



Smart Maintenance, Analysis and Remediation of Transport Infrastructure

SMARTRAIL FINAL REPORT



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1 Final publishable summary report

1.1 Executive Summary

In order to effectively manage ageing railway infrastructure, a well-defined safety assessment framework is required. In the SMARTRAIL project, a reliability-based framework was developed for an optimized whole life management of rail infrastructure elements including; bridges, tracks and slopes. This allows for the modelling of the uncertainty associated with the input parameters and the effective application of site-specific data (e.g. loading/strength). Methods to obtain real-time information on the performance of rail infrastructure, which update the reliability, based model and allow real-time assessment were developed and tested on railway infrastructure across the EU. These techniques included; the development of innovative sensors to monitor the corrosion rate of steel and concrete bridges, the application of geophysical techniques as a non-destructive method of evaluating the condition of open-track and embankments, the use of simple accelerometers to derive a vibration based method of measuring the development of bridge scour and the development of an early warning system for rainfall induced landslides.

The framework documentation includes typical distributions of stochastic variables and recommends target levels of reliability. The approach was illustrated by application of the methodology to two demonstration projects, a steel railway bridge in Poland and a 150-year-old railway embankment in Ireland. A particular feature of reliability-based assessment is that it provides information on when remediation work should be performed on a given element. Given the different challenges faced by infrastructure managers across the EU and the range of local materials available to effect solutions, a series of full-scale demonstration projects were undertaken in conjunction with infrastructure managers who participated in the SMARTRAIL project. These included the remediation of a metallic bridge using ultra high-strength fibre reinforced concrete in Croatia, the use of geosynthetics to prevent ballast fouling in Slovenia, and the demonstration of the efficacy of a new technique which uses vertical anchors to provide a smooth variation of stiffness across the transition zone for the reconstructed Buna Bridge in Croatia.

In order to make rational choices on the economic and environmental benefits of any remedial works, a life cycle analysis (LCA) and life cycle cost (LCC) tool were developed within the project. The tool, which can be accessed using an attractive graphical user interface via the SMARTRAIL website, was used to prove the environmental and economic cost benefits associated with the remediation techniques demonstrated in the project.

The SMARTRAIL project was a truly collaborative project which through the establishment of a user platform, involved major stakeholders including rail operators, infrastructure managers, engineers, researchers, regulatory bodies and policy makers from the beginning of the project. Engagement with industry was undertaken in the form of face to face interviews, questionnaires, workshops and bilateral agreements. A number of specialist workshops, conference sessions and scientific papers were organized and published. A particular feature of the project is the publication of non-technical user guidelines that should facilitate the widespread exploitation of the results of the project.

1.2 Summary description of project context and objectives

1.2.1 Context

Safe and efficient transport infrastructure is a fundamental requirement to facilitate and encourage the movement of goods and people throughout the European Union. There is approximately 215,400 km of rail lines in the EU which represent a significant asset. Many of the rail networks in Eastern Europe and in parts of Western Europe were developed more than 150 years ago. These networks were not built to conform to modern standards and suffer from low levels of investment and in some cases poor maintenance strategies. Replacement costs for civil engineering infrastructure items such as rail track, bridges and tunnels are prohibitive. In the current economic climate it is vital that we maintain and develop our transport network and optimize the use of all resources. It is essential therefore those methods used to analyse and monitor the existing infrastructure result in realistic scientific assessments of safety which allow the effective programming of remedial works. The SMARTRAIL project was designed to bring together experts in the fields of rail and road transport infrastructure with the aim to develop state of the art inspection; monitoring and assessment techniques which would allow rail operators to manage ageing infrastructure networks in a cost-effective and environmentally friendly manner.

Several European countries have highly advanced rail networks where the primary areas of concern in relation to infrastructure performance are related to achieving ever higher network speeds. In newer member states such as Slovenia and Croatia and even in some Western European countries, historic lack of investment in rail infrastructure had led to the situation that some elements of the network are in very poor condition. In these countries, parts of the rail infrastructure would be deemed to have reached the end of its useful life when analysed using conventional assessment methods. When incidents occur such as structural failures or derailments, it is common practice in certain regions to simply close the line. Because of the lack of viable alternative modes of transport, such drastic action cannot be adopted in most countries.

Climate change effects are increasing the burden on ageing transport networks with the incidence of infrastructure failure increasing. The construction of the trans-European transport network (TEN-T), which aims to provide interconnection and interoperability of national transport networks within the EU, is seen as vital for the economic competitiveness of the Union and is central to the objectives of achieving balanced and sustainable development. The Irish railways were amongst the first constructed in Europe, and the 180 m span Malahide viaduct which carries the Dublin-Belfast line just North of Dublin is one of the oldest railway viaducts in the world. On August 21st 1999 a bridge pier collapsed as a local passenger train crossed the viaduct and the Belfast-Dublin express service approached. The collapse, which was caused by scour of the foundations (which was not noted by a visual assessment performed days before the failure) caused the line to be closed for seven months and a repair bill in the region of €4 million. The scour problem which caused the failure was accelerated by high flows in the estuary caused by recent flooding.

1.2.2 Objectives

The SMARTRAIL vision is to provide a framework for infrastructure operators to ensure the safe, reliable and efficient operation of ageing European railway networks. This will be achieved through a holistic approach, which will consider input from state of the art inspection, assessment and remediation techniques and use this data to consider “what if” scenarios using whole life cycle cost models. The project focuses on the heavy civil engineering infrastructure (such as bridges, tunnels, rail track and slopes) associated with ageing rail networks. Each element represents a very high cost item (usually quantified in millions of Euro) and unplanned replacement of any single element would cause unacceptable delays for the network (generally measured in months). The project aims to allow:

- (i) Increased traffic volume and loading with particular consideration for increased freight capacity. The techniques will consider the effects of changing climate on infrastructure, for example; incidents of flooding causing accelerated scour of bridge foundations, high intensity rainfall events causing slope failures and freeze-thaw causing damage to bridge and tunnel structures.
- (ii) The SMARTRAIL consortium brings together experts in the fields of infrastructure assessment in the road and rail industries, national infrastructure operators and specialist SME’s to achieve these critical aims.

