilience expected of all assets as the minimum acceptable, for example, Resilience Level 3 means all assets will have a resilience index of 3 or higher)
- Unit Cost (cost needs to be supplied: minor repair, medium repair, major repair and replacement cost)
- Hierarchy information (including condition rating and quantity)

Situation	Cond.	Resilience Index
Best	1	4
Good	2	3
Fair	3	2
Poor	4	1
Worst	5	0

TABLE 4: RESILIENCE INDEX TO CONDITION RATING RELATIONSHIP

Sometimes it is not advisable to provide minor or medium repair for assets that have suffered major damage and are in the worst condition/resilience index. Providing minor repair may not be possible as the entire asset needs to be replaced in full or at least major repair carried out. Within CAMS this can be input as a replacement priority factor so these assets are budgeted for with high priority.

In addition, priority considerations could be also informed by the changing vulnerabilities, due to the evolution of external threats landscape. In this context, the dynamic Threats Severity Ranking and Combinatorial Countermeasures Prioritisation framework, as developed by UREAD and extensively described in D7.1, would inform CAMS with the prioritised vulnerability fixes to support dynamic optimisation of resilience investments for the maintenance of a target resilience level responsive to the ever-changing sources and likely impacts of threats.

TSR-CCP is based on an ontologically committed and methodologically guided analysis to arrive at an operational-context-aware managed mix of highest priority countermeasure sets to support cost-effective and efficient resilience assurance against security and privacy threats as an exemplar. This led to 38 highest priority countermeasures being prescribed by TSR-CCP for safeguarding against 363 ranked privacy and security threats facing an IoT-enabled Railways System.

Accordingly, TSR-CCP supports Agile Resilience Assurance to protect and mitigate against any risks in any domain provided one could estimate the likelihood of the risks leading to threats and materialising as attacks/incidents and the scale of their impacts.

However, it is important that the threats and countermeasures analysis provides for intuitive visualisation as offered in TSR-CCP decision tables. CAMS also provides the following Graphical User Interface to input the budget optimisation parameters (FIGURE 18). The minimum replacement threshold provides the minimum resilience threshold level to which the condition of an asset has to be raised after it has reached resilience index 0. This means you cannot do minor/medium repair on a completely failed assets, rather needs major repair/full replacement to improve threshold to level 3 (FIGURE 18) or higher (4).

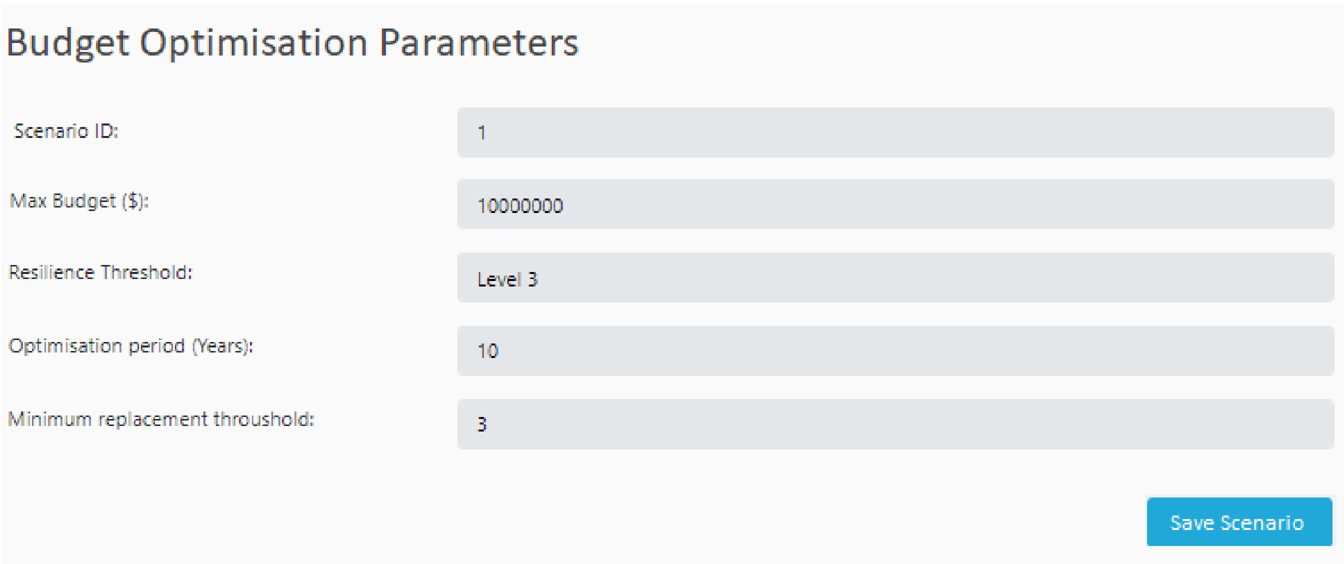

FIGURE 18: CAMS BUDGET OPTIMISATION GUI

The optimisation can produce a graph as shown in FIGURE 19. The colours represent three levels of applied resilience thresholds. The resilience thresholds are coded as 0 to 4 with 0 being the lowest level of resilience and 4 being the highest resilience. Three levels of resilience optimised budgets can be seen below. The lowest budget is for assets that are at resilience level 2. This means all the assets are brought up to an index level of 2 or higher. The highest budget is for resilience level 4, which brings all assets to a resilience level of 4, which is the highest resilience.

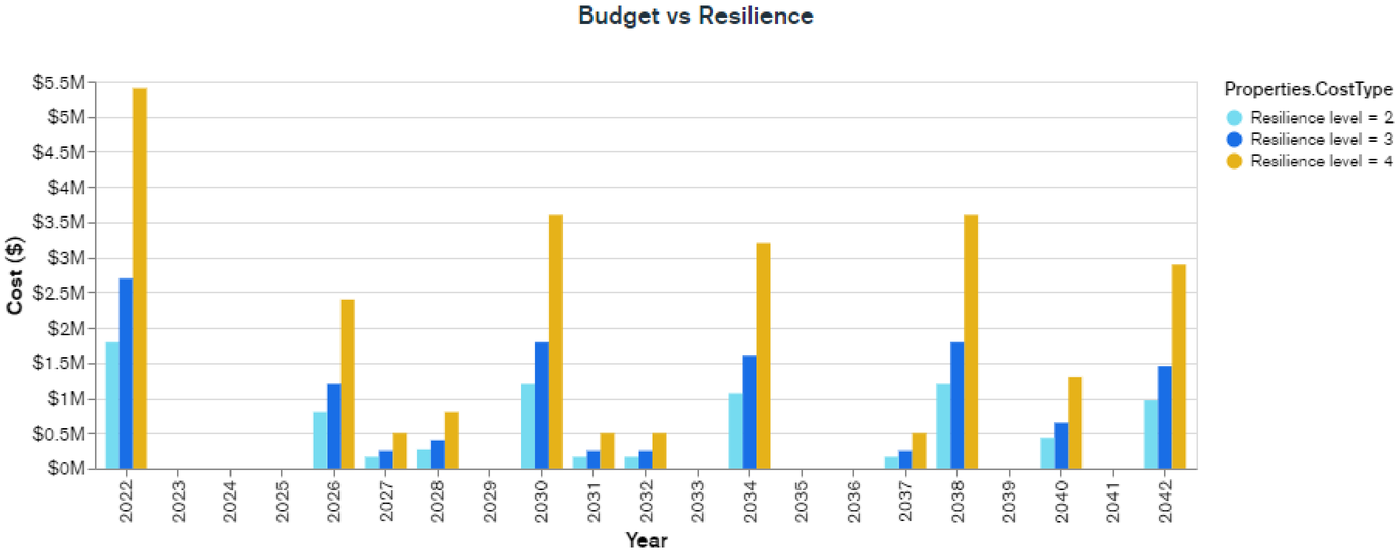

FIGURE 19: CAMS BUDGET OPTIMISATION WITH RESILIENCE LEVEL

5.2.1 MdM Simulation Exercise

This section presents the results of Madrid simulation exercises in terms of budget optimisation. FIGURE 20 shows the graph of the budget required for the maintenance of the facility for the next 40 years on the assumption of no incidents occurring. As can be seen, the different peaks represent the cost of the replacement cycles for the assets that are nearing end of their useful lives. The cost is distributed across multiple years and in this instance the cost of year 2022 is mild compared to the full lifecycle cost across the next 40 years.

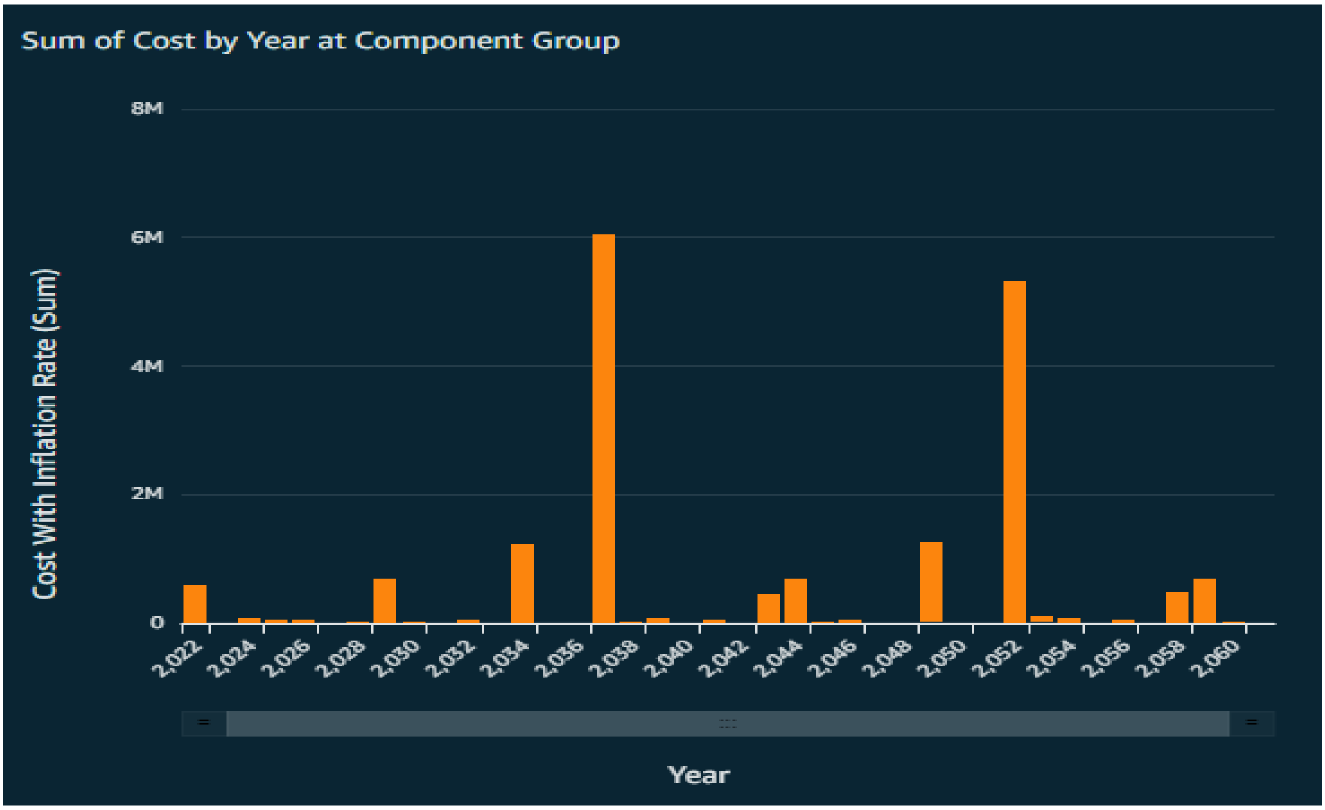

FIGURE 20: MADRID SE – COST BY YEAR AT COMPONENT GROUP

FIGURE 21shows the impacted graph after an incident occurs in 2022. The bar chart is split by colour to represent the component of cost affected due to the incident occurring. Note the spike in 2022 due to the requirement to replace a large proportion of assets all at once due to the bomb blast. The spike also occurs twice in the 40-year lifecycle since some of components have reached their natural end of life after the initial replacement in 2022. The increase in cost is significant and can see there is a large gap between what is seen in FIGURE 20 vs. FIGURE 21. This significant cost is not budgeted for, and an effective strategy needs to be put in place to ensure adequate operation of the station after the incident.

FIGURE 21: MADRID SE – BUDGET REQUIRED POST INCIDENT

The above cost focuses on identifying all assets that are damaged and replacing them. This can be a very costly exercise after a disastrous event due to the significant damage caused. A better approach is to identify and attend to repairable assets which can reduce the initial cost during the year of the incident, spreading the cost over multiple years. In CAMS, this budget optimisation utilises the resilience index level. This means that all the assets that are damaged are not considered to be replaced, but some repaired to an adequate level ensuring the station is operational but may not be at its optimal performance. This is the best outcome with the budget strain that has been created due to the unexpected cost increase.

As seen in FIGURE 22, three variations of costs for the three levels of resilience: two, three and four, have been calculated. The highest budget is for level 4 as all assets are repaired/replaced to a resilience index level 4. This cost is different from the above replacement schedule as the goal is to keep the resilience level high and not replacing everything that is dropped to condition 5. The peak cost in 2022 is due to the incident occurring in that year. The repeat costing seen throughout the next years is due to natural deterioration resulting in the already replaced assets reducing in condition and reaching the resilience level selected. These assets are again replaced/repaired providing the budget shown for the next 10 years.

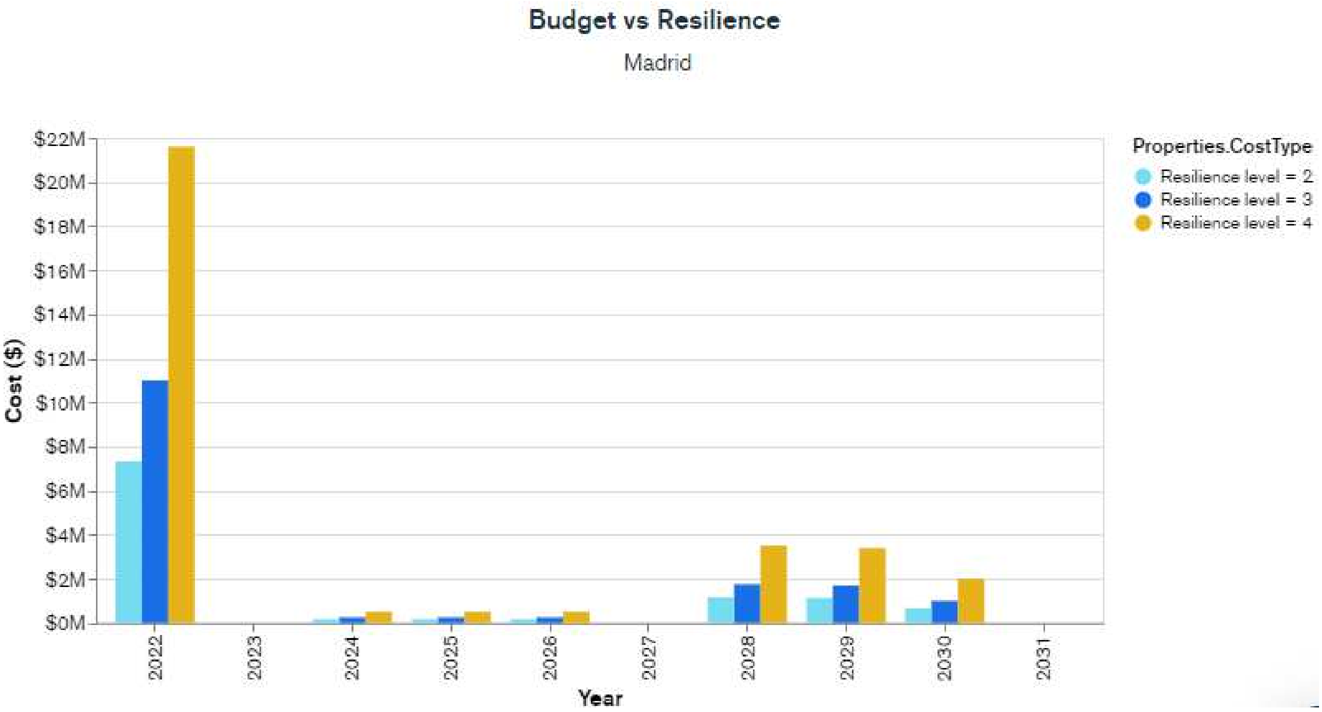

FIGURE 22: MADRID SE- OPTIMISED BUDGET PLAN FOR DIFFERENT RESILIENCE LEVELS

The tables in ANNEX II show samples of how FIGURE 22 has been generated. It shows the calculation steps taken to achieve the result above. A sample list of components (Table 12) used for the analysis is shown (Column 1 and 2). All components within the station have been analysed using the CAMS budget optimising algorithm. The third column represents the resilience after the event which is when the condition of the assets is at its poorest. Year 1 action shows values from 1 to 4 (minor, medium, major repair, and lastly full replacement). Cost of the work is highlighted in the next column. The resilience improvement is shown in the next column followed by the resilience degradation due to natural deterioration. The natural aging process is slow, and the optimisation effects can only be observed when considering several years of budget planning. The optimisation algorithm helps identify the best condition in which the elements should be replaced/repaired to get the best value for cost over time.

Table 10 and Table 11show a range of replacement schedules and their resulting resilience index in brackets for non-optimised and budget optimised scenarios for a sample of assets from the MdM scenario. The table summarises the resilience rating and the schedule of work that needs to be completed on these assets. The values L1, 2, 3 and 4 correspond to the minor, medium, major repair and full replacement. The improved resilience index is shown next to the action within the bracket. For example, L3(2) represents an action level 3 (L3)and an achieved resilience of 2 ("(2)"). As seen, many of the assets are in resilience state 0 (Column 3) after the incident. Minimum threshold resilience is set to level 2 which is achieved in the bracket next to the action).

For Asset ID 12 - "Auxiliary signals", the minimum resilience threshold is set to 2. Due to the damaged caused by the incident, Resilience After incident has dropped to 0 (Table 10). To bring the resilience level back up to 2, an action L2 (Medium repair) is completed. The resilience level has increased to 2 as shown in the bracket due to this action (2022 L2(2)). Due to natural deterioration, in 2024 the resilience level has dropped back to 1 (Please refer to detailed calculation in ANNEX II-Table 12). To meet the minimum threshold of 2, L1 – minor repair is conducted which brings the resilience rating back to 2.

This is done without optimising the cost, and therefore, each two years year there is an additional cost of minor repair due to natural deterioration for the next 10 years.

For the same asset Table 11, shows the budget optimised mechanism to replace the asset with the objective of minimising budget for 10 years. For the optimised case, in the first year 2022, the asset is brought to a minimum resilience level to 2. This ensures that the initial cost (incident year) is kept minimal while the minimum resilience threshold is met, and the station is back in operation. However, in 2024, medium repair is completed to achieve a resilience of 3(L2(3)) which brings the resilience threshold to 3 instead of 2. This ensures that in the year 2026 no repair needs to be carried out to ensure minimum threshold is met.

In these two examples the total required cost for non – optimised vs. optimised is €12,180 and €11,760 respectively, saving €420 over the course of 10 year

Looking at the same asset with the resilience threshold of 3, for the optimised scenario (ANNEX II-Table 15), in 2024, Medium repair, L2 (instead of minor repair, L1) is carried out, bringing the resilience level to level 4 (instead of level 3 – minimum). As the resilience level is high, in the following years, there is no need to work on the same asset for the next few years until natural deterioration brings the resilience below 3 (2030). The cost of asset for non-optimised vs. optimised is €15,750 and €15,330 respectively which brings a cost saving due to minimising the repair work that is done on this asset over time. Calculation for this can be found in Table 16 and Table 17.

Table 18 shows the summary of works that are completed for threshold level 4 (detailed calculation outlined in Table 19). This threshold cannot be optimised as threshold 4 is the highest threshold, thus, being the most expensive solution. Table 5shows the difference in optimised and non-optimised budgets for the above scenario and the percentage reduction in budget due to the optimisation for the whole station.

Resilience Threshold	Optimised %Reduction
Level 2	7.56%
Level 3	11.05%

TABLE 5: MADRID SE- BUDGET COMPARISON FOR ALL ASSETS

5.2.2 Ankara Simulation Exercise

The output below shows the replacement budget required for replacement of assets after simulated incident in Ankara exercise. As can be seen, the peak in 2022 represents the cost of assets that need to be replaced due to the incident.

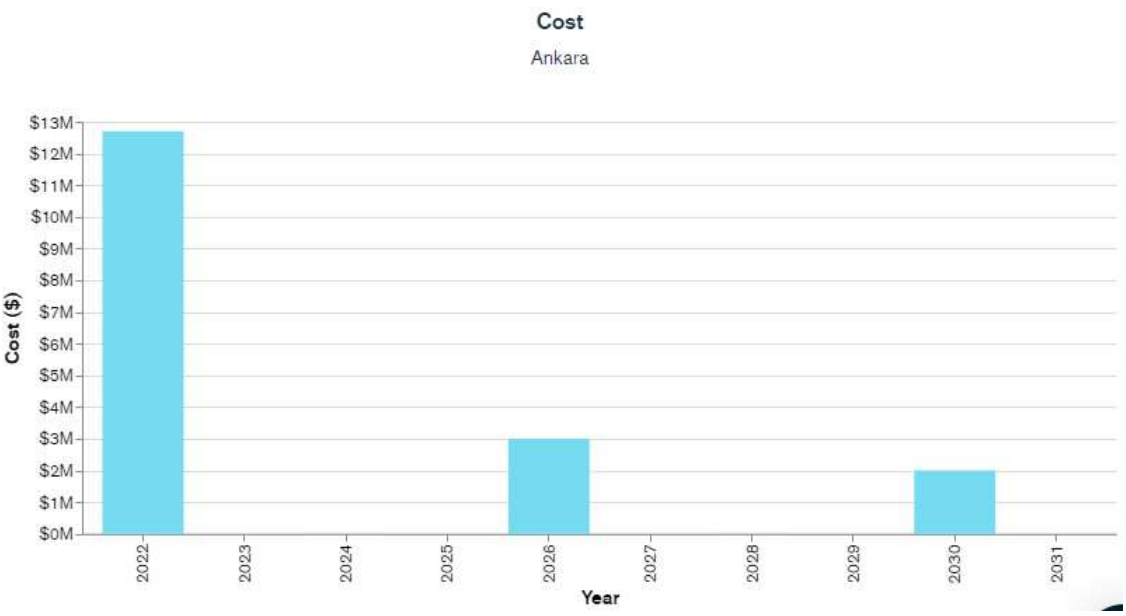

FIGURE 23: ANKARA SE - REPLACEMENT COST PROFILE

The output is calculated using replacement schedule for all that have reached condition 5. This can be resource intensive as replacements can be expensive compared to repair work. Resilience threshold canbe used as a tool to reduce the unexpected cost that is added due to the incident occurring.

FIGURE 24 provides an optimised budget plan for the assets which consider minimising the total required budget over 10 years. Using different target resilience threshold levels, the total cost can be adjusted to the level of budget available. An overall resilience level has been selected across all assets. Further fine tuning can be done if different levels of resilience levels are selected base on the criticality/impact of the assets.

Expected budgets for resilience levels 2, 3 and 4 is produced. Calculations for both non-optimised and optimised resilience budgets can be found in Table 20 to Table 27. Table 28 shows the schedule of works for resilience threshold of 4 (Calculation can be found in Table 29). This scenario does not have an optimised solution as resilience level 4 is the maximum. Detailed explanation of the calculation method can be found in the previous simulation exercise in section 5.2.1.

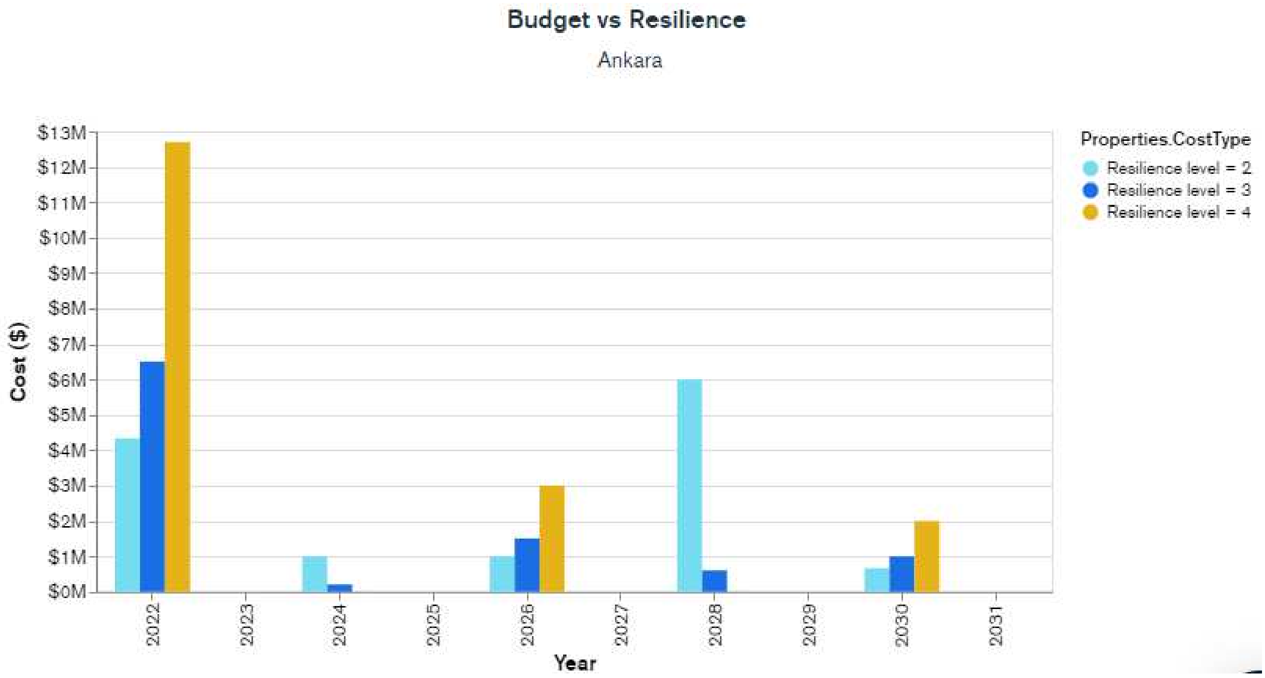

FIGURE 24: ANKARA SE - OPTIMISED BUDGET PLAN FOR DIFFERENT RESILIENCE LEVELS

Table 6 shows the budget difference for the above scenario and the cost saving that can be achieved by optimising the budget over the next 10 years.

Resilience Threshold	Optimised %Reduction
Level 2	6.37%
Level 3	8.18%

TABLE 6: ANKARA SE - BUDGET COMPARISON FOR ALL ASSETS

5.2.3 RFI Simulation Exercise

FIGURE 25 shows the lifecycle cost of the station during simulated incident in Rome simulation exercise. As can be seen the cost of replacement in the first year (2022) is high as the damage caused by the incident needs to be mitigated. The cost provided below focuses on the replacement of the assets that are damaged during the incident.

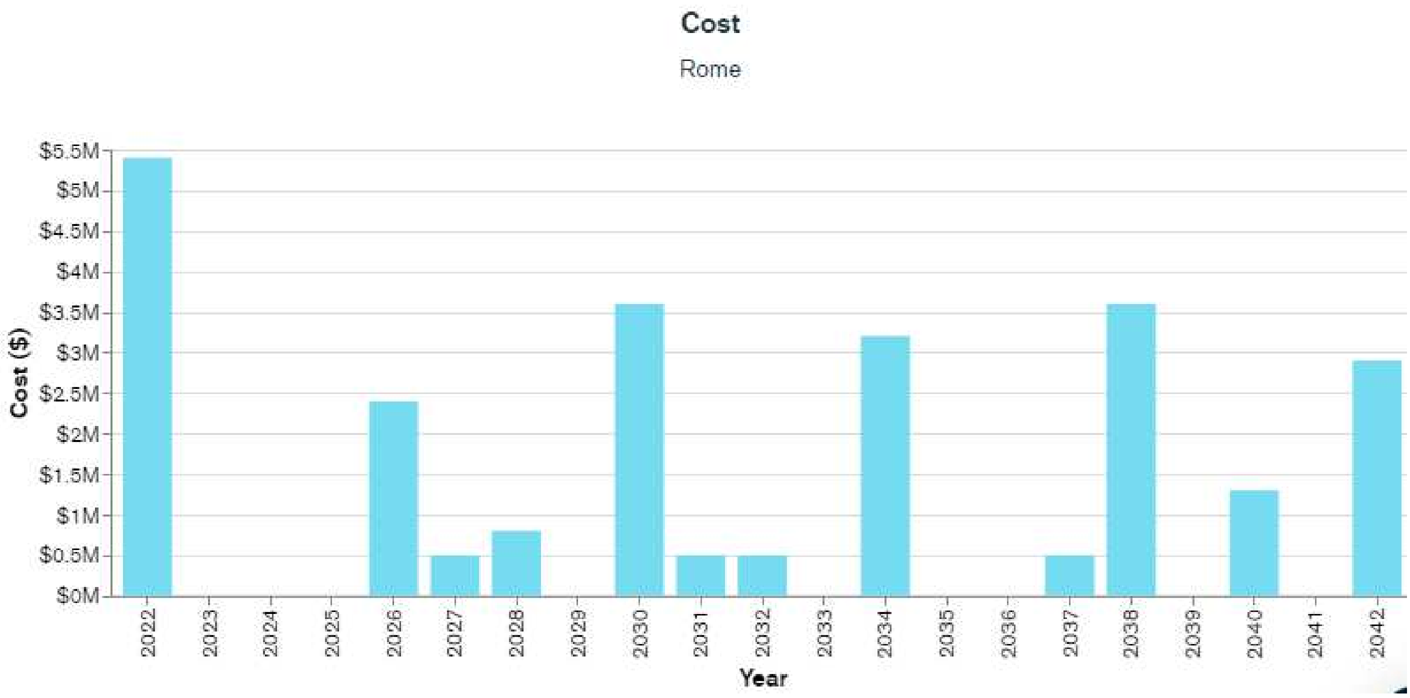

FIGURE 25: RFI SE- REPLACEMENT COST POST INCIDENT

As mentioned in the previous simulations, the above budget is not practical as only replacements are carried out and not repairs (which costs less). Introducing major and minor repairs alongside replacements can provide a budget that is manageable. FIGURE 26 shows the optimised budget for the Rome Simulation exercise. This profile also operates with three levels of resilience.

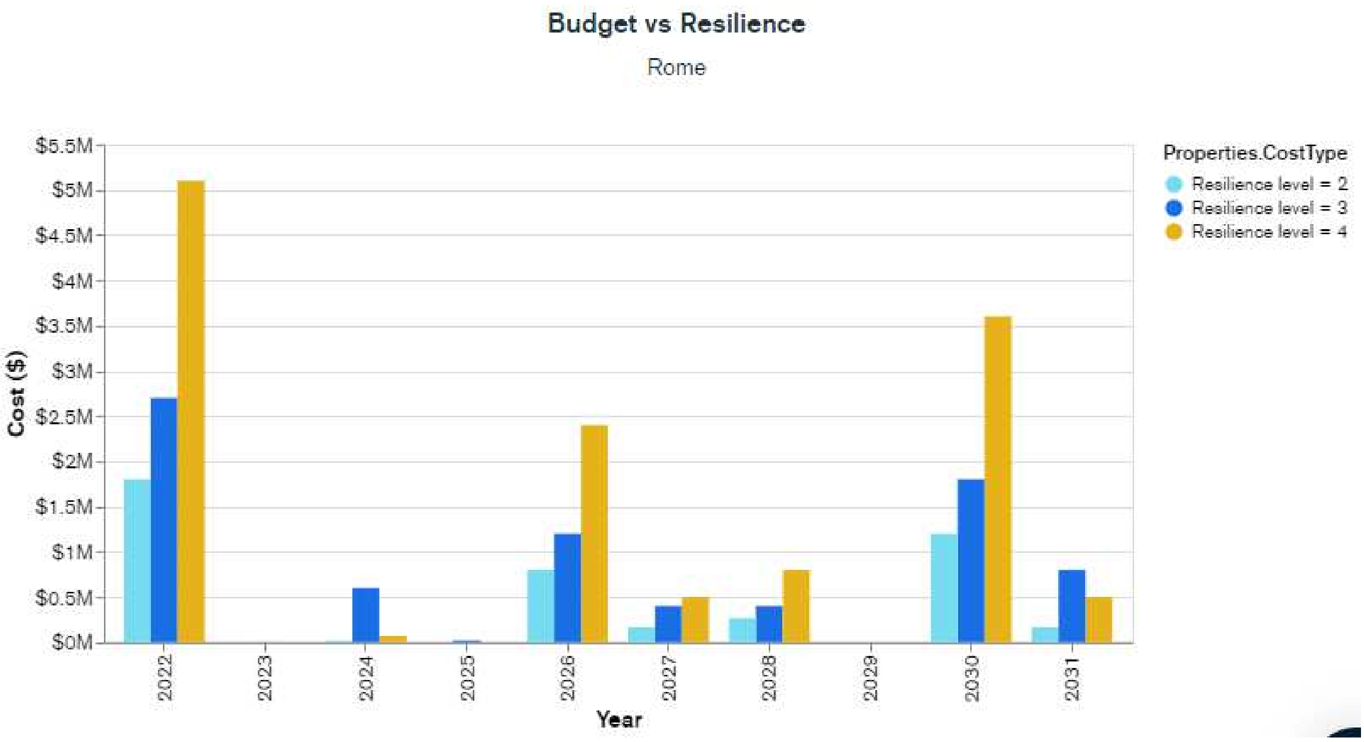

FIGURE 26: RFI SE- OPTIMISED BUDGET PLAN FOR DIFFERENT RESILIENCE LEVELS

Table 30 to Table 39 shows the calculation steps taken to produce the above graph. As mentioned in the previous simulation exercise, optimisation cannot be completed for threshold level 4 as all assets are replaced if any of them goes below resilience level 4.Table 7 shows the comparison of cost between optimised and non-optimised scenarios for thresholds 2 and 3. Detailed explanation of how this cost is calculated can be found in section 5.2.1.

Resilience Threshold	Optimised %Reduction
Level 2	4.86%
Level 3	7.60%

TABLE 7: RFI SE - BUDGET COMPARISON FOR ALL ASSETS

5.2.4 Milan Simulation Exercise

FIGURE 27 shows the cost that was calculated using CAMS in Milan Simulation exercise. A sample budget has been applied to simulate the backlog that has been created over time due to the budget not being enough detailed. As can be seen, there is a spike in 2022 due to the incident occurring and which gives a total of 7.3 million in cost. The applied simulated budget is 6 million for that year.

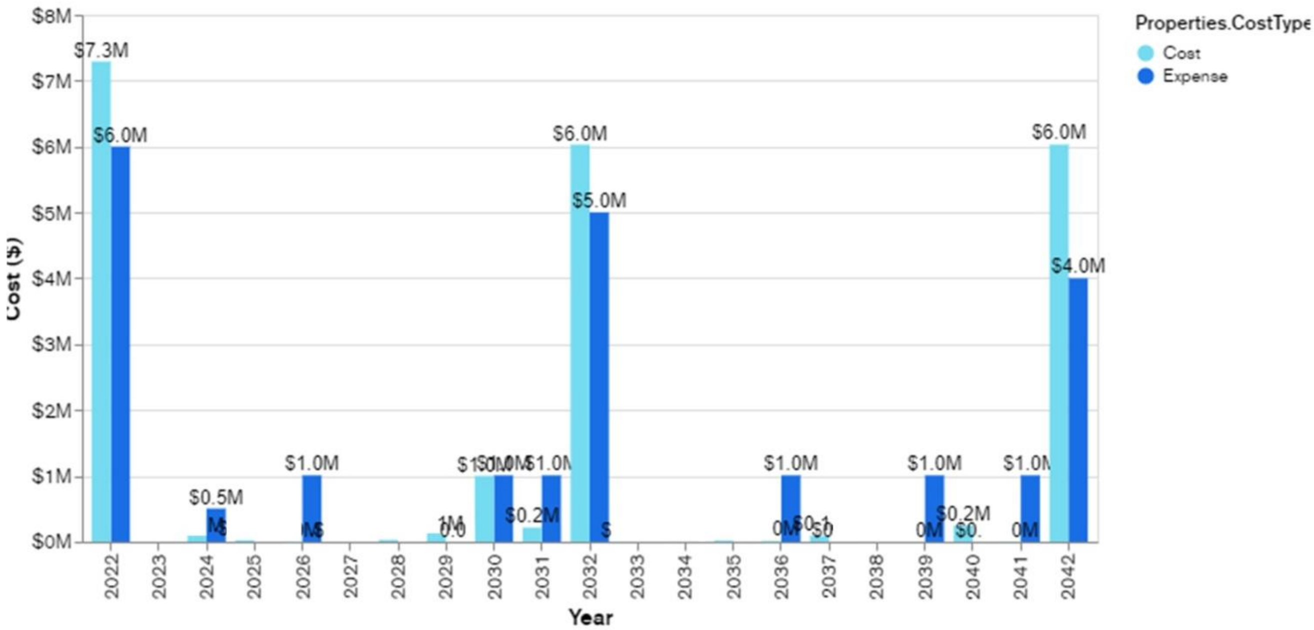

FIGURE 27: CDM SE- BUDGET VS. COST

Using the above numbers, a cumulative backlog plot can be created so that the backlog or the surplus of funding can be visualised as shown below. In this hypothetical scenario, the chart starts with a backlog of one million and continues to reduce over the next few years. By 2042 there is a surplus or approximately half a million available which is a positive outcome.