In order to achieve the SMARTRAIL concept (see Figure1), we require the following critical and interdependent elements:

1. A sensor network embedded in key elements of rail infrastructure. These will collect real-time in-situ measurements of key parameters, which will be transmitted, via an advanced IT network to provide critical input data.
2. State of the art Structural Health Monitoring (SHM) procedures, which will provide up to the minute assessments of the safety of the infrastructure elements.
3. A suite of environmentally friendly low-cost remediation measures that are region-specific, and provide minimal disruption will be demonstrated. The suite of measures will be capable of providing short-term remedial solutions for critical sections of the network identified by the SHM models.
4. The sensor networks and SHM techniques will be implemented at demonstration sites (in Slovenia, Poland, Greece, Croatia and Ireland). After assessments of current safety have been undertaken environmentally friendly forms of remediation will be undertaken and the effect in terms of SHM will be quantified.
5. Life Cycle Analysis models that will take input from the SHM and identify the most efficient maintenance programmes for each infrastructure operator, considering financial costs and environmental assessment.



Figure 1: The SMARTRAIL Concept of Remote Monitoring, Assessment and Remediation

Summary of Objectives of the SMARTRAIL project:

1. A range of measures are proposed to move infrastructure owners away from reliance on visual inspection methods and towards more reliable and efficient techniques which include; Embedded sensor networks which can monitor stress, strain, water pressure etc. and Improved geophysical techniques suggested as an alternative to visual inspection and to be used in conjunction with direct in-situ investigation methods.
2. Advanced Structural Health Monitoring (SHM) models that allow engineers to make rational evaluations (based on statistical data) of the probability of failure of elements of infrastructure were developed for bridges and embankments. The probability of failure increases with time and planned interventions can be optimized to allow best use of resources.
3. Major demonstration projects were performed to investigate a novel method of dealing with transition zones, the Buna Bridge reconstruction in Croatia and improving the performance of open-track sections of the Slovenian rail network.
4. A dedicated asset management tool that can collate the input data from monitoring, SHM models and remediation methods. together with information from databases collated by the infrastructure managers to perform Whole Life Cycle Analyses was delivered.

2 Description of main S & T results/foregrounds

2.1 Introduction

The cost of European network maintenance, renewal and upgrading is immense. As the infrastructure continues to age, climate change effects result in increased degradation, loading rates increase and Europe attempts to extend its transport borders. As a result, the development of cost-effective means of inspection, assessment and upgrading of the rail network has never been more important. The current state of the art for these techniques in the critical areas was considered by the SMARTRAIL project and significant progress was achieved in the technical work packages, WP1 to WP4. These advances are described in this section of the report.

2.2 Monitoring and Inspection

The aim of this WP was to bring about a step change in the traditional methods of visual inspection and ad-hoc monitoring by developing and demonstrating integrated monitoring systems which utilize the latest embedded sensor technology and optimized in-situ testing methods.

Increased rainfall and flooding is leading to a sudden increase in the number of landslides on transport networks in recent years. As part of the SMARTRAIL project an instrumented Smart Slope experiment was performed on a 150 year old railway slope in Ireland. The embankment was instrumented with embedded sensors to monitor changes in moisture content and subjected to an extreme rainfall event. The embankment is located on the former Kingscourt - Navan railway line on the periphery of Nobber village in Co. Meath, Ireland. Data from the experiment was used to develop a method, which relates rainfall to the advance of the wetting front in a slope during a rainfall event. This provides a technique for calculating the remaining time until landslide initiation for a given rainstorm. This is accomplished by computing the remaining water storage capacity between the ground and the critical slip surface and, based on the infiltration characteristics of the soil; the time necessary for the wetting front (See Figure 2) to reach the requisite depth is calculated. A laboratory test was performed which measured the time taken for water to percolate a known distance through soil. This was then compared to the time predicted by the method presented in this report. The predicted values were shown to closely approximate the measured values. The method is thus suitable as an early warning system for rainfall induced landslides.

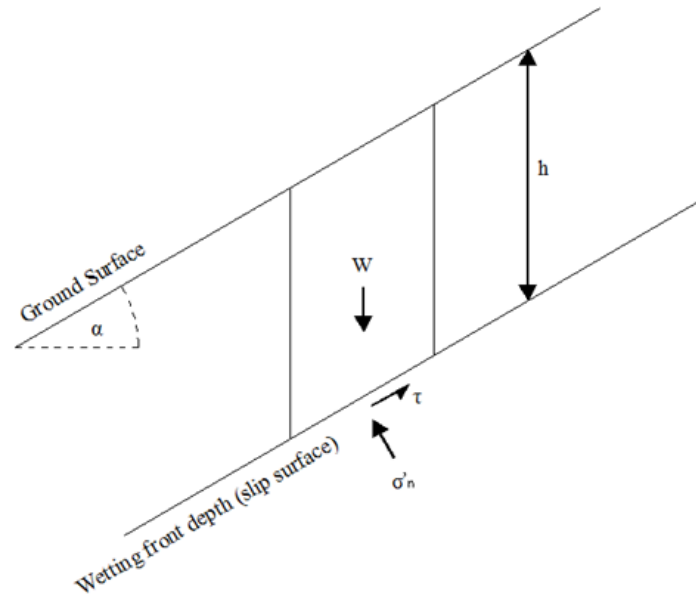


Figure 2: Development of wetting front in slope during rainfall

2.2.1 Inspection of Slopes and Railway Infrastructure using NDT Techniques

SMARTRAIL project partner NTUA (National Technical University of Athens) conducted field trials on three test sections along the Greek rail network. GPR surveys were conducted at train speeds using 1 GHz and 400 MHz antennae attached to the front of a train, See Figure 3. A detailed analysis of the system performance is presented in Deliverable 1.3. The researchers reported some very valuable and practical findings to maximise the accuracy of surveys: (i) a configuration of a high-frequency antenna (i.e. 1 GHz) and a low-frequency antenna (i.e. 400MHz) optimised the sensing results. (ii) Proper orientation of antennas is dependent on individual site criteria and, for this purpose, several test scans, with different orientations and position of antennas, are required. (iii) The accuracy of ballast thickness estimation using GPR is dependent on the accuracy of the knowledge of the velocity of radar waves travelling within the track bed. And (iv) the dielectric constant is the major ballast property governing GPR response and thickness evaluation and, for this purpose, GPR analysis results must be calibrated using trial pits and laboratory testing.

The Multi-Channel Analysis of Surface Waves (MASW) geophysical technique was performed at two demonstration projects for the SMARTRAIL project. At one, the Buna Bridge replacement project near Zagreb in Croatia described in Work Package 3, MASW profiles were obtained by the SMARTRAIL project partner IGH to develop a ground model for the site where bridge replacement and the construction of novel transition zones was undertaken. In addition Apex Ltd, an Irish geophysical investigation company at the instrumented slope experiment performed at Nobber, applied the technique. The purpose of its use here was to attempt to track changes in moisture content (during the infiltration experiment) through changes in the soil stiffness.

Because of the presence of the steep slope and relatively shallow depth of infiltrating water, interpretation of these results proved challenging and work to resolve the profiles is on-going at the time of writing this report.



Figure 3: Test underway at Greek test site

2.2.2 Development of a methodology for NDT assessment of bridge foundations subjected to scour

Scour is one of the leading causes of bridge failure. As part of the SMARTRAIL project a user guideline on bridge scour monitoring discusses the advantages and disadvantage of various industry standard methods for monitoring bridge scour. Given the importance of scour, one of the main objectives of the SMARTRAIL project was the development of a low-cost and reliable method of monitoring scour in real time. The overall response of a bridge to both static and dynamic loads is influenced by interaction of the structure with the soil through its foundations (this is known as a soil-structure interaction problem). The exact interaction is complex and time-dependent, being governed by many different parameters. Accelerometers placed on bridge piers can detect fluctuations in the fundamental dynamic characteristics. Any change in the soil condition, e.g. loss of material or change in density will alter the soil stiffness and therefore reduce the natural frequency change of the structure. In the SMARTRAIL project the effect of scour on a piled foundation system was investigated through scale model experimental tests in the laboratory (see Figure 4 below) and prototype tests conducted in the field.

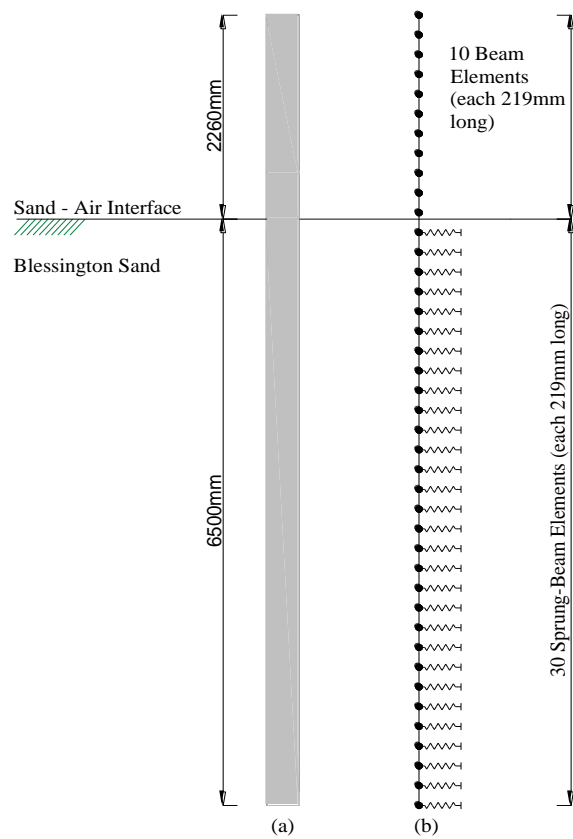


Figure 4 Pile modelled as simple mean-spring model

In the experiments, the top of a pile was excited using an impulse force and the resulting acceleration response was recorded. This process was repeated for a number of scour depths. The natural frequency for a given scour depth was determined using a Fourier transform and large decreases in natural frequency were noted as the scour depth increased. A numerical model shown in Figure 5 was developed which was capable of tracking these changes in natural frequency thus providing a real-time method of recording scour. The model is relatively simple and the input parameters are the geometry and structural characteristics of the structure and the small-strain stiffness of the soil. This latter value is easily measurable using geophysical techniques such as the MASW method described in the SMARTRAIL project. The numerical model was shown to produce excellent estimates of the change in frequency using a range of input soil stiffness values.

The field demonstration was a relatively simple experiment, which included only the foundation, i.e. no structure was present. In order to investigate whether the approach could be applicable to full-scale bridge monitoring, the numerical model was developed to include a full super-structure and a sensitivity study was performed.

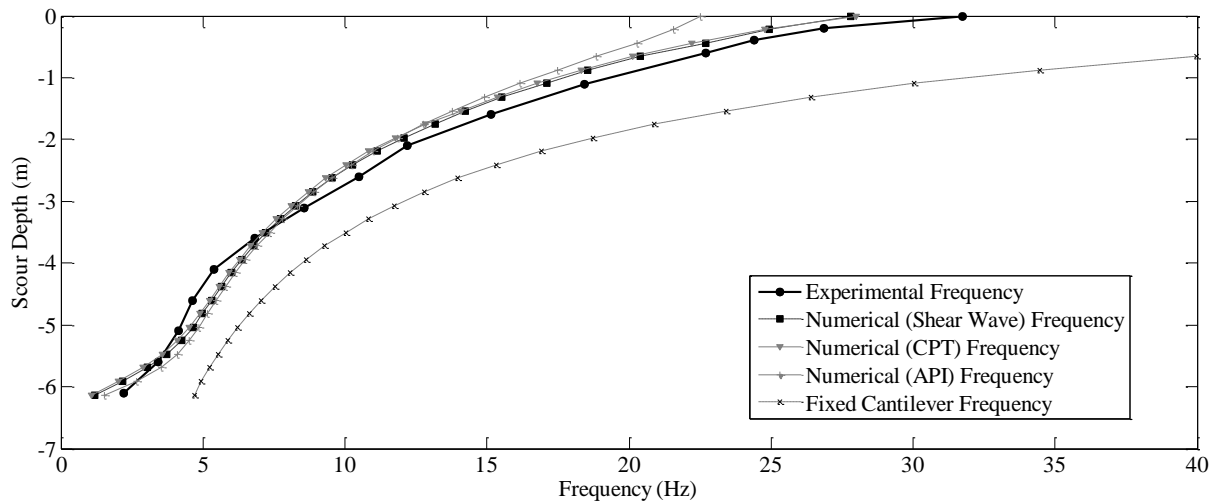


Figure 5: Frequency Change with Scour showing Experimental Response, Numerical Response and Analytical Upper-Bound Equivalent Cantilever.