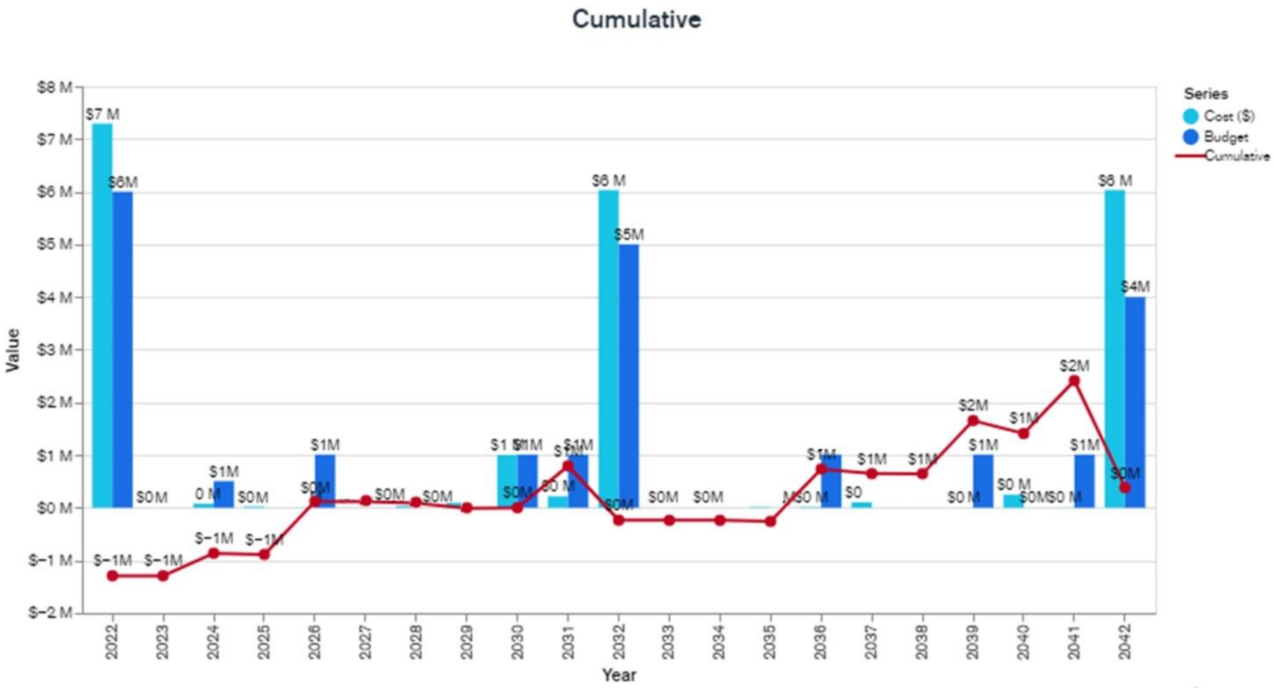

FIGURE 28: CDM SE - CUMULATIVE BACKLOG

The above required budget is hypothetical and not practical in most cases. In reality the available budget is not enough, and some level of optimisation must be run to reduce the required budget while keeping the quality of operation at an acceptable level. The resilience index is used to prioritise assets to be repaired/replaced with the limited available budget. Below is the optimised budget for the Milan Simulation exercise. This profile also considers three levels of resilience.

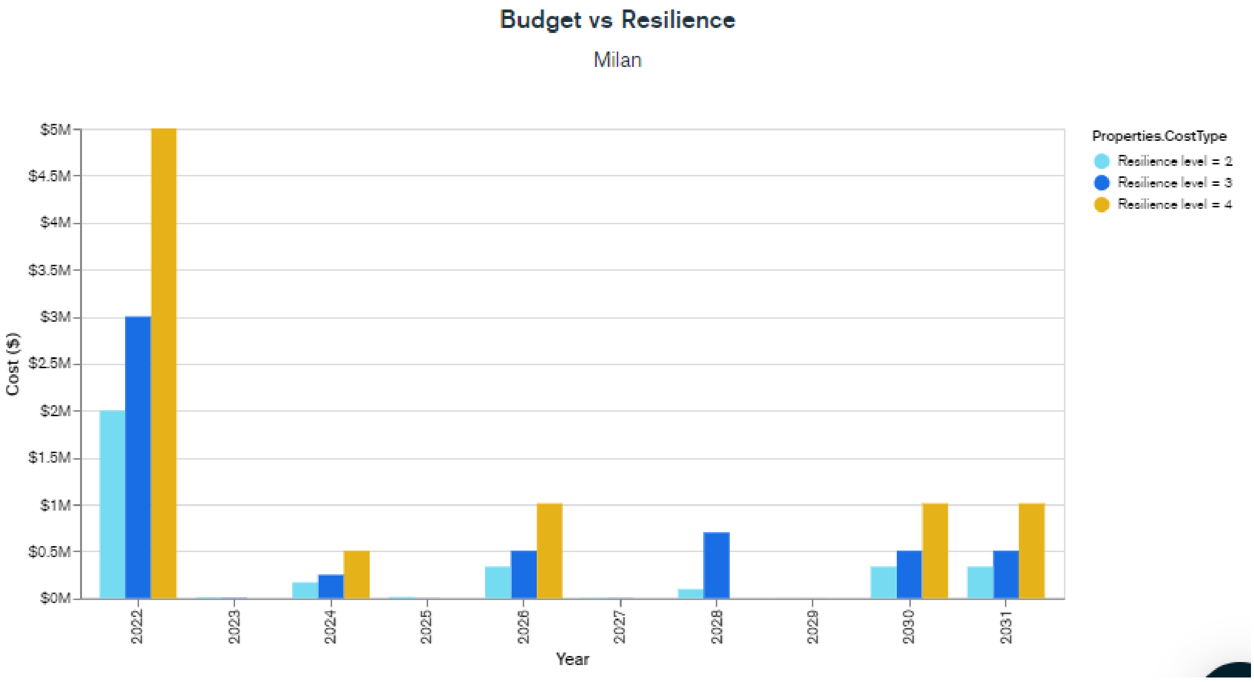

FIGURE 29: CDM SE - BUDGET OPTIMISATION

Table 40 and Table 41 show the difference replacement schedules and their outcome resilience index in brackets for non-optimised and budget optimised scenarios for a sample of assets from the Milan scenario (resilience level 2). As can be seen many of the assets are in resilience state 0 after the incident and having the threshold of minimum 2 requires actions to be taken in the year 2022. The option is available to whether improve the condition to the required minimum 2 or higher. The benefit is that in the long run (10 years in this case) the total expenditure can be minimised by improving replacing in full compared to doing minimum repair. In the non-optimised version, the minimum rule of level 2 is satisfied. In the budget optimised version, in 2022, some assets are replaced, and improved to resilience levels above 2. The overall budget over 10 years is minimised as there is less repetitive maintenance work due to the improvement in conditions. Calculations for threshold level 2, 3 and 4 can be found in Table 40 to Table 49. Budget is not optimised for threshold level 4 as it is the highest threshold that can be applied.

Table 8 shows 10-year budget difference between optimised and non-optimised budget scenarios. As can be seen there is a saving due to the optimisation.

Resilience Threshold	Optimised %Reduction
Level 2	7.32%
Level 3	9.00%

TABLE 8: CDM - BUDGET COMPARISON FOR ALL ASSETS

6. Summary and Conclusion

6.1 Summary

The methodologies in the S4RIS platform have been designed to effectively address the end-users identified within the scope of the SAFETY4RAILS project. Based on a conceptual framework and the results of the four simulation exercises, the optimisation of the system has been achieved. RMIT has reviewed the data collection processes adopted by the various end-users with different scenarios and developed a specification method for data collection. In the final exercises (RFI & CdM), two sets of railway component data were used to calibrate the deterioration model. The calibrated model has been validated using a separate set of inspected data. In addition, deterioration prediction has been incorporated into the decision optimisation for railway assets. Accordingly, in the following section, RMIT has presented quantitative conclusions based on CAMS (investment) assessments and budget optimisation during the SAFETY4RAILS project.

6.2 Conclusion

For the Madrid simulation exercise two strategies have been outlined in this report. Firstly, the cost of replacing all assets that are in poor condition (condition 5 and resilience level 0) and that were replaced or renewed. The replacement also was extended to the future years using the deterioration algorithms found in CAMS. The replacement cost of year one is very high as the condition of assets in the year of incident is very poor (i.e., many assets in condition 5).

Another alternative to replacing assets in full is to identify which elements can be repaired instead of replacement in full. Four levels of actions were introduced L1 to L4 (L1 minor repair, L2 medium repair, L3 Major repair and L4 full replacement). Resilience thresholds were introduced to provide a variation to the minimum budgets required to have the stations under operating conditions.

Having a threshold of 2 means that all assets within the station are raised or above this threshold (approximate condition rating of 3). In this case the station can be in operation, however, all assets are not in their optimal condition.

Thresholds 3 and 4 aim to improve the operational condition of the station. The effect of this improvement is the added cost.

In addition to the initial cost, CAMS calculated the cost associated with natural deterioration of assets after the incident. This deterioration results in poor assets in the future years which also needs to be replaced/repaired to ensure continual operation of the station.

As seen in simulation exercise for Madrid, the cost of replacement of all assets in condition 5 is very high in the year of the incident. Introducing resilience thresholds, the cost in the first year as well as the recurring costs due to natural deterioration has been reduced compared to full replacement of assets in poor condition.

Within each resilience level an optimised solution vs. non-optimised version of budget was calculated. The goal of optimising is to reduce the overall cost of repair/replacement of assets over a period of time (in this case 10 years into the future after the incident). In the non-optimised scenario, only the minimum threshold is satisfied. So, if the minimum threshold is set to 2, all assets are improved only up to a 2 (if they are a 1 or a 0). In the optimised budget scenario, some assets are improved beyond level 2 if there is a significant saving of doing that improvement over time. Instead of performing minor repair that must be done every year for 10 years (which costs a small amount every year but may add up to a large sum over 10 years), a major repair/replacement can provide an overall improved resilience of the station while minimising the small repair work that needs to be performed each year to keep the minimum threshold met. This optimised schedule of works helps provide a lower overall cost than that of non-optimised scenario when considering all the assets that belong to the station.

For Madrid simulation the optimised cost was lower by 7.56% and 11.05% for threshold levels 2 and 3 respectively.

No optimisation can be run for threshold level 4 as the maximum threshold level that assets can be improved to be level 4. This account for replacing all assets those are below threshold 4 for each year. While this can keep the station in optimal condition, budgetary constraints make this option impractical.

Similar work was done for Ankara simulation exercise and the optimised cost reduction was calculated as 6.37% and 8.18% for Levels 2 and 3 respectively.

For Rome simulation the reductions of costs for optimised scenario vs. non-optimised were at 4.86% and 7.6% for Levels 2 and 3 respectively.

For Milan simulation exercise the figures were 7.32% and 9% for levels 2 and 3, respectively.

Based on the Central Asset Management System (CAMS), RMIT developed the SAFETY4RAILS CAMS Rail System to analyse the financial and budgetary state of the rail infrastructure at a granular level, as well as to identify the vulnerabilities of each critical component. In the initial static analysis, triggers for dynamic monitoring will be identified. Whenever any issue is detected, the daily operations team will be notified by CAMS during the recovery phase. In the future, CAMS will move from being a maintenance and upkeep tool to being able to handle a wider range of extreme events or hazards. The system is cloud-based, and security of data will be analysed in detail, as well as audit and control. Infrastructure such as rail and metro systems will be monitored automatically after incidents. RMIT smart programs and IoT initiatives will contribute to the outcomes. By using machine learning and probabilistic simulation, we will be able to observe a greater range of options, leading to more effective policies and strategies. By digitising and granularly capturing the entire rail infrastructure and evaluating its vulnerabilities, accuracy will far exceed current levels. There will be variable risk ratings for events and triggers which affect the risk rating and financial and budget planning forecast. Refer to Annex II for a detailed calculation for the above items.

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Bibliography

1. SAFETY4RAILS (H2020 GA no. 883532).
2. SAFETY4RAILS, Deliverable D3.1 Identification and characterisation of cyber(-physical) systems and threats in railway environment, February 2022.
3. SAFETY4RAILS, Deliverable D7.1 Investment assessment model for cost-benefit evaluation of risk mitigation and recovery, July 2022.
4. SAFETY4RAILS, Deliverable D7.2 Consequence cost model various failure scenarios, August 2022.
5. SAFETY4RAILS, Deliverable D7.3 Budget simulation module of S4RIS, August 2022.
6. SAFETY4RAILS, Deliverable D7.4 Resilience assessment model of optimised investment, August 2022.
7. SAFETY4RAILS, Deliverable D8.3 Final version of development of a blueprint exercise handbook, June 2022.
8. Hessam Mohseni, Deterioration prediction of community buildings in Australia, 201261{77}.
9. Gutierrez de Ceballos JP, Turégano-Fuentes F, Perez-Diaz D, Sanz-Sanchez M, Martin-Llorente C, Guerrero-Sanz JE. 11 March 2004: The terrorist bomb explosions in Madrid, Spain – an analysis of the logistics, injuries sustained and clinical management of casualties treated at the closest hospital. Critical Care 2004.
10. Article number 2007-123-36, Published www.socialstyrelsen.se, September 2007.
11. Lu, X. Yu, M. Jia, G. Wang, Simplified fragility analysis methods for minimum life-cycle cost seismic design of generic structures (2010).
12. Capacci, F. Biondini, Probabilistic life-cycle seismic resilience assessment of ageing bridge networks considering infrastructure upgrading, Structure and Infrastructure Engineering 16 (2020) 659{675}.
13. Mohseni, S. Setunge, G. Zhang, R. Wakefield, Markov process for deterioration modelling and asset management of community buildings, Journal of Construction Engineering and Management 143 (2017) 04017003.
14. M. Qeshta, M. J. Hashemi, R. Gravina, S. Setunge, Review of resilience assessment of coastal bridges to extreme wave-induced loads, Engineering Structures 185 (2019) 332 {352}.
15. Tran, H. D. 2007. Investigation of Deterioration Models for Stormwater Pipe Systems. PhD Thesis, Victoria University.
16. Micevski, T., Kuczera, G. &Coombes, P. 2002. Markov Model for Storm Water Pipe Deterioration. Journal of Infrastructure Systems, 8, 49-56.
17. Ross, S. M. 2000. Introduction to probability models, San Diego, Calif.; Academic
18. Decision-making model for sustainable management of Australian community buildings: combined approach using analytical hierarchy process and neuro-fuzzy system, Pushpitha Kalutara, Guomin Zhang, Sujeeva Setunge& Ron Wakefield
19. Enhancing Resilience of Critical Road Structures: Bridges, Culverts and Floodways Under Natural Hazards, Sujeeva Setunge, Priyan Mendis, Karu Karunasena, Kevin Zhang, Dilanthi Amaratunga, WeenaLokuge, NilupaHerath, Long Shi, HessamMohseni, Huu Tran & Kanishka Atapattu, May 2021.
20. Condition Monitoring and Condition Aggregation for Optimised Decision Making in Management of Buildings, Hessam Mohseni1, Sujeeva Setunge, Guoming Zhang, and Ron Wakefield
21. Decision-making for the Sustainable Management of Community Buildings in Australia using Fuzzy Logic, Pushpitha Kalutara, Guomin Zhang, Sujeeva Setunge, Ron Wakefield

22. Deterioration prediction of community buildings in Australia, HESSAM MOHSENI, 2012.
23. A gamma wears process. Reliability, IEEE Transactions on, 24, 152-153, ABDEL-HAMEED, M. 1975.
24. Risk management in the construction industry using combined fuzzy FMEA and fuzzy AHP. Journal of Construction Engineering and Management, 136, 1028-1036, ABDELGAWAD, M. & FAYEK, A. R. 2010
25. Stochastic Processes for modeling bridge deterioration. Mechanics of Structures and Materials, 2009 London. Taylor & Francis Group, p. 533-538, ABOURA, K., SAMALI, B., CREWS, K. & LI, J.
26. Parameter estimation for reactive transport by a Monte-Carlo approach. AIChE Journal, 52, 2281-2289, AGGARWAL, M. & CARRAYROU, J. 2006.
27. An introduction to management science: Quantitative approaches to decision making, South-Western Pub, ANDERSON, D. R., SWEENEY, D. J., WILLIAMS, T. A. & MARTIN, R. K. 2007.
28. Risk management - Principles and guidelines, AS/NZS 2009. AS/NZS ISO 31000:2009.
29. A Framework Linking Knowledge of Insulation Ageing to Asset Management-[Feature Article]. Electrical Insulation Magazine, IEEE, 24, 38-46, BAHADOORSINGH, S. & ROWLAND, S. 2008.
30. Estimating Transition Probabilities in Markov Chain-Based Deterioration Models for Management of Wastewater Systems. Journal of Water Resources Planning and Management ASCE, 132(1), 15-24, BAIK, H. S., JEONG, H. S. & ABRAHAM, D. M. 2006.
31. Guidebook to decision-making methods. Retrieved from Department of Energy, USA: http://emiweb. inel. gov/Nissmg/Guidebook_2002. Pdf, BAKER, D., BRIDGES, D., HUNTER, R., JOHNSON, G., KRUPA, J., MURPHY, J. & SORENSON, K. 2002.
32. Probabalistic approach for predicting life cycle costs and performance of buildings and civil infrastructures. Proceedings of the 2nd International Symposium on Integrated Life-time Engineering of Buildings and Infrastructures, 2003. 553-558, BAMFORTH, P.
33. Mathematical theory of reliability, Siam Philadelphia, BARLOW, R. E., PROSCHAN, F. & HUNTER, L. C. 1996.
34. Discrete choice analysis: theory and application to travel demand, MIT press, BEN-AKIVA, M. & LERMAN, S. 1985.
35. Asset management framework for geotechnical infrastructure. Journal of Infrastructure Systems, 9, 107-116, BERNHARDT, K. L. S., LOEHR, J. E. & HUACO, D. 2003.
36. How buildings learn: what happens after they're built, BRAND, S. 1994.
37. Office Score: Refurbishment support tool for office building [Online]. Available: http://www.officescorer.info/ [Accessed 12/09/2004, BRE & DTI. 2002.
38. Markov chain Monte Carlo method and its application. Journal of the Royal Statistical Society: Series D (The Statistician), 47, 69-100, BROOKS, S. 1998.
39. Asset management for transmission and distribution. Power and Energy Magazine, IEEE, 3, 39-45, BROWN, R. E. & HUMPHREY, B. G. 2005.
40. Asset Management Part 1: Specification for the optimised management of physical assets. British Standards, BSI 2008. PAS 55 -1
41. Comparison of methodologies to predict bridge deterioration. Transportation Research Record: Journal of the Transportation Research Board, 1597, 34-42, BULUSU, S. & SINHA, K. C. 1997.
42. Building inspection. Business World (Philippines), BUSINESSWORLD 2008.
43. Pavement performance prediction model using the Markov process, BUTT, A. A., SHAHIN, M. Y., FEIGHAN, K. J. & CARPENTER, S. H. 1987.