A simplified numerical model of a bridge pier-foundation system was developed comprising an embedded pile, a pile cap interface, a cylindrical bridge column to represent the pier and a pinned/fixed connection to model the boundary condition with the deck superstructure. The bridge pier was restrained laterally at the top using either a pinned or a fixed connection. In one case it was free to rotate about the pin and in the second, no rotation was allowed. The mass of the deck has no effect on the dynamic response of the pier and in this model as only the connection type governs the response. The range of bridge pier diameters and lengths, which were investigated in this sensitivity study, are outlined in Table 1. The pile cap mass is lumped at the interface node between the bridge pile and the pier.

Table 1 Parametric analysis.

Parameter	Value
Diameters tested (m)	1 m, 1.5 m
Pier lengths considered (m)	5 m, 10 m, 15 m
Scour depth considered (m)	0 m – 3 m
Pile cap dimensions (m)	2 m x 2 m x 1 m
Pile cap mass (kg)	9600 kg
Pile diameter (m)	0.34 m
Pile penetration (m)	6.57 m
Pile material	Steel ($\rho = 7850 \text{ kg m}^{-3}$)
Pier material	Concrete ($\rho = 2400 \text{ kg m}^{-3}$)

The soil stiffness was obtained using typical shear wave velocity measurements measured in dense sand. The pile length and geometry was fixed for the purpose of consistency while the other parameters were varied. The results of this analysis are presented in as a ratio of the change in natural frequency with reference to the zero scour frequency response. This allows a window of expected frequency shift magnitudes to be ascertained for the given geometries considered.

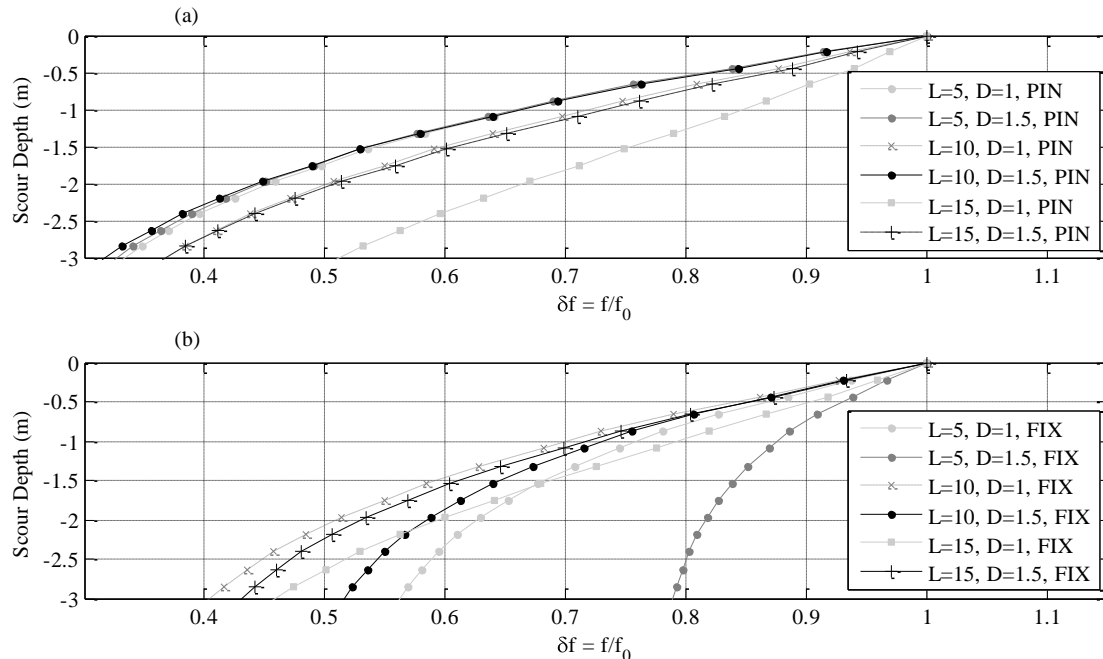


Figure 6: Frequency change sensitivity study for 3 m scour depth. (a) pinned connection with deck assumed; (b) fixed connection with deck assumed as boundary conditions with superstructure.

The results of the analysis were quite sensitive to the boundary condition assumed and the geometry considered. Frequency changes over a 3 m scour depth ranged from 50% to 69% for the pinned connection and 21% to 60% for the fixed connection. The purpose of this analysis was not to determine exact frequency shifts corresponding to a real life bridge but merely to assess if adequate frequency shifts were observed when a full bridge pier and connection with a bridge deck was considered. From the analysis, it was clear that scour had a significant effect on the dynamic response of the bridge pier-pile foundation system for the given geometries and structural fixities considered.

2.2.3 Use of instrumentation to monitor the condition of bridge structures

Bridge weigh-in-motion (BWiM) has been used to monitor road bridges for a number of years. The system provides in-situ measurement of axle loads and vehicle gross weights. In the SMARTRAIL project the objective was to develop a Railway BWiM system and this was undertaken in two parts. In the first part of the work two algorithms for load identification were investigated. A method using online calibration proved insensitive to environmental conditions was shown to be practical.

The BWiM system was tested at two demonstration sites, one in Slovenia and one in Poland. A comparison of the performance of piezoelectric sensors with strain gauges was undertaken. Both gauges proved to be sufficiently accurate for the BWiM application with their accuracy

improving significantly when multiple sensors were deployed, with four providing ideal measurements.

SMARTRAIL project partner ZAG developed a measurement kit with sensors for monitoring electrochemical impedance. The system was tested in a demonstration project on a bridge in Slovenia with the system proving to provide reliable results.

2.3 Assessment and Models

2.3.1 Introduction

Many parts of Europe's rail network were constructed in the mid-19th century long before the advent of modern construction standards. Historic levels of low investment, poor maintenance strategies and the deleterious effects of climate change have resulted in critical elements of the rail network such as bridges, tunnels and earthworks being at a significant risk of failure. The aim of this work package was to develop models which assist infrastructure managers in planning repair/rehabilitation strategies. This was mainly achieved through the development of a general railway infrastructure safety framework. This framework uses probabilistic modelling to determine the critical infrastructural elements to be repaired and can be used to optimise repair strategies. Some of the main results from the framework, including the results from practical application examples, will be discussed herein.

2.3.2 Probability Framework

Assessment Procedure:

Prior to discussing the procedure of probability based assessment, the various different types of assessment were summarised. Assessment of railway infrastructure may involve line assessment, bridge assessment or element assessment - see Figure 7. Line assessment involves a broad overview of a section of the railway network to determine critical components. This could be carried out, for example, with a simple comparison of the original design load and the current loading conditions. Bridge assessment typically involves a load and capacity assessment whereas element assessment may involve a more detailed assessment of a critical member.

For a certain type of assessment (i.e. line, bridge, element), three different classes of assessment procedure can be used; non-formal (visual) inspection, measurement based inspection (e.g. Structural Health Monitoring) and model based assessment. The framework focused mainly on model based assessment. Information was given on methods for refining the model based assessment if the initial assessment fails. This refinement can be achieved through improved data acquisition for load (e.g. Weigh-In-Motion systems) and resistance (e.g. Non-Destructive Testing) or with more detailed structural analysis methods (plastic, non-linear, etc.). Improved safety verification methods can also be used and these probabilistic based assessment procedures are discussed in detail in this work.

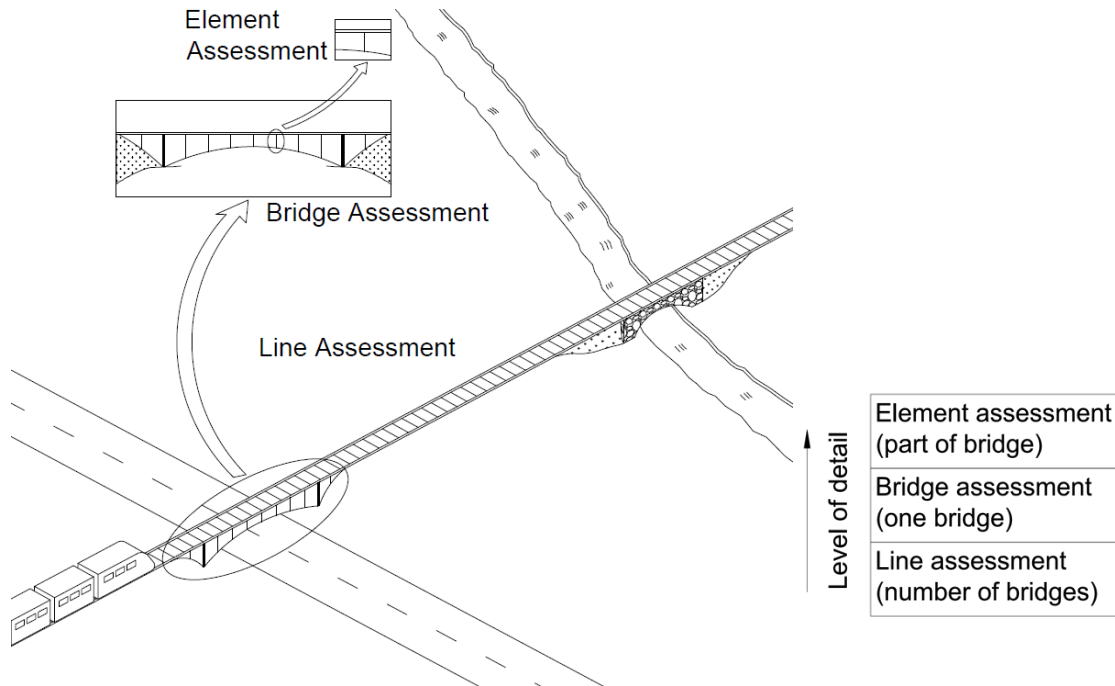


Figure 7: Types of assessment

Probabilistic Assessment:

The objective of any safety assessment is to determine if the requirements to functionality, service life and safety, are fulfilled or not. If these safety requirements cannot be verified with a simple deterministic approach, a probabilistic assessment approach can be used to determine if the probability of failure of a limit state is sufficiently low. In the context of probabilistic assessment, the limit state function is of the form:

$$g(x) = R - L \tag{1}$$

Where L and R represent the load and resistance variables, respectively, and the probability of failure (P_f) is given by:

$$P_f(x) = P(g(x) < 0) \tag{2}$$

In the context of the framework presented, the probability of failure may be assessed for any one of the following limit states:

- Ultimate Limit States
- Serviceability Limit States
- Fatigue Limit States
- Durability Limit States

Various codes of practice specify requirements of safety for each of the above limit states and they are published in the framework. These are usually specified in terms of the Reliability Index, β .

$$\beta = -\Phi^{-1}(P_f) \quad (3)$$

Where Φ is the standard normal Cumulative Density Function.

The design parameters that are involved in the definition of a limit state, i.e. loading, strength or geometry, have uncertainties associated with them. In order to compute the reliability index, these parameters are modelled stochastically. The framework gives distributions and values to be used for stochastic modelling of the load and resistance variables required for model-based assessment. Guidance is given on the modelling of, for example, permanent load (e.g. self-weight, ballast, track), live load (e.g. train weights, thermal actions), dynamic effects, material strength parameters, etc. Reference is also given to codes of practice for probabilistic based assessment.

The impact of climate change on the safety of railway infrastructures during the course of their design lives is also examined. Climate change may alter the intensity of environmental loads and influence rates of deterioration. Environmental changes have a significant effect on the corrosion of reinforced concrete which can cause cracking and spalling. The framework examines the effect of climate change on carbonation and chloride induced corrosion, which are influenced by climate change factors such as the level of CO_2 in the atmosphere and temperature. With respect to carbonation-induced corrosion, models are given for the diffusion coefficient of the concrete in order to model the time to initiation. Probabilistic models are also given for chloride induced corrosion, in terms of critical chloride concentration. Data from the Intergovernmental Panel on Climate Change (IPCC) was referenced to derive probabilistic temperature change models. A model was also developed for the effect of changing temperature on structural steel deterioration

The effect of climate change on slope stability was also considered. Climate change effects are resulting in rainfall with increased intensity and duration in many regions of the world. These events can lead to shallow translational landslides on natural and man-made slopes. A probabilistic based approach for modelling the slope stability of unsaturated soil slopes is detailed.