44. A European diagnosis and decision-making tool for office building upgrading. Energy and Buildings, 34, 113-119, CACCAVELLI, D. & GUGERLI, H. 2002. TOBUS -
45. Delivering a Re-life Project, CARLYLE, B., HOLLAND, J., GRIERSON, S., GILLIGAN, Q. M. & HUNT, R.
46. Definitions of Inspections and Surveys of Buildings Construction Industry Council, CIC 1997.
47. Stochastic process for extrapolating concrete creep. Journal of the Engineering Mechanics Division, 103, 1069-1088, CINLAR, E., OSMAN, E. M. & BAZANT, Z. P. 1977.
48. An introduction to Markov chain analysis. 1975. Geo Abstracts, COLLINS, L.
49. Element-level bridge deterioration modeling using condition durations. 83rd TRB Annual Meeting, January, Washington, DC, 2004, DELISLE, R., SULLO, P. & GRIVAS, D.
50. Method for estimating transition probability in bridge deterioration models. Journal of Infrastructure Systems, 4, 56-62, DESTEFANO, P. D. & GRIVAS, D. A. 1998.
51. Building adaptation, Spon Press, DOUGLAS, J. 2006.
52. Building Surveys and Reports. 4 ed. Hoboken: Wiley-Blackwell, DOUGLAS, J. 2010.
53. Statistics for Research, Wiley – Interscience, DOWDY, S., WEARDEN, S. & CHILKO, D. 2011.
54. Shuffled complex evolution approach for effective and efficient global minimisation. Journal of optimisation theory and applications, 76, 501-521, DUAN, Q., GUPTA, V. K. & SOROOSHIAN, S. 1993.
55. Application of Gamma process for deterioration prediction of buildings from discrete condition data. Statistical Concepts and Methods for the Modern World. Colombo, Sri Lanka, EDIRSINGHE, R., SETUNGE, S. & ZHANG, G. 2011.
56. Reliability based deterioration and replacement decision model for community buildings. ICOMS. Hobart, Australia, EDIRSINGHE, R., SETUNGE, S. & ZHANG, G. 2012.
57. Condition Prediction of Deteriorating Concrete Bridges Using Bayesian Updating. Journal of Structural Engineering, 125, 1118-1125, ENRIGHT, M. & FRANGOPOL, D. 1999.
58. Department of Transportation. Federal Highway Administration, FHWA, U. 2001.
59. Soft Computing Applications in Infrastructure Management. Journal of Infrastructure Systems, ASCE, 10(4), 157-166, FLINTSCH, G. W. & CHEN, C. 2004.
60. EPIQR software. Energy and Buildings, 31, 129-136, FLOURENTZOS, F., DROUTSA, K. & WITTCHEN, K. B. 2000.
61. MEDIC -- a method for predicting residual service life and refurbishment investment budgets. Energy and Buildings, 31, 167-170, FLOURENTZOU, F., BRANDT, E. & WETZEL, C. 2000.
62. Probabilistic models for life-cycle performance of deteriorating structures: review and future directions. Progress in Structural Engineering and Materials, 6, 197-212, FRANGOPOL, D. M., KALLEN, M. J. & NOORTWIJK, J. M. 2004.
63. Introduction to decision making methods. Laboratory of Operations Research and Decision Systems, Computer and Automation Institute. Hungarian: Academy of Sciences, FÜLÖP, J. 2005.
64. Bayesian data analysis, Chapman & Hall/CRC, GELMAN, A., CARLIN, J. B., STERN, H. S. & RUBIN, D. B. 2003.
65. Bspec. Aspec - www.dspec.com.au, GISSAINTERNATIONAL 2012.
66. Asset management maturity. ICOMS - Presentation. Hobart, Australia, HARDWICK, J. 2012.
67. Introduction to decision making. Home page: http://www.vanguard.edu/rharris/crebook5.htm, HARRIS, R. 1998.

68. Physical Asset Management, London, Springer, HASTINGS, N. A. J. 2010.
69. Probabilistic Risk Assessment. IEEE Press, Tokyo, HENLEY, J. E. & H., K. 1992.
70. Performance based methods for service life prediction. State of the art reports, CIB Report: Publication, 294, HOVDE, P. J. & MOSER, K. 2004.
71. Determining Remaining and Useful Life. AUSTRALIAN INFRASTRUCTURE FINANCIAL MANAGEMENT GUIDELINES, 5, HOWARD, J., SAVAGE, M. & CHAMPION, C. 2006.
72. Infrastructure management: Design, construction, maintenance, rehabilitation, and renovation, New York, McGraw-Hill, HUDSON, W. R., HAAS, R. & UDDIN, W. 1997.
73. Analysis of Urban Granular Pavement Deterioration for Use in Asset Management Modelling - A Literature Review. Queensland Government - Department of Main Roads, HUNT, P. & BUNKER, J. 2001.
74. International Infrastructure Management Manual, IIMM 2006.
75. International Infrastructure Management Manual International Edition. New Zealand: National Asset Management Support Group (NAMS Limited), The Institute of Public Works Engineering Australia (IPWEA), IIMM 2011.
76. Australian Infrastructure Financial Management Guidelines. Institute of Public Works Engineering Australia, IPWEA 2009.
77. International Infrastructure Management Manual. Version 4.0, 2011. New Zealand: New Zealand National Asset Management Steering Group (NAMS), IPWEA & NAMS 2011.
78. Institute of Public Works Engineering Australia (IPWEA).
79. Guide to surveys and inspections of buildings and similar structures. London: The Institution of Structural Engineers, ISTRUCTE 1991.
80. Operations Research Models and Methods. John Wiley and Sons, JENSEN, P. A. & BARD, J. F. 2003.
81. Guide and bibliography to service life and durability research for building materials and components. 2004. CIB, JERNBERG, P., LACASSE, M. A., HAAGENRUD, S. E. & SJÖSTRÖM, C.
82. Bridge performance prediction model using the Markov chain. Transportation Research Record 1180, 25-32, JIANG, Y., SAITO, M. & SINHA, K. C. 1988.
83. Bridge service life prediction model using the Markov chain. Transportation Research Record, JIANG, Y. & SINHA, K. C. 1989.
84. JIN, X. H. & DOLOI, H. 2009. Modeling risk allocation in privately financed infrastructure projects using fuzzy logic. Computer-Aided Civil and Infrastructure Engineering, 24, 509-524.
85. Ordinal Data Modeling. Springer, Amtesdam, JOHNSON, V. E. & ALBERT, J. H. 1992.
86. Fuzzy group decision-making for facility location selection. Information Sciences, 157, 135-153, KAHRAMAN, C., RUAN, D. & DOĞAN, I. 2003.
87. Optimal maintenance decisions under imperfect inspection. Reliability engineering & system safety, 90, 177-185, KALLEN, M. & VAN NOORTWIJK, J. 2005.
88. A PROPOSED DECISION-MAKING MODEL TO PRIORITISE BUILDING ELEMENTS, KALUTARA, P., ZHANG, G., SETUNGE, S. & MOHSENI, H. 2011.
89. MAINTENANCE ACTIONS TOWARDS ACHIEVING SUSTAINABILITY IN COMMUNITY BUILDINGS IN AUSTRALIA. WCEAM World Congress on Engineering Asset Management. Cincinnati, OH, USA.
90. Application of Monte-Carlo simulation to estimate the kinetic parameters for pyrolysis—Part I. The Canadian Journal of Chemical Engineering, 90, 163-170, KAUSHAL, P. & ABEDI, J. 2012.

91. Comprehensive review of structural deterioration of water mains: Statistical models. Urban Water, 3, 131-150, KLEINER, Y. & RAJANI, B. 2001.

92. Modeling Failure Risk in Buried Pipes Using Fuzzy Markov Deterioration Process. In proceedings of Pipelines, ASCE, 7-16, KLEINER, Y., SADIQ, R. & RAJANI, B. 2004.

93. Incremental Seismic Rehabilitation of School Buildings (K-12). FEMA 395. FEMA, KRIMGOLD, F., HATTIS, D. & GREEN, M. 2003.

94. Probabilistic Approach to the Estimation of Urban Stormwater Pollution Loads on Receiving Waters. World Water Congress 2005, ASCE, pp.143-156, KUZIN, S. A. & ADAMS, B. J. 2005.

95. Design and testing of a generalised reduced gradient code for nonlinear programming. ACM Transactions on Mathematical Software (TOMS), 4, 34-50, LASDON, L. S., WAREN, A. D., JAIN, A. & RATNER, M. 1978.

96. Covariates and random effects in a gamma process model with application to degradation and failure. Lifetime Data Analysis, 10, 213-227, LAWLESS, J. & CROWDER, M. 2004.

97. Building maintenance management, Crosby Lockwood Staples, LEE, R. 1976.

98. Poisson regression analysis under alternate sampling strategies. Transportation Science, 14, 346-364, LERMAN, S. R. & GONZALEZ, S. L. 1980.

99. Application of Neural Network Model to Forecast Short-Term Pavement Crack Condition: Florida Case Study. Journal of Infrastructure Systems, 7, 166-171, LOU, Z., GUNARATNE, M., LU, J. J. & DIETRICH, B. 2001.

100. Towards standardisation of service life prediction of roofing membranes. 1998-12-08 1999 Nashville, TN., U.S.A., 3-18, LOUNIS, Z., LACASSE, M. A., VANIER, D. J. & KYLE, B. R.

101. A discrete stochastic model for performance prediction of roofing systems. Proc. CIB World Congress, 1998. Citeseer, 203-313, LOUNIS, Z., VANIER, D. & LACASSE, M.

102. Optimal infrastructure management decisions under uncertainty. Transportation Research Part C: Emerging Technologies, 1, 77-88, MADANAT, S. 1993.

103. Estimation of Infrastructure Transition Probabilities from Condition Rating Data. Journal of Infrastructure Systems, 1, 120-125, MADANAT, S., MISHALANI, R. & IBRAHIM, W. 1995.

104. Poisson regression models of infrastructure transition probabilities. Journal of Transportation Engineering, 121, 267-272, MADANAT, S. & WAN IBRAHIM, W. H. 1995.

105. Probabilistic infrastructure deterioration models with panel data. Journal of Infrastructure Systems, 3, 4-9, MADANAT, S. M., KARLAFTIS, M. G. & MCCARTHY, P. S. 1997.

106. Generalised least-squares parameter estimation from multiequation implicit models. AIChE Journal, 49, 2577-2594, MARSHALL, S. L. 2003.

107. Towards the development of transition probability matrices in the Markovian model for the predicted service life of buildings. PhD, University of Pretoria, MCDULING, J. J. 2006.

108. Markov Model for Storm Water Pipe Deterioration. Journal of Infrastructure Systems, ASCE, 8(2), 49-56, MICEVSKI, T., KUCZERA, G. & COOMBES, P. 2002.

109. Estimating infrastructure transition probabilities using stochastic duration models. ASCE Journal of Infrastructure Systems, 2, 1-33, MISHALANI, R. G. & MADANAT, S. M. 2002.

110. Remaining life prediction of electronic products using life consumption monitoring approach. Proceedings of the European Microelectronics Packageing and Interconnection Symposium, Cracow, 2002. 136-142, MISHRA, S., PECHT, M., SMITH, T., MCNEE, I. & HARRIS, R.

111. Assessment in Water Supply Systems, Vilniaus Gedimino technikos universitetas, MISIŪNAS, D. 2008. Failure Monitoring and Asset Condition
112. Physical Asset Management Handbook (4th Edition). Clarion Technical Publishers, MITCHELL, J. S. 2012.
113. Basics of Engineering Statistics, White Word Publications, MOELLER, C. 2012.
114. Deterioration Prediction of Community Buildings in Australia. The International Journal of the Constructed Environment, Volume 1, pp. 175-196, MOHSENI, H., SETUNGE, S., ZHANG, G. & EDIRSINGHE, R. 2011a.
115. Deterioration Prediction for Community Buildings in Australia. The Constructed Environment Conference. Venice, Italy, MOHSENI, H., SETUNGE, S., ZHANG, G., EDIRSINGHE, R. & WAKEFIELD, R. 2010.
116. Deterioration Prediction of Superstructure Elements of Community Buildings in Australia Using a Probabilistic Approach WCEAM World Congress on Engineering Asset Management. Cincinnati, OH, USA, MOHSENI, H., SETUNGE, S., ZHANG, G. & KALUTARA, P. 2011b.
117. Probabilistic Deterioration Prediction and Cost Optimisation for Community Buildings Using Monte-Carlo Simulation. ICOMS Asset Management Conference. Hobart, Australia, MOHSENI, H., SETUNGE, S., ZHANG, G. & WAKEFIELD, R. 2012a.
118. Risk Mitigation and Expenditure Projection Utilising Probabilistic Deterioration Prediction. The Asset Journal, 6, MOHSENI, H., SETUNGE, S., ZHANG, G. & WAKEFIELD, R. 2012b.
119. Deterioration Prediction of Community Buildings in Australia. ICOMS Asset Management Conference. Gold Coast, Australia, MOHSENI, H., SETUNGE, S., ZHANG, G., WAKEFIELD, R. & KALUTARA, P. 2011c.
120. Engineering Statistics, New York, Wiley, MONTGOMERY, D. C., RUNGER, G. C. & HUBELE, N. F. 2004.
121. Modeling Bridge Deterioration Using Case-based Reasoning. Journal of Infrastructure Systems, 8, 86-95, MORCOUS, G., RIVARD, H. & HANNA, A. 2002a.
122. Case-Based Reasoning System for Modeling Infrastructure Deterioration. Journal of Computing in Civil Engineering, 16, 104-114, MORCOUS, G., RIVARD, H. & HANNA, A. M. 2002b.
123. Predicting Deterioration for the Saudi Arabia Urban Road Network. University of Nottingham, MUBARAKI, M. A. 2010.
124. Public Policy Goals, Means, and Methods. Review of Policy Research, 3, 192-192, NAGEL, S. S. 1984.
125. NAMS 2009. Building Condition & Performance Assessment Guidelines. Practice Note 3 - Buildings. IPWEA; NAMS.
126. Optimised Decision-Making Guidelines - A sustainable approach to manageing infrastructure. Edition 1.0, NAMSGROUP, N. N. A. M. S. 2004.
127. e-Handbook of Statistical Methods, NIST/SEMATECH 2012.
128. A risk-based approach to distribution system asset management and a survey of perceived risk exposure among distribution companies. CIRED-19th International conference on electricity distribution, Vienna, 2007, NORDGÅRD, D. E., GJERDE, O., SAND, K., CATRINU, M. D., LASSILA, J., PARTANEN, J., BONNOIT, S. & AUPIED, J.
129. Derivation of transition probability matrices for pavement deterioration modelling. Journal of transportation engineering, 132, ORTIZ-GARCÍA, J., COSTELLO, S. & SNAITH, M. S. 2006.

130. RISK Optimiser Guide. In: CORPORATION, P. (ed.) Version 5.7 ed, PALISADE 2010.

131. Gamma process model for time-dependent structural reliability analysis. Bridge Maintenance, Safety, Management and Cost: Proceedings of the 2nd International Conference on Bridge Maintenance, Safety and Management, 18-22 October 2004, Kyoto, Japan, 2004. Taylor & Francis, 101, PANDEY, M. & VAN NOORTWIJK, J.

132. Stochastic Processes, Oakland, Society for Industrial and Applied Mathematics, PARZEN, E. 1987.

133. Framework for investment decision-making under risk and uncertainty for infrastructure asset management. Research in Transportation Economics, 8, 199-214, PIYATRAPOOMI, N., KUMAR, A. & SETUNGE, S. 2004.

134. National financial sustainability study of local government, Price waterhouse Coopers, PWC 2006.

135. Maintenance assessment report for 111 George street. QDPWH. Brisbane, QBUILD 2003.

136. Tools for Diagnosis and Prediction of Deterioration of Timber Bridges in Australia. RMIT, RANJITH, S. 2010.

137. Deterioration Prediction of Timber Bridge Elements Using the Markov Chain. Journal of Performance of Constructed Facilities, RANJITH, S., SETUNGE, S., GRAVINA, R. & VENKATESAN, S. 2011.

138. Construction Cost Guide, RAWLINSONS 2010.

139. SEED-Config: A case-based reasoning system for conceptual building design. AI EDAM, 14, 415-430, RIVARD, H. & FENVES, S. J. 2000.

140. Road maintenance management: Concepts and systems, Basingstoke, UK, Macmillan Press, ROBINSON, R., SNAITH, M. S. & DANIELSON, U. 1998.

141. Decision making for leaders: the analytic hierarchy process for decisions in a complex world, RWS publications, SAATY, T. L. 1990.

142. A system for bridge network condition assessment and prediction Incorporating Sustainable Practice. Mechanics of Structures and Materials, 2011 London. Taylor & Francis Group, 739-744, SAMALI, B., CREWS, K. & K., K. A.

143. Bridge deterioration models for states with small bridge inventories. Transportation Research Record, SANDERS, D. & ZHANG, Y. 1994.

144. Optimisation of maintenance expenditure for buildings: refurbish or demolish. IABSE 2005 Conference. CRC for Construction Innovation, SHAH, A. & KUMAR, A. 2005.

145. New techniques for modeling pavement deterioration, SHAHIN, M. Y., NUNEZ, M. M., BROTEN, M. R., CARPENTER, S. H. & SAMEH, A. 1987.

146. Use of Markov chain for deterioration modeling and risk management of infrastructure assets. Information and Automation, 2006. ICIA 2006. International Conference on, 2006. IEEE, 384-389, SHARABAH, A., SETUNGE, S. & ZEEPHONGSEKUL, P.

147. A Reliability Based Approach for Service Life Modeling of Council Owned Infrastructure Assets. ICOMS Asset Management Conference. Melbourne, Australia, SHARABAH, A., SETUNGE, S. & ZEEPHONGSEKUL, P. 2007.

148. Fault-tree model of bridge element deterioration due to interaction. Journal of Infrastructure Systems, 3, 103-110, SIANIPAR, P. R. M. & ADAMS, T. M. 1997.

149. The application of probabilistic and qualitative methods to asset management decision making. SPE Asia Pacific Conference on Integrated Modelling for Asset Management, 2000, SIMPSON, G., LAMB, F., FINCH, J. & DINNIE, N.

150. Multiple criteria decision making combined with finance: A categorised bibliographic study. European Journal of operational research, 150, 496-515, STEUER, R. E. & NA, P. 2003.

151. Aggregated condition data bridging the gap between property management and asset management ENHR Conference "Housing in an expanding Europe: theory, policy, participation and implementation. Ljublijana, Slovenia, STRAUB, A. 2006.

152. Investigation of Deterioration Models for Storm Water Pipe Systems. PhD Thesis, Victoria University, TRAN, H. D. 2007.

153. GSA BIM guide for spatial program validation. version 0.96. General Services Administration, U.S.GENERALSERVICESADMINISTRATION 2007.

154. Challenging Issues in Modeling Deterioration of Combined Sewers. Journal of Infrastructure Systems, 7, 77-84, WIRAHADIKUSUMAH, R., ABRAHAM, D. & ISELEY, T. 2001.

155. Life-cycle performance of New York City bridges. Transportation Research Record, YANEV, B. & CHEN, X. 1993.

156. Application of a fuzzy based decision-making methodology to construction project risk assessment. International Journal of Project Management, 25, 589-600, ZENG, J., AN, M. & SMITH, N. J. 2007.

157. Fuzzy analytical hierarchy process risk assessment approach for joint venture construction projects in China. Journal of Construction Engineering and Management, 133, 771-779, ZHANG, G. & ZOU, P. X. 2007.

158. ZHANG, T. & GUAY, M. 2002. Adaptive parameter estimation for microbial growth kinetics. AIChE Journal, 48, 607-616, ZHANG, Y. & AUGENBROE, G. 2005.

159. Uncertainty Analysis in Using Markov Chain Model to Predict Roof Life Cycle Performance. 10DBMC International Conférence On Durability of Building Materials and Components. LYON [France].

160. Nader Naderpajouh, RMIT University - SAFETY4RAILS, 15th November 2020, 5.[Online]. Available:24100464. [Accessed: 11 June 2020].

161. RMIT university – (CAMS Platform) https://test.camsassethub.com.au/products/#cam.

Additionally, on the RMIT University's platform (https://test.camsassethub.com.au/about-us/), more information is available about CAMS Quality and Development standards.