Simplified Approach

The comprehensive reliability based framework is suitable for sophisticated users and for the management of network infrastructure at a regional or national level. Engineers at a local level may prefer a simpler approach for everyday use such as a Load and Resistance Factor Design (LRFD). For this purpose, a simplified approach was developed which is benchmarked against the comprehensive methods described above. The approach involves the optimisation of the partial safety factors used in design while still achieving a target reliability index. This may be done, for example, for a specific set of structures or for structures of a similar age. A designer may then use recalibrated safety factors which optimise the assessment of a particular set of

structures, while still achieving adequate safety. The recalibration process is summarised in Figure 8.

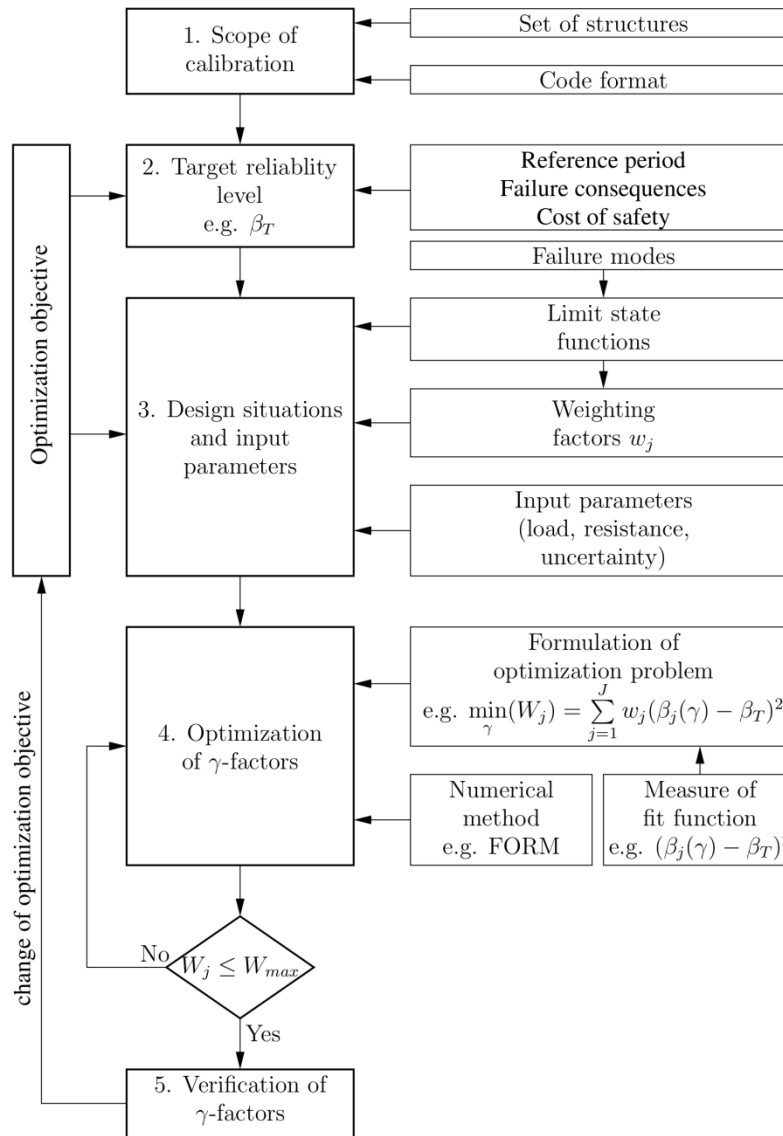


Figure 8: Flow chart for safety factor recalibration

2.3.3 Probabilistic Assessment Examples

Nieporęt Bridge, Poland

The detailed framework discussed above was applied to a steel truss railway bridge in Poland. A detailed Finite element model was created using commercially available software (Figure 9) and a deterministic assessment was carried out. The cross beams of the structure were shown to have insufficient capacity under railway load model LM71 of EN 1991-2:2003. Therefore, a full probabilistic assessment was carried out. The variables which were stochastically modelled included dead load, superimposed dead load, live load (vertical train loading), dynamic

amplification and yield strength. Model uncertainty was accounted for in each variable, with the exception of dynamic amplification. The load model was derived using bridge-specific information. The random variables were programmed in Matlab, along with a FORM analysis to compute the reliability index. The probabilistic assessment showed that the reliability index of the cross beams was sufficiently high to provide adequate safety at the ultimate limit state. A sensitivity analysis was also carried out. The results of the probabilistic analysis were later verified by programming another model in a secondary Finite Element programme, Opensees.

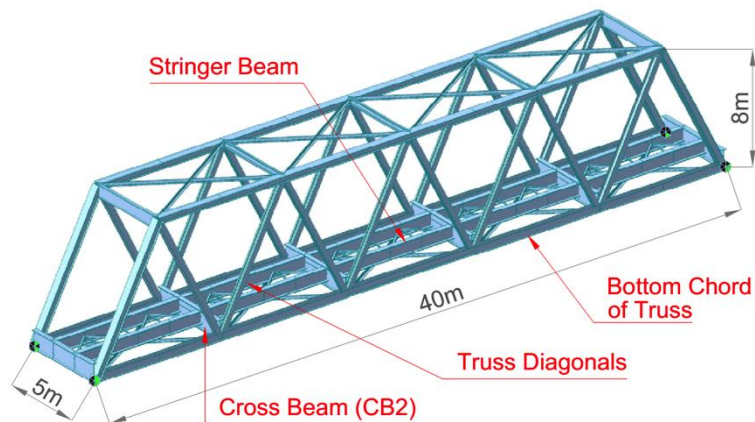


Figure 9: Finite Element model of the Nieporęt bridge.

Slope Stability Assessment, Ireland

A probabilistic slope stability analysis was also carried out on an Irish railway embankment. The stochastically modelled parameters included friction angle, soil suction, slope angle, unit weight of soil and rate of increase in shear strength due to matric suction. It should be noted that soil suction is not a random variable. Rather, the suction is a response to the level of rainfall. This was measured at the site in question over a five month period using tensiometers and the data was used to derive a stochastic model for suction. The reliability index was calculated for variations in the wetting front depth. It was shown that at a depth of 1m, a reliability index of 2.7 was achieved which is substantially higher than the minimum value of 2.2 required by most infrastructure owners.

Simplified Probabilistic Bridge Assessment, Austria

The simplified approach was illustrated with an example of a single span steel railway bridge in Austria. A probabilistic analysis of the bridge was carried out. Limit state functions were computed for various limit states in terms of the partial safety factors for dead load (γ_G) and live load (γ_Q). Various solvers were then used to minimise the error between the reliability index achieved and various target reliability indices. The safety factors required to meet variations in target reliability were then calculated. This approach can be used to develop charts which can be used to optimise safety factors for a range of bridges.

2.4 New rehabilitation technologies to extend service life of existing railway infrastructure

2.4.1 Assessment of typical problems on existing railway tracks

The main objective of this task was to provide a survey on typical problems on existing railway tracks. This was performed based on the literature study and questionnaire survey. In cooperation with railway agencies from Croatia and Slovenia pilot sections have been selected, which are representing typical problems (Figure 10 & 11) on existing ageing railway infrastructure. Those pilot sections were used later in the project for the implementation of new design solutions.

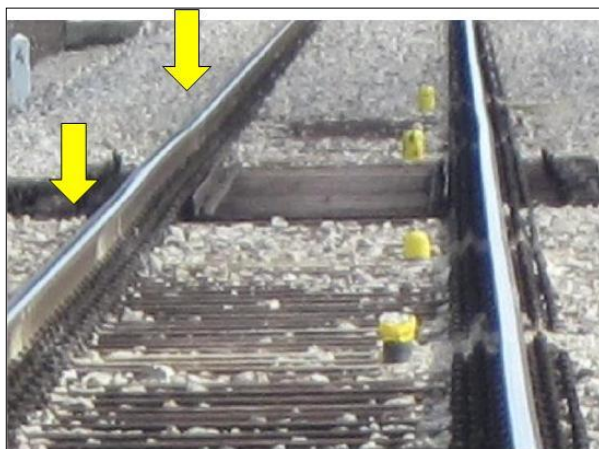


Figure 10 Deformed geometry of superstructure of the Buna Bridge (before and after)

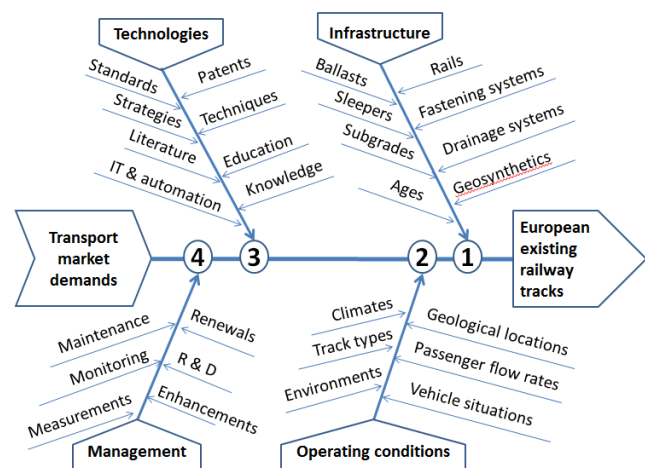


Figure 11: Key factors contributing to European existing railway tracks (from report D3.1)

In order to identify challenges and problems of existing railway infrastructure encountered by railway operators and to explore the potential to facilitate development of new rehabilitation technologies, an extensive survey was performed, which has utilized a questionnaire survey among European railway managers and a literature survey. The results of the survey are published in the report Deliverable 3.1 European Existing Railway Tracks: A Survey Report on typical problems and assessment framework for existing railways.

Rehabilitation methods for open track and transition zones

Strengthening of the embankments and substructure of the open tracks, and transition zones, are found as very problematic parts on the track and disproportional compared to other sections of the railway track. In WP 3 five test sites were developed focusing on open tracks and transition zones. One of them was Buna Bridge in Croatia where bridge and transition zone

remediation have been assessed and four open track sections in Slovenia where sub-grade problems are encountered.

Design of the transition zones

This task was focused on how to achieve smooth transition between different types of track structure where abrupt change in the rigidity of track structure and track settlement occurs between individual transverse profiles, as a result of the change in the structural elements or the foundation, with particular reference to the expected loads and vibrations.

Buna Bridge, in Croatia was selected as a pilot project. Bridge was originally designed in 1893, repaired in 1953, and in 2010 was selected for the full replacement, see Figure 12.



Figure 12: Bunja Bridge in 2012, before rehabilitation

A major geotechnical and geophysical investigation of the Bunja Bridge site was undertaken before the rehabilitation design see Figure 13.

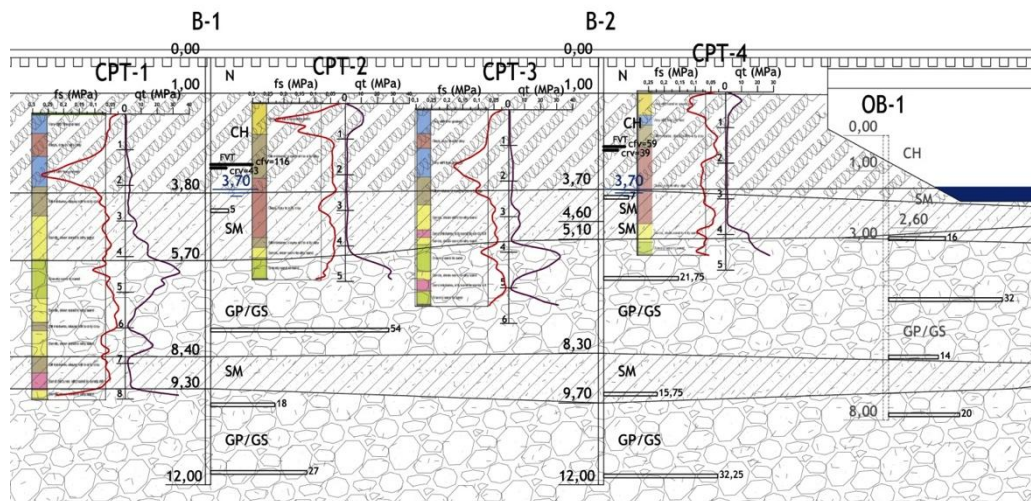


Figure 13 Ground characteristics

New rehabilitation methods are applied on design of transition zones implementing anchoring, geotextiles and geogrids. Design project of transition zones has been developed in close cooperation of IGH, ZAG and TUM experts, with the continuous support of Croatian Railways. 2-D and 3-D model has been developed for both transition zone solutions and was calibrated with the monitoring results after the project has been executed and tested.