ANNEXES

ANNEX I. Glossary And Acronyms

TABLE 9: GLOSSARY AND ACRONYMS

Term	Definition/description
CdM	Comune di Milano (City of Milan)
CO	Confidential
D	Deliverable
DMS	Distributed Messaging System
DoA	Description of Action
GUI	Graphical user interface
IoT	Internet of things
EGO	Ankara Metro
ERTMS	European Railway Traffic Management System
ETCS	European Train Control (and Management) System
ETML	European Traffic Management Layer
EVC	European Vital Computer
GSM-R	Global System for Mobiles – Railway
IDS	Intrusion Detection System
IoC	Indicator of Compromise
IT	Information Technology
KMC	Key Management Centre
MA	Movement Authority
MdM	Metro de Madrid
OSINT	Open-Source Intelligence
OT	Operational Technology
RFI	Rete Ferroviaria Italiana
S4RIS	SAFETY4RAILS Information System
SCADA	Supervisory Control and Data Acquisition
SOC	Security Operations Centre

TCC	Traffic Control System
TL	Task leader
ToC	Table of Contents
TRL	Technology Readiness Level
WG	Working Group
WP	Work package
WS	Work Workshop

ANNEX II. Schedule of works

Madrid Simulation Exercise

Resilience Threshold 2

TABLE 10: NON-OPTIMISED SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 2 (MDM)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	0	L2(2)	L0(2)	L0(2)	L0(2)	L0(2)
2	Overhead line	0	L2(2)	L1(2)	L1(2)	L1(2)	L1(2)
3	Switch	0	L2(2)	L2(2)	L2(2)	L2(2)	L2(2)
4	Bridge	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
5	Tunnel	1	L1(2)	L0(2)	L0(2)	L0(2)	L0(2)
6	Level crossing	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L0(3)	L0(2)	L1(2)	L1(2)
9	Tunnel video surveillance	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
10	Light signals	4	L0(4)	L0(2)	L2(2)	L2(2)	L2(2)
11	Traffic light signals	0	L2(2)	L2(2)	L2(2)	L2(2)	L2(2)
12	Auxiliary signals	0	L2(2)	L1(2)	L1(2)	L1(2)	L1(2)
13	Balise	0	L2(2)	L1(2)	L1(2)	L1(2)	L1(2)
14	Antennas	0	L2(2)	L2(2)	L2(2)	L2(2)	L2(2)
15	Speed sensor	0	L2(2)	L0(2)	L0(2)	L0(2)	L0(2)
16	Fixed signals	0	L2(2)	L0(2)	L0(2)	L0(2)	L0(2)

TABLE 11: OPTIMISED SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 2 (MDM)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	0	L2(2)	L0(2)	L0(2)	L0(2)	L0(2)
2	Overhead line	0	L2(2)	L1(2)	L2(3)	L0(2)	L1(2)
3	Switch	0	L2(2)	L2(2)	L2(2)	L2(2)	L2(2)
4	Bridge	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
5	Tunnel	1	L1(2)	L0(2)	L0(2)	L0(2)	L0(2)
6	Level crossing	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L0(3)	L2(4)	L0(3)	L0(2)
9	Tunnel video surveillance	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
10	Light signals	4	L0(4)	L1(3)	L1(2)	L3(3)	L1(2)
11	Traffic light signals	0	L2(2)	L2(2)	L2(2)	L2(2)	L2(2)
12	Auxiliary signals	0	L2(2)	L2(3)	L0(2)	L1(2)	L1(2)
13	Balise	0	L2(2)	L2(3)	L1(3)	L0(2)	L1(2)
14	Antennas	0	L2(2)	L2(2)	L2(2)	L2(2)	L2(2)
15	Speed sensor	0	L2(2)	L0(2)	L0(2)	L0(2)	L0(2)
16	Fixed signals	0	L2(2)	L0(2)	L0(2)	L0(2)	L0(2)

TABLE 12: NON – OPTIMISED SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 2 – CALCULATION (MDM)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
			2022				2024			
1	Rail	0	2	2	€ 216,000	2	0	2	€ -	2
2	Overhead line	0	2	2	€ 108,000	1	1	2	€ 60,000	1
3	Switch	0	2	2	€ 144,000	0	2	2	€ 144,000	0
4	Bridge	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	1	1	2	€ 200,000	2	0	2	€ -	2
6	Level crossing	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	0	3	€ -	2
9	Tunnel video surveillance	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	4	0	4	€ -	2	0	2	€ -	0
11	Traffic light signals	0	2	2	€ 1,620	0	2	2	€ 1,620	0
12	Auxiliary signals	0	2	2	€ 3,780	1	1	2	€ 2,100	1
13	Balise	0	2	2	€ 270	1	1	2	€ 150	1
14	Antennas	0	2	2	€ 1,944	0	2	2	€ 1,944	0
15	Speed sensor	0	2	2	€ 1,350	2	0	2	€ -	2
16	Fixed signals	0	2	2	€ 173	2	0	2	€ -	2

CONTINUED FROM TABLE 12: NON – OPTIMISED SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 2 – CALCULATION (MDM)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4 Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
2	Overhead line	1	2	€ 60,000	1	1	2	€ 60,000	1	1	2	€ 60,000	1
3	Switch	2	2	€ 144,000	0	2	2	€ 144,000	0	2	2	€ 144,000	0
4	Bridge	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
6	Level crossing	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	0	2	€ -	1	1	2	€ 1,200	1	1	2	€ 1,200	1
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	2	2	€ 270	0	2	2	€ 270	0	2	2	€ 270	0
11	Traffic light signals	2	2	€ 1,620	0	2	2	€ 1,620	0	2	2	€ 1,620	0
12	Auxiliary signals	1	2	€ 2,100	1	1	2	€ 2,100	1	1	2	€ 2,100	1
13	Balise	1	2	€ 150	1	1	2	€ 150	1	1	2	€ 150	1
14	Antennas	2	2	€ 1,944	0	2	2	€ 1,944	0	2	2	€ 1,944	0
15	Speed sensor	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
16	Fixed signals	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2

TABLE 13: OPTIMISED COST CALCULATION (RESILIENCE THRESHOLD 2-MDM)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
			2022				2024			
1	Rail	0	2	2	€ 216,000	2	0	2	€ -	2
2	Overhead line	0	2	2	€ 108,000	1	1	2	€ 60,000	1
3	Switch	0	2	2	€ 144,000	0	2	2	€ 144,000	0
4	Bridge	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	1	1	2	€ 200,000	2	0	2	€ -	2
6	Level crossing	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	0	3	€ -	2
9	Tunnel video surveillance	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	4	0	4	€ -	2	1	3	€ 150	1
11	Traffic light signals	0	2	2	€ 1,620	0	2	2	€ 1,620	0
12	Auxiliary signals	0	2	2	€ 3,780	1	2	3	€ 3,780	2
13	Balise	0	2	2	€ 270	1	2	3	€ 270	2
14	Antennas	0	2	2	€ 1,944	0	2	2	€ 1,944	0
15	Speed sensor	0	2	2	€ 1,350	2	0	2	€ -	2
16	Fixed signals	0	2	2	€ 173	2	0	2	€ -	2

CONTINUED FROM TABLE 13: OPTIMISED COST CALCULATION (RESILIENCE THRESHOLD 2-MDM)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4 Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
2	Overhead line	2	3	€ 108,000	2	0	2	€ -	1	1	2	€ 60,000	1
3	Switch	2	2	€ 144,000	0	2	2	€ 144,000	0	2	2	€ 144,000	0
4	Bridge	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
6	Level crossing	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	2	4	€ 2,160	3	0	3	€ -	2	0	2	€ -	1
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	1	2	€ 150	0	3	3	€ 525	1	1	2	€ 150	0
11	Traffic light signals	2	2	€ 1,620	0	2	2	€ 1,620	0	2	2	€ 1,620	0
12	Auxiliary signals	0	2	€ -	1	1	2	€ 2,100	1	1	2	€ 2,100	1
13	Balise	1	3	€ 150	2	0	2	€ -	1	1	2	€ 150	1
14	Antennas	2	2	€ 1,944	0	2	2	€ 1,944	0	2	2	€ 1,944	0
15	Speed sensor	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
16	Fixed signals	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2

TABLE 14: NON-OPTIMISED SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 3 (MDM)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	0	L3(3)	L0(3)	L0(3)	L0(3)	L0(3)
2	Overhead line	0	L3(3)	L1(3)	L1(3)	L1(3)	L1(3)
3	Switch	0	L3(3)	L3(3)	L3(3)	L3(3)	L3(3)
4	Bridge	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
5	Tunnel	1	L2(3)	L0(3)	L0(3)	L0(3)	L0(3)
6	Level crossing	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L0(3)	L1(3)	L1(3)	L1(3)
9	Tunnel video surveillance	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
10	Light signals	4	L0(4)	L1(3)	L2(3)	L2(3)	L2(3)
11	Traffic light signals	0	L3(3)	L2(3)	L2(3)	L2(3)	L2(3)
12	Auxiliary signals	0	L3(3)	L1(3)	L1(3)	L1(3)	L1(3)
13	Balise	0	L3(3)	L1(3)	L1(3)	L1(3)	L1(3)
14	Antennas	0	L3(3)	L3(3)	L3(3)	L3(3)	L3(3)
15	Speed sensor	0	L3(3)	L0(3)	L0(3)	L0(3)	L0(3)
16	Fixed signals	0	L3(3)	L0(3)	L0(3)	L0(3)	L0(3)

TABLE 15: OPTIMISED SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 3 (MDM)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	0	L3(3)	L0(3)	L0(3)	L0(3)	L0(3)
2	Overhead line	0	L3(3)	L2(4)	L1(4)	L1(4)	L0(3)
3	Switch	0	L3(3)	L3(3)	L3(3)	L3(3)	L3(3)
4	Bridge	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
5	Tunnel	1	L2(3)	L0(3)	L0(3)	L0(3)	L0(3)
6	Level crossing	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L0(3)	L2(4)	L1(4)	L0(3)
9	Tunnel video surveillance	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
10	Light signals	4	L0(4)	L2(4)	L2(4)	L1(3)	L2(3)
11	Traffic light signals	0	L3(3)	L2(3)	L2(3)	L2(3)	L2(3)
12	Auxiliary signals	0	L3(3)	L2(4)	L1(4)	L0(3)	L1(3)
13	Balise	0	L3(3)	L2(4)	L0(3)	L1(3)	L1(3)
14	Antennas	0	L3(3)	L3(3)	L3(3)	L3(3)	L3(3)
15	Speed sensor	0	L3(3)	L0(3)	L0(3)	L0(3)	L0(3)
16	Fixed signals	0	L3(3)	L0(3)	L1(4)	L0(4)	L0(4)

TABLE 16: NON – OPTIMISED SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 3 – CALCULATION (MDM)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
			2022				2024			
1	Rail	0	3	3	€ 420,000	3	0	3	€ -	3
2	Overhead line	0	3	3	€ 210,000	2	1	3	€ 60,000	2
3	Switch	0	3	3	€ 280,000	0	3	3	€ 280,000	0
4	Bridge	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	1	2	3	€ 360,000	3	0	3	€ -	3
6	Level crossing	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	0	3	€ -	2
9	Tunnel video surveillance	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	4	0	4	€ -	2	1	3	€ 150	1
11	Traffic light signals	0	3	3	€ 3,150	1	2	3	€ 1,620	1
12	Auxiliary signals	0	3	3	€ 7,350	2	1	3	€ 2,100	2
13	Balise	0	3	3	€ 525	2	1	3	€ 150	2
14	Antennas	0	3	3	€ 3,780	0	3	3	€ 3,780	0
15	Speed sensor	0	3	3	€ 2,625	3	0	3	€ -	3
16	Fixed signals	0	3	3	€ 336	3	0	3	€ -	3

CONTINUED FROM TABLE 16: NON – OPTIMISED SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 3 – CALCULATION (MDM)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
2	Overhead line	1	3	€ 60,000	2	1	3	€ 60,000	2	1	3	€ 60,000	2
3	Switch	3	3	€ 280,000	0	3	3	€ 280,000	0	3	3	€ 280,000	0
4	Bridge	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
6	Level crossing	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	1	3	€ 1,200	2	1	3	€ 1,200	2	1	3	€ 1,200	2
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	2	3	€ 270	1	2	3	€ 270	1	2	3	€ 270	1
11	Traffic light signals	2	3	€ 1,620	1	2	3	€ 1,620	1	2	3	€ 1,620	1
12	Auxiliary signals	1	3	€ 2,100	2	1	3	€ 2,100	2	1	3	€ 2,100	2
13	Balise	1	3	€ 150	2	1	3	€ 150	2	1	3	€ 150	2
14	Antennas	3	3	€ 3,780	0	3	3	€ 3,780	0	3	3	€ 3,780	0
15	Speed sensor	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3

TABLE 17: OPTIMISED COST CALCULATION (RESILIENCE THRESHOLD 3-MDM)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
			2022				2024			
1	Rail	0	3	3	€ 420,000	3	0	3	€ -	3
2	Overhead line	0	3	3	€ 210,000	2	2	4	€ 108,000	3
3	Switch	0	3	3	€ 280,000	0	3	3	€ 280,000	0
4	Bridge	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	1	2	3	€ 360,000	3	0	3	€ -	3
6	Level crossing	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	0	3	€ -	2
9	Tunnel video surveillance	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	4	0	4	€ -	2	2	4	€ 270	2
11	Traffic light signals	0	3	3	€ 3,150	1	2	3	€ 1,620	1
12	Auxiliary signals	0	3	3	€ 7,350	2	2	4	€ 3,780	3
13	Balise	0	3	3	€ 525	2	2	4	€ 270	3
14	Antennas	0	3	3	€ 3,780	0	3	3	€ 3,780	0
15	Speed sensor	0	3	3	€ 2,625	3	0	3	€ -	3
16	Fixed signals	0	3	3	€ 336	3	0	3	€ -	3

CONTINUED FROM TABLE 17: SCHEDULE OF WORKS –OPTIMISED COST CALCULATION (RESILIENCE THRESHOLD 3-MDM)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4 Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
2	Overhead line	1	4	€ 60,000	3	1	4	€ 60,000	3	0	3	€ -	2
3	Switch	3	3	€ 280,000	0	3	3	€ 280,000	0	3	3	€ 280,000	0
4	Bridge	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
6	Level crossing	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	2	4	€ 2,160	3	1	4	€ 1,200	3	0	3	€ -	2
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	2	4	€ 270	2	1	3	€ 150	1	2	3	€ 270	1
11	Traffic light signals	2	3	€ 1,620	1	2	3	€ 1,620	1	2	3	€ 1,620	1
12	Auxiliary signals	1	4	€ 2,100	3	0	3	€ -	2	1	3	€ 2,100	2
13	Balise	0	3	€ -	2	1	3	€ 150	2	1	3	€ 150	2
14	Antennas	3	3	€ 3,780	0	3	3	€ 3,780	0	3	3	€ 3,780	0
15	Speed sensor	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	1	4	€ 96	4	0	4	€ -	4	0	4	€ -	4

TABLE 18: SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 4 (MDM)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	0	L4(4)	L0(4)	L0(4)	L0(4)	L0(4)
2	Overhead line	0	L4(4)	L1(4)	L1(4)	L1(4)	L1(4)
3	Switch	0	L4(4)	L3(4)	L3(4)	L3(4)	L3(4)
4	Bridge	3	L4(4)	L0(4)	L0(4)	L0(4)	L0(4)
5	Tunnel	1	L3(4)	L0(4)	L0(4)	L0(4)	L0(4)
6	Level crossing	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L1(4)	L1(4)	L1(4)	L1(4)
9	Tunnel video surveillance	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
10	Light signals	4	L0(4)	L2(4)	L2(4)	L2(4)	L2(4)
11	Traffic light signals	0	L4(4)	L2(4)	L2(4)	L2(4)	L2(4)
12	Auxiliary signals	0	L4(4)	L1(4)	L1(4)	L1(4)	L1(4)
13	Balise	0	L4(4)	L1(4)	L1(4)	L1(4)	L1(4)
14	Antennas	0	L4(4)	L3(4)	L3(4)	L3(4)	L3(4)
15	Speed sensor	0	L4(4)	L0(4)	L0(4)	L0(4)	L0(4)
16	Fixed signals	0	L4(4)	L0(4)	L0(4)	L0(4)	L0(4)

TABLE 19: SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 4 – CALCULATION (MDM)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
			2022				2024			
1	Rail	0	4	4	€ 600,000	4	0	4	€ -	4
2	Overhead line	0	4	4	€ 300,000	3	1	4	€ 60,000	3
3	Switch	0	4	4	€ 400,000	1	3	4	€ 280,000	1
4	Bridge	3	4	4	€ 100,000	4	0	4	€ -	4
5	Tunnel	1	3	4	€ 700,000	4	0	4	€ -	4
6	Level crossing	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	1	4	€ 1,200	3
9	Tunnel video surveillance	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	4	0	4	€ -	2	2	4	€ 270	2
11	Traffic light signals	0	4	4	€ 4,500	2	2	4	€ 1,620	2
12	Auxiliary signals	0	4	4	€ 10,500	3	1	4	€ 2,100	3
13	Balise	0	4	4	€ 750	3	1	4	€ 150	3
14	Antennas	0	4	4	€ 5,400	1	3	4	€ 3,780	1
15	Speed sensor	0	4	4	€ 3,750	4	0	4	€ -	4
16	Fixed signals	0	4	4	€ 480	4	0	4	€ -	4

CONTINUED FROM TABLE 19: SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 4 – CALCULATION (MDM)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4 Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
2	Overhead line	1	3	€ 525	2	1	3	€ 525	2	1	3	€ 525	2
3	Switch	3	3	€ 7,000	0	3	3	€ 7,000	0	3	3	€ 7,000	0
4	Bridge	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
6	Level crossing	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
1	Rail	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
2	Overhead line	1	4	€ 60,000	3	1	4	€ 60,000	3	1	4	€ 60,000	3
3	Switch	3	4	€ 280,000	1	3	4	€ 280,000	1	3	4	€ 280,000	1
4	Bridge	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
5	Tunnel	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
6	Level crossing	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	1	4	€ 1,200	3	1	4	€ 1,200	3	1	4	€ 1,200	3
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	2	4	€ 270	2	2	4	€ 270	2	2	4	€ 270	2

TABLE 20: NON-OPTIMISED SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 2 (EGO)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	0	L2(2)	L0(2)	L0(2)	L0(2)	L0(2)
2	Overhead line	0	L2(2)	L1(2)	L1(2)	L1(2)	L1(2)
3	Switch	0	L2(2)	L2(2)	L2(2)	L2(2)	L2(2)
4	Bridge	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
5	Tunnel	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
6	Level crossing	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L0(3)	L0(2)	L1(2)	L1(2)
9	Tunnel video surveillance	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
10	Light signals	4	L0(4)	L0(2)	L2(2)	L2(2)	L2(2)
11	Traffic light signals	4	L0(4)	L0(2)	L2(2)	L2(2)	L2(2)
12	Auxiliary signals	0	L2(2)	L1(2)	L1(2)	L1(2)	L1(2)
13	Balise	0	L2(2)	L1(2)	L1(2)	L1(2)	L1(2)
14	Antennas	4	L0(4)	L1(2)	L2(2)	L2(2)	L2(2)
15	Speed sensor	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
16	Fixed signals	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)

TABLE 21: OPTIMISED SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 2 (EGO)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
2	Overhead line	4	L0(4)	L0(3)	L0(2)	L2(3)	L0(2)
3	Switch	4	L0(4)	L1(2)	L2(2)	L2(2)	L2(2)
4	Bridge	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
5	Tunnel	1	L1(2)	L0(2)	L0(2)	L0(2)	L0(2)
6	Level crossing	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L0(3)	L2(4)	L0(3)	L0(2)
9	Tunnel video surveillance	0	L2(2)	L0(2)	L0(2)	L0(2)	L0(2)
10	Light signals	0	L2(2)	L2(2)	L2(2)	L2(2)	L2(2)
11	Traffic light signals	0	L2(2)	L2(2)	L2(2)	L2(2)	L2(2)
12	Auxiliary signals	0	L2(2)	L2(3)	L2(4)	L0(3)	L0(2)
13	Balise	0	L2(2)	L1(2)	L3(4)	L2(4)	L2(4)
14	Antennas	4	L0(4)	L1(2)	L2(2)	L2(2)	L2(2)
15	Speed sensor	0	L2(2)	L1(3)	L1(4)	L0(4)	L0(4)
16	Fixed signals	4	L2(4)	L1(4)	L2(4)	L2(4)	L4(4)

TABLE 22: NON – OPTIMISED SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 2 – CALCULATION (EGO)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
					2022				2024	
1	Rail	0	2	2	€ 416,988	2	0	2	€ -	2
2	Overhead line	0	2	2	€ 1,081	1	1	2	€ 601	1
3	Switch	0	2	2	€ 7,258	0	2	2	€ 7,258	0
4	Bridge	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	3	0	3	€ -	3	0	3	€ -	3
6	Level crossing	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	0	3	€ -	2
9	Tunnel video surveillance	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	4	0	4	€ -	2	0	2	€ -	0
11	Traffic light signals	4	0	4	€ -	2	0	2	€ -	0
12	Auxiliary signals	0	2	2	€ 7,938	1	1	2	€ 4,410	1
13	Balise	0	2	2	€ 510	1	1	2	€ 284	1
14	Antennas	4	0	4	€ -	1	1	2	€ 2,574	0
15	Speed sensor	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	3	0	3	€ -	3	0	3	€ -	3

CONTINUED FROM TABLE 22: NON – OPTIMISED SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 2 – CALCULATION (EGO)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4 Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
2	Overhead line	1	2	€ 601	1	1	2	€ 601	1	1	2	€ 601	1
3	Switch	2	2	€ 7,258	0	2	2	€ 7,258	0	2	2	€ 7,258	0
4	Bridge	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
6	Level crossing	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	0	2	€ -	1	1	2	€ 2,621	1	1	2	€ 2,621	1
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	2	2	€ 351	0	2	2	€ 351	0	2	2	€ 351	0
11	Traffic light signals	2	2	€ 4,082	0	2	2	€ 4,082	0	2	2	€ 4,082	0
12	Auxiliary signals	1	2	€ 4,410	1	1	2	€ 4,410	1	1	2	€ 4,410	1
13	Balise	1	2	€ 284	1	1	2	€ 284	1	1	2	€ 284	1
14	Antennas	2	2	€ 4,633	0	2	2	€ 4,633	0	2	2	€ 4,633	0
15	Speed sensor	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3

TABLE 23: OPTIMISED COST CALCULATION (RESILIENCE THRESHOLD 2- EGO)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
			2022				2024			
1	Rail	4	0	4	€ -	4	0	4	€ -	4
2	Overhead line	4	0	4	€ -	3	0	3	€ -	2
3	Switch	4	0	4	€ -	1	1	2	€ 2,240	0
4	Bridge	4	0	4	€ -	4	0	4	€ -	4
5	Tunnel	1	1	2	€ 216,000	2	0	2	€ -	2
6	Level crossing	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	0	3	€ -	2
9	Tunnel video surveillance	0	2	2	€ 202	2	0	2	€ -	2
10	Light signals	0	2	2	€ 351	0	2	2	€ 351	0
11	Traffic light signals	0	2	2	€ 2,430	0	2	2	€ 2,430	0
12	Auxiliary signals	0	2	2	€ 7,938	1	2	3	€ 7,938	2
13	Balise	0	2	2	€ 486	1	1	2	€ 270	1
14	Antennas	4	0	4	€ -	1	1	2	€ 1,872	0
15	Speed sensor	0	2	2	€ 2,268	2	1	3	€ 1,260	3
16	Fixed signals	4	2	4	€ 173	4	1	4	€ 96	4

CONTINUED FROM TABLE 23: OPTIMISED COST CALCULATION (RESILIENCE THRESHOLD 2- EGO)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4 Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
2	Overhead line	0	2	€ -	1	2	3	€ 832	2	0	2	€ -	1
3	Switch	2	2	€ 4,032	0	2	2	€ 4,032	0	2	2	€ 4,032	0
4	Bridge	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
5	Tunnel	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
6	Level crossing	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	2	4	€ 3,931	3	0	3	€ -	2	0	2	€ -	1
9	Tunnel video surveillance	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
10	Light signals	2	2	€ 351	0	2	2	€ 351	0	2	2	€ 351	0
11	Traffic light signals	2	2	€ 2,430	0	2	2	€ 2,430	0	2	2	€ 2,430	0
12	Auxiliary signals	2	4	€ 7,938	3	0	3	€ -	2	0	2	€ -	1
13	Balise	3	4	€ 945	3	2	4	€ 486	3	2	4	€ 486	3
14	Antennas	2	2	€ 3,370	0	2	2	€ 3,370	0	2	2	€ 3,370	0
15	Speed sensor	1	4	€ 1,260	4	0	4	€ -	4	0	4	€ -	4
16	Fixed signals	2	4	€ 173	4	2	4	€ 173	4	4	4	€ 480	4

TABLE 24: NON-OPTIMISED SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 3 (EGO)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
2	Overhead line	4	L0(4)	L0(3)	L1(3)	L1(3)	L1(3)
3	Switch	4	L0(4)	L2(3)	L3(3)	L3(3)	L3(3)
4	Bridge	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
5	Tunnel	1	L2(3)	L0(3)	L0(3)	L0(3)	L0(3)
6	Level crossing	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L0(3)	L1(3)	L1(3)	L1(3)
9	Tunnel video surveillance	0	L3(3)	L0(3)	L0(3)	L0(3)	L0(3)
10	Light signals	0	L3(3)	L2(3)	L2(3)	L2(3)	L2(3)
11	Traffic light signals	0	L3(3)	L2(3)	L2(3)	L2(3)	L2(3)
12	Auxiliary signals	0	L3(3)	L1(3)	L1(3)	L1(3)	L1(3)
13	Balise	0	L3(3)	L1(3)	L1(3)	L1(3)	L1(3)
14	Antennas	4	L0(4)	L2(3)	L3(3)	L3(3)	L3(3)
15	Speed sensor	0	L3(3)	L0(3)	L0(3)	L0(3)	L0(3)
16	Fixed signals	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)

TABLE 25: OPTIMISED SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 3 (EGO)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
2	Overhead line	4	L0(4)	L0(3)	L2(4)	L0(3)	L1(3)
3	Switch	4	L0(4)	L2(3)	L3(3)	L4(4)	L2(3)
4	Bridge	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
5	Tunnel	1	L2(3)	L0(3)	L0(3)	L0(3)	L0(3)
6	Level crossing	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L0(3)	L2(4)	L0(3)	L1(3)
9	Tunnel video surveillance	0	L3(3)	L0(3)	L1(4)	L1(4)	L2(4)
10	Light signals	0	L3(3)	L2(3)	L2(3)	L2(3)	L2(3)
11	Traffic light signals	0	L3(3)	L2(3)	L2(3)	L2(3)	L2(3)
12	Auxiliary signals	0	L3(3)	L1(3)	L2(4)	L1(4)	L0(3)
13	Balise	0	L3(3)	L1(3)	L1(3)	L2(4)	L0(3)
14	Antennas	4	L0(4)	L2(3)	L3(3)	L3(3)	L3(3)
15	Speed sensor	0	L3(3)	L0(3)	L0(3)	L0(3)	L0(3)
16	Fixed signals	4	L0(4)	L1(4)	L1(4)	L0(4)	L2(4)

TABLE 26: NON – OPTIMISED SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 3 – CALCULATION (EGO)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
			2022				2024			
1	Rail	4	0	4	€ -	4	0	4	€ -	4
2	Overhead line	4	0	4	€ -	3	0	3	€ -	2
3	Switch	4	0	4	€ -	1	2	3	€ 4,032	0
4	Bridge	4	0	4	€ -	4	0	4	€ -	4
5	Tunnel	1	2	3	€ 388,800	3	0	3	€ -	3
6	Level crossing	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	0	3	€ -	2
9	Tunnel video surveillance	0	3	3	€ 392	3	0	3	€ -	3
10	Light signals	0	3	3	€ 683	1	2	3	€ 351	1
11	Traffic light signals	0	3	3	€ 4,725	1	2	3	€ 2,430	1
12	Auxiliary signals	0	3	3	€ 15,435	2	1	3	€ 4,410	2
13	Balise	0	3	3	€ 945	2	1	3	€ 270	2
14	Antennas	4	0	4	€ -	1	2	3	€ 3,370	0
15	Speed sensor	0	3	3	€ 4,410	3	0	3	€ -	3
16	Fixed signals	4	0	4	€ -	4	0	4	€ -	4

Continued From Table 26: Non – Optimised Schedule Of Works For Resilience Threshold 3 – Calculation (EGO)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
2	Overhead line	1	3	€ 462	2	1	3	€ 462	2	1	3	€ 462	2
3	Switch	3	3	€ 7,840	0	3	3	€ 7,840	0	3	3	€ 7,840	0
4	Bridge	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
5	Tunnel	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
6	Level crossing	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	1	3	€ 2,184	2	1	3	€ 2,184	2	1	3	€ 2,184	2
9	Tunnel video surveillance	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
10	Light signals	2	3	€ 351	1	2	3	€ 351	1	2	3	€ 351	1
11	Traffic light signals	2	3	€ 2,430	1	2	3	€ 2,430	1	2	3	€ 2,430	1
12	Auxiliary signals	1	3	€ 4,410	2	1	3	€ 4,410	2	1	3	€ 4,410	2
13	Balise	1	3	€ 270	2	1	3	€ 270	2	1	3	€ 270	2
14	Antennas	3	3	€ 6,552	0	3	3	€ 6,552	0	3	3	€ 6,552	0
15	Speed sensor	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4

TABLE 27: OPTIMISED COST CALCULATION (RESILIENCE THRESHOLD 3-EGO)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
			2022				2024			
1	Rail	4	0	4	€ -	4	0	4	€ -	4
2	Overhead line	4	0	4	€ -	3	0	3	€ -	2
3	Switch	4	0	4	€ -	1	2	3	€ 4,032	0
4	Bridge	4	0	4	€ -	4	0	4	€ -	4
5	Tunnel	1	2	3	€ 388,800	3	0	3	€ -	3
6	Level crossing	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	0	3	€ -	2
9	Tunnel video surveillance	0	3	3	€ 392	3	0	3	€ -	3
10	Light signals	0	3	3	€ 683	1	2	3	€ 351	1
11	Traffic light signals	0	3	3	€ 4,725	1	2	3	€ 2,430	1
12	Auxiliary signals	0	3	3	€ 15,435	2	1	3	€ 4,410	2
13	Balise	0	3	3	€ 945	2	1	3	€ 270	2
14	Antennas	4	0	4	€ -	1	2	3	€ 3,370	0
15	Speed sensor	0	3	3	€ 4,410	3	0	3	€ -	3
16	Fixed signals	4	0	4	€ -	4	1	4	€ 96	4

CONTINUED FROM TABLE 27: OPTIMISED COST CALCULATION (RESILIENCE THRESHOLD 3-EGO)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4 Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
2	Overhead line	2	4	€ 832	3	0	3	€ -	2	1	3	€ 462	2
3	Switch	3	3	€ 7,840	0	4	4	€ 11,200	1	2	3	€ 4,032	0
4	Bridge	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
5	Tunnel	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
6	Level crossing	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	2	4	€ 3,931	3	0	3	€ -	2	1	3	€ 2,184	2
9	Tunnel video surveillance	1	4	€ 112	4	1	4	€ 112	4	2	4	€ 202	4
10	Light signals	2	3	€ 351	1	2	3	€ 351	1	2	3	€ 351	1
11	Traffic light signals	2	3	€ 2,430	1	2	3	€ 2,430	1	2	3	€ 2,430	1
12	Auxiliary signals	2	4	€ 7,938	3	1	4	€ 4,410	3	0	3	€ -	2
13	Balise	1	3	€ 270	2	2	4	€ 486	3	0	3	€ -	2
14	Antennas	3	3	€ 6,552	0	3	3	€ 6,552	0	3	3	€ 6,552	0
15	Speed sensor	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	1	4	€ 96	4	0	4	€ -	4	2	4	€ 173	4

TABLE 28: SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 4 (EGO)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
2	Overhead line	4	L0(4)	L1(4)	L1(4)	L1(4)	L1(4)
3	Switch	4	L0(4)	L3(4)	L3(4)	L3(4)	L3(4)
4	Bridge	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
5	Tunnel	1	L3(4)	L0(4)	L0(4)	L0(4)	L0(4)
6	Level crossing	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L1(4)	L1(4)	L1(4)	L1(4)
9	Tunnel video surveillance	0	L4(4)	L0(4)	L0(4)	L0(4)	L0(4)
10	Light signals	0	L4(4)	L2(4)	L2(4)	L2(4)	L2(4)
11	Traffic light signals	0	L4(4)	L2(4)	L2(4)	L2(4)	L2(4)
12	Auxiliary signals	0	L4(4)	L1(4)	L1(4)	L1(4)	L1(4)
13	Balise	0	L4(4)	L1(4)	L1(4)	L1(4)	L1(4)
14	Antennas	4	L0(4)	L3(4)	L3(4)	L3(4)	L3(4)
15	Speed sensor	0	L4(4)	L0(4)	L0(4)	L0(4)	L0(4)
16	Fixed signals	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)

TABLE 29: SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 4 – CALCULATION (EGO)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
			2022				2024			
1	Rail	4	0	4	€ -	4	0	4	€ -	4
2	Overhead line	4	0	4	€ -	3	1	4	€ 462	3
3	Switch	4	0	4	€ -	1	3	4	€ 7,840	1
4	Bridge	4	0	4	€ -	4	0	4	€ -	4
5	Tunnel	1	3	4	€ 756,000	4	0	4	€ -	4
6	Level crossing	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	1	4	€ 2,184	3
9	Tunnel video surveillance	0	4	4	€ 560	4	0	4	€ -	4
10	Light signals	0	4	4	€ 975	2	2	4	€ 351	2
11	Traffic light signals	0	4	4	€ 6,750	2	2	4	€ 2,430	2
12	Auxiliary signals	0	4	4	€ 22,050	3	1	4	€ 4,410	3
13	Balise	0	4	4	€ 1,350	3	1	4	€ 270	3
14	Antennas	4	0	4	€ -	1	3	4	€ 6,552	1
15	Speed sensor	0	4	4	€ 6,300	4	0	4	€ -	4
16	Fixed signals	4	0	4	€ -	4	0	4	€ -	4

CONTINUED FROM TABLE 27: SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 4 – CALCULATION (EGO)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4 Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
2	Overhead line	1	4	€ 462	3	1	4	€ 462	3	1	4	€ 462	3
3	Switch	3	4	€ 7,840	1	3	4	€ 7,840	1	3	4	€ 7,840	1
4	Bridge	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
5	Tunnel	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
6	Level crossing	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	1	4	€ 2,184	3	1	4	€ 2,184	3	1	4	€ 2,184	3
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	2	4	€ 351	2	2	4	€ 351	2	2	4	€ 351	2
11	Traffic light signals	2	4	€ 2,430	2	2	4	€ 2,430	2	2	4	€ 2,430	2
12	Auxiliary signals	1	4	€ 4,410	3	1	4	€ 4,410	3	1	4	€ 4,410	3
13	Balise	1	4	€ 270	3	1	4	€ 270	3	1	4	€ 270	3
14	Antennas	3	4	€ 6,552	1	3	4	€ 6,552	1	3	4	€ 6,552	1
15	Speed sensor	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
16	Fixed signals	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4

TABLE 30: NON-OPTIMISED SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 2 (RFI)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	0	L2(2)	L0(2)	L0(2)	L0(2)	L0(2)
2	Overhead line	0	L2(2)	L1(2)	L1(2)	L1(2)	L1(2)
3	Switch	0	L2(2)	L2(2)	L2(2)	L2(2)	L2(2)
4	Bridge	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
5	Tunnel	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
6	Level crossing	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L0(3)	L0(2)	L1(2)	L1(2)
9	Tunnel video surveillance	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
10	Light signals	4	L0(4)	L0(2)	L2(2)	L2(2)	L2(2)
11	Traffic light signals	4	L0(4)	L0(2)	L2(2)	L2(2)	L2(2)
12	Auxiliary signals	0	L2(2)	L1(2)	L1(2)	L1(2)	L1(2)
13	Balise	0	L2(2)	L1(2)	L1(2)	L1(2)	L1(2)
14	Antennas	4	L0(4)	L1(2)	L2(2)	L2(2)	L2(2)
15	Speed sensor	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
16	Fixed signals	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)

TABLE 31: OPTIMISED SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 2 (RFI)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	0	L2(2)	L0(2)	L0(2)	L0(2)	L0(2)
2	Overhead line	0	L2(2)	L1(2)	L2(3)	L0(2)	L1(2)
3	Switch	0	L2(2)	L2(2)	L2(2)	L2(2)	L2(2)
4	Bridge	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
5	Tunnel	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
6	Level crossing	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L0(3)	L0(2)	L2(3)	L0(2)
9	Tunnel video surveillance	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
10	Light signals	4	L1(4)	L0(2)	L2(2)	L2(2)	L2(2)
11	Traffic light signals	4	L0(4)	L2(4)	L2(4)	L2(4)	L0(2)
12	Auxiliary signals	0	L2(2)	L2(3)	L2(4)	L0(3)	L0(2)
13	Balise	0	L2(2)	L1(2)	L1(2)	L1(2)	L1(2)
14	Antennas	4	L0(4)	L1(2)	L2(2)	L2(2)	L2(2)
15	Speed sensor	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
16	Fixed signals	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)

TABLE 32: NON – OPTIMISED SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 2 – CALCULATION (RFI)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
			2022				2024			
1	Rail	0	2	2	€ 416,988	2	0	2	€ -	2
2	Overhead line	0	2	2	€ 1,081	1	1	2	€ 601	1
3	Switch	0	2	2	€ 7,258	0	2	2	€ 7,258	0
4	Bridge	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	3	0	3	€ -	3	0	3	€ -	3
6	Level crossing	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	0	3	€ -	2
9	Tunnel video surveillance	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	4	0	4	€ -	2	0	2	€ -	0
11	Traffic light signals	4	0	4	€ -	2	0	2	€ -	0
12	Auxiliary signals	0	2	2	€ 7,938	1	1	2	€ 4,410	1
13	Balise	0	2	2	€ 510	1	1	2	€ 284	1
14	Antennas	4	0	4	€ -	1	1	2	€ 2,574	0
15	Speed sensor	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	3	0	3	€ -	3	0	3	€ -	3

CONTINUED FROM TABLE 32: NON – OPTIMISED SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 2 – CALCULATION (RFI)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4 Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
2	Overhead line	1	2	€ 601	1	1	2	€ 601	1	1	2	€ 601	1
3	Switch	2	2	€ 7,258	0	2	2	€ 7,258	0	2	2	€ 7,258	0
4	Bridge	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
6	Level crossing	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	0	2	€ -	1	1	2	€ 2,621	1	1	2	€ 2,621	1
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	2	2	€ 351	0	2	2	€ 351	0	2	2	€ 351	0
11	Traffic light signals	2	2	€ 4,082	0	2	2	€ 4,082	0	2	2	€ 4,082	0
12	Auxiliary signals	1	2	€ 4,410	1	1	2	€ 4,410	1	1	2	€ 4,410	1
13	Balise	1	2	€ 284	1	1	2	€ 284	1	1	2	€ 284	1
14	Antennas	2	2	€ 4,633	0	2	2	€ 4,633	0	2	2	€ 4,633	0
15	Speed sensor	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3

TABLE 33: OPTIMISED COST CALCULATION (RESILIENCE THRESHOLD 2-RFI)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
			2022				2024			
1	Rail	0	2	2	€ 416,988	2	0	2	€ -	2
2	Overhead line	0	2	2	€ 1,081	1	1	2	€ 601	1
3	Switch	0	2	2	€ 7,258	0	2	2	€ 7,258	0
4	Bridge	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	3	0	3	€ -	3	0	3	€ -	3
6	Level crossing	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	0	3	€ -	2
9	Tunnel video surveillance	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	4	1	4	€ 195	2	0	2	€ -	0
11	Traffic light signals	4	0	4	€ -	2	2	4	€ 4,082	2
12	Auxiliary signals	0	2	2	€ 7,938	1	2	3	€ 7,938	2
13	Balise	0	2	2	€ 510	1	1	2	€ 284	1
14	Antennas	4	0	4	€ -	1	1	2	€ 2,574	0
15	Speed sensor	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	3	0	3	€ -	3	0	3	€ -	3

CONTINUED FROM TABLE 33: OPTIMISED COST CALCULATION (RESILIENCE THRESHOLD 2-RFI)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4 Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
2	Overhead line	2	3	€ 1,081	2	0	2	€ -	1	1	2	€ 601	1
3	Switch	2	2	€7,258	0	2	2	€ 7,258	0	2	2	€ 7,258	0
4	Bridge	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	0	3	€ -	3	0	3	€ -	3	0	3	€	3
6	Level crossing	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	0	2	€ -	1	2	3	€ 4,717	2	0	2	€ -	1
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	2	2	€ 351	0	2	2	€ 351	0	2	2	€ 351	0
11	Traffic light signals	2	4	€ 4,082	2	2	4	€ 4,082	2	0	2	€ -	0
12	Auxiliary signals	2	4	€ 7,938	3	0	3	€ -	2	0	2	€ -	1
13	Balise	1	2	€ 284	1	1	2	€ 284	1	1	2	€ 284	1
14	Antennas	2	2	€ 4,633	0	2	2	€ 4,633	0	2	2	€ 4,633	0
15	Speed sensor	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3

TABLE 34: NON-OPTIMISED SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 3 (RFI)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	0	L3(3)	L0(3)	L0(3)	L0(3)	L0(3)
2	Overhead line	0	L3(3)	L1(3)	L1(3)	L1(3)	L1(3)
3	Switch	0	L3(3)	L3(3)	L3(3)	L3(3)	L3(3)
4	Bridge	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
5	Tunnel	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
6	Level crossing	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L0(3)	L1(3)	L1(3)	L1(3)
9	Tunnel video surveillance	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
10	Light signals	4	L0(4)	L1(3)	L2(3)	L2(3)	L2(3)
11	Traffic light signals	4	L0(4)	L1(3)	L2(3)	L2(3)	L2(3)
12	Auxiliary signals	0	L3(3)	L1(3)	L1(3)	L1(3)	L1(3)
13	Balise	0	L3(3)	L1(3)	L1(3)	L1(3)	L1(3)
14	Antennas	4	L0(4)	L2(3)	L3(3)	L3(3)	L3(3)
15	Speed sensor	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
16	Fixed signals	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)

TABLE 35: OPTIMISED SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 3 (RFI)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	0	L3(3)	L0(3)	L0(3)	L0(3)	L0(3)
2	Overhead line	0	L3(3)	L1(3)	L3(4)	L1(4)	L2(4)
3	Switch	0	L3(3)	L4(4)	L3(4)	L2(3)	L3(3)
4	Bridge	3	L0(3)	L0(3)	L0(3)	L0(3)	L2(4)
5	Tunnel	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
6	Level crossing	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L1(4)	L0(3)	L2(4)	L0(3)
9	Tunnel video surveillance	4	L1(4)	L0(4)	L0(4)	L0(4)	L0(4)
10	Light signals	4	L0(4)	L2(4)	L1(3)	L2(3)	L2(3)
11	Traffic light signals	4	L0(4)	L2(4)	L2(4)	L2(4)	L1(3)
12	Auxiliary signals	0	L3(3)	L1(3)	L1(3)	L2(4)	L0(3)
13	Balise	0	L3(3)	L1(3)	L2(4)	L1(4)	L0(3)
14	Antennas	4	L0(4)	L2(3)	L3(3)	L4(4)	L2(3)
15	Speed sensor	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
16	Fixed signals	3	L1(4)	L0(4)	L0(4)	L0(4)	L0(4)

TABLE 36: NON – OPTIMISED SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 3 – CALCULATION (RFI)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost		Deterioration Resilience	Year 2 Action	Resilience After Action	Cost		Deterioration Resilience
			2022					2024				
1	Rail	0	3	3	€	810,810	3	0	3	€	-	3
2	Overhead line	0	3	3	€	2,102	2	1	3	€	601	2
3	Switch	0	3	3	€	14,112	0	3	3	€	14,112	0
4	Bridge	3	0	3	€	-	3	0	3	€	-	3
5	Tunnel	3	0	3	€	-	3	0	3	€	-	3
6	Level crossing	4	0	4	€	-	4	0	4	€	-	4
7	Catenary mast	4	0	4	€	-	4	0	4	€	-	4
8	Line video surveillance	4	0	4	€	-	3	0	3	€	-	2
9	Tunnel video surveillance	4	0	4	€	-	4	0	4	€	-	4
10	Light signals	4	0	4	€	-	2	1	3	€	195	1
11	Traffic light signals	4	0	4	€	-	2	1	3	€	2,268	1
12	Auxiliary signals	0	3	3	€	15,435	2	1	3	€	4,410	2
13	Balise	0	3	3	€	992	2	1	3	€	284	2
14	Antennas	4	0	4	€	-	1	2	3	€	4,633	0
15	Speed sensor	3	0	3	€	-	3	0	3	€	-	3
16	Fixed signals	3	0	3	€	-	3	0	3	€	-	3

CONTINUED FROM TABLE 33: NON – OPTIMISED SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 3 – CALCULATION (RFI)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
2	Overhead line	1	3	€ 601	2	1	3	€601	2	1	3	€ 601	2
3	Switch	3	3	€ 14,112	0	3	3	€ 14,112	0	3	3	€ 14,112	0
4	Bridge	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
6	Level crossing	0	4	€ -	4	0	4	€-	4	0	4	€ -	4
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	1	3	€ 2,621	2	1	3	€ 2,621	2	1	3	€ 2,621	2
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	2	3	€ 351	1	2	3	€ 351	1	2	3	€ 351	1
11	Traffic light signals	2	3	€4,082	1	2	3	€ 4,082	1	2	3	€ 4,082	1
12	Auxiliary signals	1	3	€4,410	2	1	3	€ 4,410	2	1	3	€ 4,410	2
13	Balise	1	3	€284	2	1	3	€ 284	2	1	3	€ 284	2
14	Antennas	3	3	€9,009	0	3	3	€ 9,009	0	3	3	€ 9,009	0
15	Speed sensor	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3

TABLE 37: OPTIMISED COST CALCULATION (RESILIENCE THRESHOLD 3-RFI)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
			2022				2024			
1	Rail	0	3	3	€ 810,810	3	0	3	€ -	3
2	Overhead line	0	3	3	€ 2,102	2	1	3	€ 601	2
3	Switch	0	3	3	€ 14,112	0	4	4	€ 20,160	1
4	Bridge	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	3	0	3	€ -	3	0	3	€ -	3
6	Level crossing	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	1	4	€ 2,621	3
9	Tunnel video surveillance	4	1	4	€ 137	4	0	4	€ -	4
10	Light signals	4	0	4	€ -	2	2	4	€ 351	2
11	Traffic light signals	4	0	4	€ -	2	2	4	€ 4,082	2
12	Auxiliary signals	0	3	3	€ 15,435	2	1	3	€ 4,410	2
13	Balise	0	3	3	€ 992	2	1	3	€ 284	2
14	Antennas	4	0	4	€ -	1	2	3	€ 4,633	0
15	Speed sensor	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	3	1	4	€ 173	4	0	4	€ -	4

CONTINUED FROM TABLE 37: OPTIMISED COST CALCULATION (RESILIENCE THRESHOLD 3-RFI)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4 Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
2	Overhead line	3	4	€ 2,102	3	1	4	€ 601	3	2	4	€ 1,081	3
3	Switch	3	4	€14,112	1	2	3	€ 7,258	0	3	3	€ 14,112	0
4	Bridge	0	3	€ -	3	0	3	€ -	3	2	4	€ 37,440	4
5	Tunnel	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
6	Level crossing	0	4	€ -	4	0	4	€-	4	0	4	€ -	4
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	0	3	€ -	2	2	4	€ 4,717	3	0	3	€ -	2
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	1	3	€ 195	1	2	3	€ 351	1	2	3	€ 351	1
11	Traffic light signals	2	4	€ 4,082	2	2	4	€ 4,082	2	1	3	€ 2,268	1
12	Auxiliary signals	1	3	€ 4,410	2	2	4	€ 7,938	3	0	3	€ -	2
13	Balise	2	4	€ 510	3	1	4	€284	3	0	3	€ -	2
14	Antennas	3	3	€ 9,009	0	4	4	€ 12,870	1	2	3	€ 4,633	0
15	Speed sensor	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4

TABLE 38: SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 4 (FRI)

Asset ID	Asset Class	Resilience After Incident	2022	2024	2026	2028	2030
1	Rail	0	L4(4)	L0(4)	L0(4)	L0(4)	L0(4)
2	Overhead Line	0	L4(4)	L1(4)	L1(4)	L1(4)	L1(4)
3	Switch	0	L4(4)	L3(4)	L3(4)	L3(4)	L3(4)
4	Bridge	3	L1(4)	L0(4)	L0(4)	L0(4)	L0(4)
5	Tunnel	3	L1(4)	L0(4)	L0(4)	L0(4)	L0(4)
6	Level Crossing	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
7	Catenary Mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line Video Surveillance	4	L0(4)	L1(4)	L1(4)	L1(4)	L1(4)
9	Tunnel Video Surveillance	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
10	Light Signals	4	L0(4)	L2(4)	L2(4)	L2(4)	L2(4)
11	Traffic Light Signals	4	L0(4)	L2(4)	L2(4)	L2(4)	L2(4)
12	Auxiliary Signals	0	L4(4)	L1(4)	L1(4)	L1(4)	L1(4)
13	Balise	0	L4(4)	L1(4)	L1(4)	L1(4)	L1(4)
14	Antennas	4	L0(4)	L3(4)	L3(4)	L3(4)	L3(4)
15	Speed Sensor	3	L1(4)	L0(4)	L0(4)	L0(4)	L0(4)
16	Fixed Signals	3	L1(4)	L0(4)	L0(4)	L0(4)	L0(4)

TABLE 39: SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 4 – CALCULATION (RFI)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
			2022				2024			
1	Rail	0	4	4	€ 1,158,300	4	0	4	€ -	4
2	Overhead line	0	4	4	€ 3,003	3	1	4	€ 601	3
3	Switch	0	4	4	€ 20,160	1	3	4	€ 14,112	1
4	Bridge	3	1	4	€ 20,800	4	0	4	€ -	4
5	Tunnel	3	1	4	€ 453,600	4	0	4	€ -	4
6	Level crossing	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	1	4	€ 2,621	3
9	Tunnel video surveillance	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	4	0	4	€ -	2	2	4	€ 351	2
11	Traffic light signals	4	0	4	€ -	2	2	4	€ 4,082	2
12	Auxiliary signals	0	4	4	€ 22,050	3	1	4	€ 4,410	3
13	Balise	0	4	4	€ 1,418	3	1	4	€ 284	3
14	Antennas	4	0	4	€ -	1	3	4	€ 9,009	1
15	Speed sensor	3	1	4	€ 1,911	4	0	4	€ -	4
16	Fixed signals	3	1	4	€ 173	4	0	4	€ -	4

CONTINUE OF TABLE 38: SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 4 – CALCULATION (RFI)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4 Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
2	Overhead line	1	4	€ 601	3	1	4	€ 601	3	1	4	€ 601	3
3	Switch	3	4	€ 14,112	1	3	4	€ 14,112	1	3	4	€ 14,112	1
4	Bridge	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
5	Tunnel	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
6	Level crossing	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	1	4	€ 2,621	3	1	4	€ 2,621	3	1	4	€ 2,621	3
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	2	4	€ 351	2	2	4	€ 351	2	2	4	€ 351	2
11	Traffic light signals	2	4	€ 4,082	2	2	4	€ 4,082	2	2	4	€ 4,082	2
12	Auxiliary signals	1	4	€ 4,410	3	1	4	€ 4,410	3	1	4	€ 4,410	3
13	Balise	1	4	€ 284	3	1	4	€ 284	3	1	4	€ 284	3
14	Antennas	3	4	€ 9,009	1	3	4	€ 9,009	1	3	4	€ 9,009	1
15	Speed sensor	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
16	Fixed signals	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4

TABLE 40: NON-OPTIMISED SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 2 (CDM)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	0	L2(2)	L0(2)	L0(2)	L0(2)	L0(2)
2	Overhead line	4	L0(4)	L0(3)	L0(2)	L1(2)	L1(2)
3	Switch	4	L0(4)	L1(2)	L2(2)	L2(2)	L2(2)
4	Bridge	0	L2(2)	L0(2)	L0(2)	L0(2)	L0(2)
5	Tunnel	0	L2(2)	L0(2)	L0(2)	L0(2)	L0(2)
6	Level crossing	2	L0(2)	L0(2)	L0(2)	L0(2)	L0(2)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L0(3)	L0(2)	L1(2)	L1(2)
9	Tunnel video surveillance	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
10	Light signals	4	L0(4)	L0(2)	L2(2)	L2(2)	L2(2)
11	Traffic light signals	4	L0(4)	L0(2)	L2(2)	L2(2)	L2(2)
12	Auxiliary signals	3	L0(3)	L0(2)	L1(2)	L1(2)	L1(2)
13	Balise	0	L2(2)	L1(2)	L1(2)	L1(2)	L1(2)
14	Antennas	3	L0(3)	L2(2)	L2(2)	L2(2)	L2(2)
15	Speed sensor	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
16	Fixed signals	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)

TABLE 41: OPTIMISED SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 2 (CDM)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	0	L2(2)	L0(2)	L0(2)	L0(2)	L0(2)
2	Overhead line	4	L0(4)	L0(3)	L1(3)	L1(3)	L0(2)
3	Switch	4	L0(4)	L1(2)	L2(2)	L2(2)	L2(2)
4	Bridge	0	L2(2)	L0(2)	L1(3)	L0(3)	L0(3)
5	Tunnel	0	L2(2)	L0(2)	L0(2)	L0(2)	L0(2)
6	Level crossing	2	L0(2)	L0(2)	L0(2)	L0(2)	L0(2)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L0(3)	L0(2)	L2(3)	L0(2)
9	Tunnel video surveillance	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
10	Light signals	4	L0(4)	L2(4)	L0(2)	L2(2)	L2(2)
11	Traffic light signals	4	L0(4)	L0(2)	L2(2)	L2(2)	L2(2)
12	Auxiliary signals	3	L0(3)	L2(4)	L0(3)	L0(2)	L1(2)
13	Balise	0	L2(2)	L1(2)	L2(3)	L0(2)	L1(2)
14	Antennas	3	L0(3)	L2(2)	L2(2)	L2(2)	L2(2)
15	Speed sensor	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
16	Fixed signals	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)

TABLE 42: NON – OPTIMISED SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 2 – CALCULATION (CDM)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
			2022				2024			
1	Rail	0	2	2	€ 583,200	2	0	2	€ -	2
2	Overhead line	4	0	4	€ -	3	0	3	€ -	2
3	Switch	4	0	4	€ -	1	1	2	€ 6,048	0
4	Bridge	0	2	2	€ 56,160	2	0	2	€ -	2
5	Tunnel	0	2	2	€ 1,379,851	2	0	2	€ -	2
6	Level crossing	2	0	2	€ -	2	0	2	€ -	2
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	0	3	€ -	2
9	Tunnel video surveillance	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	4	0	4	€ -	2	0	2	€ -	0
11	Traffic light signals	4	0	4	€ -	2	0	2	€ -	0
12	Auxiliary signals	3	0	3	€ -	2	0	2	€ -	1
13	Balise	0	2	2	€ 875	1	1	2	€ 486	1
14	Antennas	3	0	3	€ -	0	2	2	€ 9,477	0
15	Speed sensor	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	3	0	3	€ -	3	0	3	€ -	3

CONTINUED FROM TABLE 42: NON – OPTIMISED SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 2 – CALCULATION (CDM)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4 Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
2	Overhead line	0	2	€ -	1	1	2	€ 382	1	1	2	€ 382	1
3	Switch	2	2	€ 10,886	0	2	2	€10,886	0	2	2	€ 10,886	0
4	Bridge	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
5	Tunnel	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
6	Level crossing	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	0	2	€ -	1	1	2	€ 4,805	1	1	2	€ 4,805	1
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	2	2	€ 527	0	2	2	€ 527	0	2	2	€ 527	0
11	Traffic light signals	2	2	€ 4,627	0	2	2	€ 4,627	0	2	2	€ 4,627	0
12	Auxiliary signals	1	2	€ 3,864	1	1	2	€ 3,864	1	1	2	€ 3,864	1
13	Balise	1	2	€ 486	1	1	2	€ 486	1	1	2	€ 486	1
14	Antennas	2	2	€ 9,477	0	2	2	€ 9,477	0	2	2	€ 9,477	0
15	Speed sensor	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3

TABLE 43: OPTIMISED COST CALCULATION (RESILIENCE THRESHOLD 2-CDM)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
			2022				2024			
1	Rail	0	2	2	€ 583,200	2	0	2	€ -	2
2	Overhead line	4	0	4	€ -	3	0	3	€ -	2
3	Switch	4	0	4	€ -	1	1	2	€ 6,048	0
4	Bridge	0	2	2	€ 56,160	2	0	2	€ -	2
5	Tunnel	0	2	2	€ 1,379,851	2	0	2	€ -	2
6	Level crossing	2	0	2	€ -	2	0	2	€ -	2
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	0	3	€ -	2
9	Tunnel video surveillance	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	4	0	4	€ -	2	2	4	€ 527	2
11	Traffic light signals	4	0	4	€ -	2	0	2	€ -	0
12	Auxiliary signals	3	0	3	€ -	2	2	4	€ 6,955	3
13	Balise	0	2	2	€ 875	1	1	2	€ 486	1
14	Antennas	3	0	3	€ -	0	2	2	€ 9,477	0
15	Speed sensor	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	3	0	3	€ -	3	0	3	€ -	3

CONTINUED FROM TABLE 43: OPTIMISED COST CALCULATION (RESILIENCE THRESHOLD 2-CDM)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4 Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
2	Overhead line	1	3	€ 382	2	1	3	€ 382	2	0	2	€ -	1
3	Switch	2	2	€ 10,886	0	2	2	€ 10,886	0	2	2	€ 10,886	0
4	Bridge	1	3	€ 31,200	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
6	Level crossing	0	2	€ -	2	0	2	€ -	2	0	2	€ -	2
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	0	2	€ -	1	2	3	€ 8,649	2	0	2	€ -	1
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	0	2	€ -	0	2	2	€ 527	0	2	2	€ 527	0
11	Traffic light signals	2	2	€ 4,627	0	2	2	€ 4,627	0	2	2	€ 4,627	0
12	Auxiliary signals	0	3	€ -	2	0	2	€ -	1	1	2	€ 3,864	1
13	Balise	2	3	€ 875	2	0	2	€ -	1	1	2	€ 486	1
14	Antennas	2	2	€ 9,477	0	2	2	€ 9,477	0	2	2	€ 9,477	0
15	Speed sensor	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3

TABLE 44: NON-OPTIMISED SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 3 (CDM)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	0	L3(3)	L0(3)	L0(3)	L0(3)	L0(3)
2	Overhead line	4	L0(4)	L0(3)	L1(3)	L1(3)	L1(3)
3	Switch	4	L0(4)	L2(3)	L3(3)	L3(3)	L3(3)
4	Bridge	0	L3(3)	L0(3)	L0(3)	L0(3)	L0(3)
5	Tunnel	0	L3(3)	L0(3)	L0(3)	L0(3)	L0(3)
6	Level crossing	2	L1(3)	L0(3)	L0(3)	L0(3)	L0(3)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L0(3)	L1(3)	L1(3)	L1(3)
9	Tunnel video surveillance	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
10	Light signals	4	L0(4)	L1(3)	L2(3)	L2(3)	L2(3)
11	Traffic light signals	4	L0(4)	L1(3)	L2(3)	L2(3)	L2(3)
12	Auxiliary signals	3	L0(3)	L1(3)	L1(3)	L1(3)	L1(3)
13	Balise	0	L3(3)	L1(3)	L1(3)	L1(3)	L1(3)
14	Antennas	3	L0(3)	L3(3)	L3(3)	L3(3)	L3(3)
15	Speed sensor	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)
16	Fixed signals	3	L0(3)	L0(3)	L0(3)	L0(3)	L0(3)

TABLE 45: OPTIMISED SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 3 (CDM)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	**Rail**	**0**	**L3(3)**	**L0(3)**	**L0(3)**	**L0(3)**	**L0(3)**
2	**Overhead line**	**4**	**L0(4)**	**L0(3)**	**L2(4)**	**L1(4)**	**L0(3)**
3	**Switch**	**4**	**L0(4)**	**L2(3)**	**L4(4)**	**L2(3)**	**L3(3)**
4	**Bridge**	**0**	**L3(3)**	**L0(3)**	**L0(3)**	**L0(3)**	**L0(3)**
5	**Tunnel**	**0**	**L3(3)**	**L0(3)**	**L0(3)**	**L0(3)**	**L0(3)**
6	**Level crossing**	**2**	**L1(3)**	**L0(3)**	**L0(3)**	**L0(3)**	**L0(3)**
7	**Catenary mast**	**4**	**L0(4)**	**L0(4)**	**L0(4)**	**L0(4)**	**L0(4)**
8	**Line video surveillance**	**4**	**L0(4)**	**L1(4)**	**L0(3)**	**L2(4)**	**L0(3)**
9	**Tunnel video surveillance**	**4**	**L0(4)**	**L0(4)**	**L0(4)**	**L0(4)**	**L0(4)**
10	**Light signals**	**4**	**L0(4)**	**L2(4)**	**L2(4)**	**L1(3)**	**L2(3)**
11	**Traffic light signals**	**4**	**L0(4)**	**L1(3)**	**L2(3)**	**L2(3)**	**L2(3)**
12	**Auxiliary signals**	**3**	**L0(3)**	**L2(4)**	**L1(4)**	**L0(3)**	**L1(3)**
13	**Balise**	**0**	**L3(3)**	**L1(3)**	**L2(4)**	**L1(4)**	**L0(3)**
14	**Antennas**	**3**	**L1(4)**	**L2(3)**	**L3(3)**	**L3(3)**	**L3(3)**
15	**Speed sensor**	**3**	**L0(3)**	**L0(3)**	**L0(3)**	**L0(3)**	**L0(3)**
16	**Fixed signals**	**0**	**L3(3)**	**L0(3)**	**L0(3)**	**L1(4)**	**L1(4)**

TABLE 46: NON – OPTIMISED SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 3 – CALCULATION (CDM)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
					2022				2024	
1	**Rail**	**0**	**3**	**3**	**€ 1,134,000**	**3**	**0**	**3**	**€ -**	**3**
2	**Overhead line**	**4**	**0**	**4**	**€ -**	**3**	**0**	**3**	**€ -**	**2**
3	**Switch**	**4**	**0**	**4**	**€ -**	**1**	**2**	**3**	**€ 10,886**	**0**
4	**Bridge**	**0**	**3**	**3**	**€ 109,200**	**3**	**0**	**3**	**€ -**	**3**
5	**Tunnel**	**0**	**3**	**3**	**€ 2,683,044**	**3**	**0**	**3**	**€ -**	**3**
6	**Level crossing**	**2**	**1**	**3**	**€ 131,789**	**3**	**0**	**3**	**€ -**	**3**
7	**Catenary mast**	**4**	**0**	**4**	**€ -**	**4**	**0**	**4**	**€ -**	**4**
8	**Line video surveillance**	**4**	**0**	**4**	**€ -**	**3**	**0**	**3**	**€ -**	**2**
9	**Tunnel video surveillance**	**4**	**0**	**4**	**€ -**	**4**	**0**	**4**	**€ -**	**4**
10	**Light signals**	**4**	**0**	**4**	**€ -**	**2**	**1**	**3**	**€ 293**	**1**
11	**Traffic light signals**	**4**	**0**	**4**	**€ -**	**2**	**1**	**3**	**€ 2,570**	**1**
12	**Auxiliary signals**	**3**	**0**	**3**	**€ -**	**2**	**1**	**3**	**€ 3,864**	**2**
13	**Balise**	**0**	**3**	**3**	**€ 1,701**	**2**	**1**	**3**	**€ 486**	**2**
14	**Antennas**	**3**	**0**	**3**	**€ -**	**0**	**3**	**3**	**€ 18,428**	**0**
15	**Speed sensor**	**3**	**0**	**3**	**€ -**	**3**	**0**	**3**	**€ -**	**3**
16	**Fixed signals**	**3**	**0**	**3**	**€ -**	**3**	**0**	**3**	**€ -**	**3**

CONTINUED FROM TABLE 46: NON – OPTIMISED SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 3 – CALCULATION (CDM)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
2	Overhead line	1	3	€ 382	2	1	3	€ 382	2	1	3	€ 382	2
3	Switch	3	3	€ 21,168	0	3	3	€ 21,168	0	3	3	€ 21,168	0
4	Bridge	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
6	Level crossing	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	1	3	€ 4,805	2	1	3	€ 4,805	2	1	3	€ 4,805	2
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	2	3	€ 527	1	2	3	€ 527	1	2	3	€ 527	1
11	Traffic light signals	2	3	€ 4,627	1	2	3	€ 4,627	1	2	3	€ 4,627	1
12	Auxiliary signals	1	3	€ 3,864	2	1	3	€ 3,864	2	1	3	€ 3,864	2
13	Balise	1	3	€ 486	2	1	3	€ 486	2	1	3	€ 486	2
14	Antennas	3	3	€ 18,428	0	3	3	€ 18,428	0	3	3	€ 18,428	0
15	Speed sensor	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3

TABLE 47: OPTIMISED COST CALCULATION (RESILIENCE THRESHOLD 3-CDM)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
					2022				2024	
1	Rail	0	3	3	€ 1,134,000	3	0	3	€ -	3
2	Overhead line	4	0	4	€ -	3	0	3	€ -	2
3	Switch	4	0	4	€ -	1	2	3	€ 10,886	0
4	Bridge	0	3	3	€ 109,200	3	0	3	€ -	3
5	Tunnel	0	3	3	€ 2,683,044	3	0	3	€ -	3
6	Level crossing	2	1	3	€ 131,789	3	0	3	€ -	3
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	1	4	€ 4,805	3
9	Tunnel video surveillance	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	4	0	4	€ -	2	2	4	€ 527	2
11	Traffic light signals	4	0	4	€ -	2	1	3	€ 2,570	1
12	Auxiliary signals	3	0	3	€ -	2	2	4	€ 6,955	3
13	Balise	0	3	3	€ 1,701	2	1	3	€ 486	2
14	Antennas	3	1	4	€ 5,265	1	2	3	€ 9,477	0
15	Speed sensor	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	3	0	3	€ -	3	1	4	€ 115	4

CONTINUED FROM TABLE 12: OPTIMISED COST CALCULATION (RESILIENCE THRESHOLD 3-CDM)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4 Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
2	Overhead line	2	4	€ 687	3	1	4	€ 382	3	0	3	€ -	2
3	Switch	4	4	€ 30,240	1	2	3	€ 10,886	0	3	3	€ 21,168	0
4	Bridge	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
5	Tunnel	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
6	Level crossing	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	0	3	€ -	2	2	4	€ 8,649	3	0	3	€ -	2
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	2	4	€ 527	2	1	3	€ 293	1	2	3	€ 527	1
11	Traffic light signals	2	3	€ 4,627	1	2	3	€ 4,627	1	2	3	€ 4,627	1
12	Auxiliary signals	1	4	€ 3,864	3	0	3	€ -	2	1	3	€ 3,864	2
13	Balise	2	4	€ 875	3	1	4	€ 486	3	0	3	€ -	2
14	Antennas	3	3	€ 18,428	0	3	3	€ 18,428	0	3	3	€ 18,428	0
15	Speed sensor	0	3	€ -	3	0	3	€ -	3	0	3	€ -	3
16	Fixed signals	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4

TABLE 48: SCHEDULE OF WORKS (SAMPLE) FOR RESILIENCE THRESHOLD 4 (CDM)

Asset ID	Asset Class	Resilience After incident	2022	2024	2026	2028	2030
1	Rail	0	L4(4)	L0(4)	L0(4)	L0(4)	L0(4)
2	Overhead line	4	L0(4)	L1(4)	L1(4)	L1(4)	L1(4)
3	Switch	4	L0(4)	L3(4)	L3(4)	L3(4)	L3(4)
4	Bridge	0	L4(4)	L0(4)	L0(4)	L0(4)	L0(4)
5	Tunnel	0	L4(4)	L0(4)	L0(4)	L0(4)	L0(4)
6	Level crossing	2	L2(4)	L0(4)	L0(4)	L0(4)	L0(4)
7	Catenary mast	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
8	Line video surveillance	4	L0(4)	L1(4)	L1(4)	L1(4)	L1(4)
9	Tunnel video surveillance	4	L0(4)	L0(4)	L0(4)	L0(4)	L0(4)
10	Light signals	4	L0(4)	L2(4)	L2(4)	L2(4)	L2(4)
11	Traffic light signals	4	L0(4)	L2(4)	L2(4)	L2(4)	L2(4)
12	Auxiliary signals	3	L1(4)	L1(4)	L1(4)	L1(4)	L1(4)
13	Balise	0	L4(4)	L1(4)	L1(4)	L1(4)	L1(4)
14	Antennas	3	L1(4)	L3(4)	L3(4)	L3(4)	L3(4)
15	Speed sensor	3	L1(4)	L0(4)	L0(4)	L0(4)	L0(4)
16	Fixed signals	3	L1(4)	L0(4)	L0(4)	L0(4)	L0(4)

TABLE 49: SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 4 – CALCULATION (CDM)

Asset ID	Asset Class	Resilience After incident	Year 1 Action	Resilience After Action	Cost	Deterioration Resilience	Year 2 Action	Resilience After Action	Cost	Deterioration Resilience
			2022				2024			
1	Rail	0	4	4	€ 1,620,000	4	0	4	€ -	4
2	Overhead line	4	0	4	€ -	3	1	4	€ 382	3
3	Switch	4	0	4	€ -	1	3	4	€ 21,168	1
4	Bridge	0	4	4	€ 156,000	4	0	4	€ -	4
5	Tunnel	0	4	4	€ 3,832,920	4	0	4	€ -	4
6	Level crossing	2	2	4	€ 237,220	4	0	4	€ -	4
7	Catenary mast	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	4	0	4	€ -	3	1	4	€ 4,805	3
9	Tunnel video surveillance	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	4	0	4	€ -	2	2	4	€ 527	2
11	Traffic light signals	4	0	4	€ -	2	2	4	€ 4,627	2
12	Auxiliary signals	3	1	4	€ 3,864	3	1	4	€ 3,864	3
13	Balise	0	4	4	€ 2,430	3	1	4	€ 486	3
14	Antennas	3	1	4	€ 5,265	1	3	4	€ 18,428	1
15	Speed sensor	3	1	4	€ 3,276	4	0	4	€ -	4
16	Fixed signals	3	1	4	€ 115	4	0	4	€ -	4

CONTINUED FROM TABLE 49: SCHEDULE OF WORKS FOR RESILIENCE THRESHOLD 4 – CALCULATION (CDM)

Asset ID	Asset Class	Year 3 Action	Resilience After Action	Cost	Deterioration Resilience	Year 4 Action	Resilience After Action	Cost	Deterioration Resilience	Year 5 Action	Resilience After Action	Cost	Deterioration Resilience
		2026				2028				2030			
1	Rail	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
2	Overhead line	1	4	€ 382	3	1	4	€ 382	3	1	4	€ 382	3
3	Switch	3	4	€ 21,168	1	3	4	€ 21,168	1	3	4	€ 21,168	1
4	Bridge	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
5	Tunnel	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
6	Level crossing	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
7	Catenary mast	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
8	Line video surveillance	1	4	€ 4,805	3	1	4	€ 4,805	3	1	4	€ 4,805	3
9	Tunnel video surveillance	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
10	Light signals	2	4	€ 527	2	2	4	€ 527	2	2	4	€ 527	2
11	Traffic light signals	2	4	€ 4,627	2	2	4	€ 4,627	2	2	4	€ 4,627	2
12	Auxiliary signals	1	4	€ 3,864	3	1	4	€ 3,864	3	1	4	€ 3,864	3
13	Balise	1	4	€ 486	3	1	4	€ 486	3	1	4	€ 486	3
14	Antennas	3	4	€ 18,428	1	3	4	€ 18,428	1	3	4	€ 18,428	1
15	Speed sensor	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4
16	Fixed signals	0	4	€ -	4	0	4	€ -	4	0	4	€ -	4

ANNEX III. CAMS Data

TABLE 50–SAMPLE OF CAMS DATA

Title: CdM SIMULATION EXERCISE					S4R_RPT_Specs_T64_T82_Tests_V0_3_DATA FOR CAMS										
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Asset ID	Asset CODE	Asset Category	Asset Type	Asset Name	Condition before incident	Condition after incident	Time required for replacement/repair	Purchase Cost	Operation	Maintenance	Renewal	Disposal	Priority of recovery	Dependencies	Quantity of repair replacement
1	A-TR-01	Track	PH	Rail	1	5	30	1	0	1	1	1	5	25	
2	A-TR-02	Track	TP	Overhead line	1	5	14	0	0	1	1	1	5	25	75
3	A-TR-03	Track	PH	Switch	1	5	14	1	1	1	0	1	1	25	5
4	A-TR-04	Track	PH	Bridge	1	2	7	1	0	1	1	1	5		100
5	A-TR-05	Track	PH	Tunnel	1	4	30	1	0	1	1	0	5		200
6	A-TR-06	Track	PH	Level crossing	1			1	0	1	0	1	5	25	5
7	A-TR-07	Track	PH	Catenary mast	1			0	0	0	1	1	5		
8	A-ST-01	Station	PA	Ticket machine	1	5	20	0	0	0	0	1	4	25	5
9	A-ST-02	Station	SE	Ticket office	1	3	14	0	1	0	1	1	2	25	2
10	A-ST-03	Station	SE	Elevator	1	5	20	0	0	0	0	1	4	25	4
11	A-ST-04	Station	SE	Escalator	1	4	30	0	0	0	1	1	4	25	2
12	A-ST-05	Station	PH	Turnstiles	1	5	30	0	0	0	0	0	3	25	2
13	A-ST-06	Station	SE	Validator	1	3	7	0	0	0	0	0	5	54	4
14	A-ST-07	Station	PIS	Electronic timetable	1	2	14	0	0	0	1	0	2	54	2
15	A-ST-08	Station	PIS	Sound announcements	1			0	0	1	1	1	2		
16	A-ST-09	Station	SE	Platform	1	5	30	1	0	0	1	1	1	25	800
17	A-ST-10	Station	SE	Vendor/retailer	1			1	0	0	0	1	4	25	4
18	A-ST-11	Station	EC	HVAC system	1			0	1	1	0	1	1		
19	A-ST-12	Station	LE	Lighting system	1	3	7	0	0	0	1	0	1	25	100
20	A-IS-01	Information system	PIS	E-ticketing system	1	5	14	1	0	0	0	0	3	25	5
21	A-IS-02	Information system	TV	Linevideo surveillance	1			1	0	1	1	0	4		
22	A-IS-03	Information system	TV	Tunnelsvideo	1			1	0	1	1	0	5		
23	A-IS-04	Information system	DMS	Malfunction detection	1			1	0	0	0	0	5		
24	A-IS-05	Information system	IT	Wi-Fi hotspots	1			0	1	0	0	0	4		
25	A-EL-01	Electrical substation	PW	Electrical substation	1	5	7	1	0	0	1	1	5	54	2
26	A-RS-01	Rolling stock	PH	Locomotive	1	3	14	1	0	0	1	1	5	25	2
27	A-RS-02	Rolling stock	PH	Rail car	1	4	14	1	0	0	1	1	5	25	2
28	A-RS-03	Rolling stock	IT	Onboard computer	1	2	14	0	0	0	1	0	5	25	5
29	A-RS-04	Rolling stock	IT	GSM-R system	1			0	0	0	1	0	5		
30	A-RS-05	Rolling stock	PH	Driver's console	1	3	20	0	0	0	1	0	5	25	3
31	A-SS-01	ilway Signalling syst	LE	Light signals	1	5	20	0	0	0	0	0	5	25	10
32	A-SS-02	ilway Signalling syst	LE	Traffic light signals	1	5	20	0	0	0	0	0	5	25	15
33	A-SS-03	ilway Signalling syst	LE	Auxiliary signals	1	5	30	0	0	0	0	0	5	25	5
34	A-SS-04	ilway Signalling syst	LE	Balise	1	5	14	0	0	0	0	0	5	54	6
35	A-SS-05	ilway Signalling syst	IT	ERTMS	1	5	30	1	1	0	0	0	5	25	1
36	A-SS-06	ilway Signalling syst	IT	Antennas	1	5	30	0	0	0	0	0	5	25	5
37	A-SS-07	ilway Signalling syst	DMS	Speed sensor	1	5	30	0	0	0	0	0	5	25	4

CdM_SE / RFI_SE / 1_NATURAL DISASTER - FLOODING / 2_INTRUSION AND BOMB PLANTED / 3_INTRUSION AND SABOTAGE / 4_COMBINEDPHYSICAL-CYBER ATTACK / 5_MIXED

SAFETY4RAILS

Partners:

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