Design of transition zones was performed differently for two sides of the bridge (see Figure 14), followed also by two different technological solutions. In this way the comparison of two rehabilitation methods was possible, as well the comparison with no-transition zone strategy. The results of research on open tracks and transition zones are published in Deliverable 3.2.

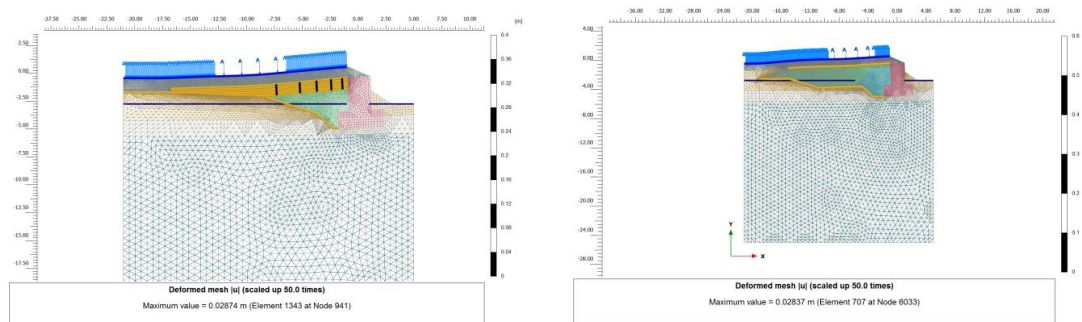


Figure 13: Modelling results of two different solutions for transition zones at the Buna Bridge

Rehabilitation of the open track

The focus of this task was on the existing aging railway tracks which are experiencing problems with a substructure due to the increase of traffic and due to the soft soils problems. Therefore the four pilot sections have been selected in Slovenia which is very representative of that kind of problem.

Pilot sections were selected on the most loaded railway lines in Slovenia, Ljubljana – Maribor and Ljubljana – Zagreb. Both lines are loaded with heavy traffic which enables a very short time for rehabilitation. In the pilot section on Ljubljana – Zagreb line approximately 50 cm of ballast was placed directly on the ground with embedded concrete sleepers, see Figure 15. The main problem was the weak subgrade material, which has caused water and mud being pumped into the ballast. Mud clogs in the ballast layer caused loss of strength and track misalignment. The section needed urgent rehabilitation. Within SMARTRAIL two rehabilitation sections have been installed in May 2012. Rehabilitation project with geogrids and geotextiles, including reflecting strips for monitoring deformations was successfully implemented in 2012. Monitoring of the settlements is performed regularly in close cooperation with Slovenian railways.

Rehabilitation of an existing railway embankment of the railway line Ljubljana-Maribor, section Poljčane-Dolga Gora, has been described in details by Lenart and Klompaker (2010). Geotechnical investigations indicated very bad ground conditions (low plasticity clay) and a high ground water level. Due to very low subgrade modulus of $E < 10$ MPa a rehabilitation by geogrid reinforcement under sub-ballast layer, 1 m below the sleeper, has been performed in 2008. The whole embankment was reconstructed at that occasion as seen in Figure 16. There was no

possibility to establish an unreinforced test section. This project was used for the monitoring analysis.

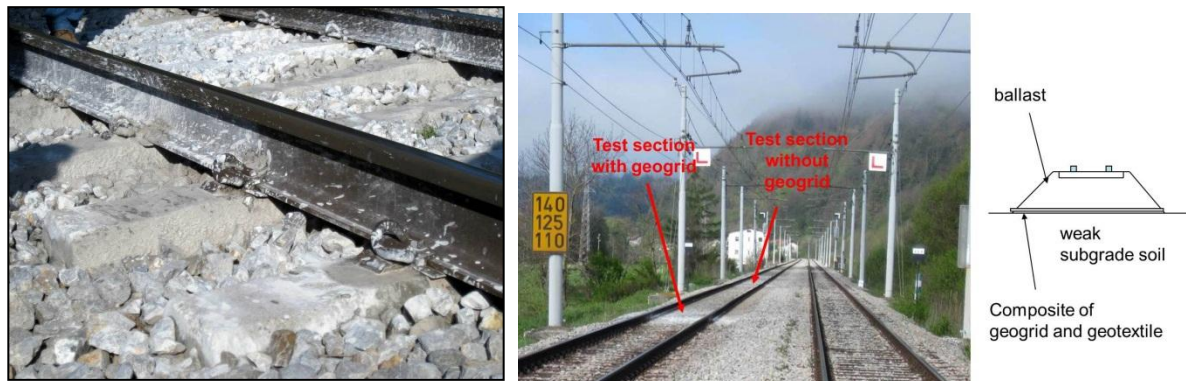


Figure 14 Test section in Slovenia on the open track



Figure 15; Reconstruction of railway embankment in Dolga Gora site: a) installation of geogrid in combination with a separation and filtration geotextile, b) installation of horizontal extensometer

Results from long term monitoring at two rehabilitated railway track sites in Slovenia are presented in the Deliverable 3.2. Rehabilitation of the railway track with installation of geogrid reinforcement at the bottom of the ballast layer (30 cm below the sleeper) and at the bottom of sub-ballast layer (1.0 m below the sleeper) has been performed. Results from both sites show a similar range of developed horizontal strain in case of deep and shallow location of the installed geogrid, while the strain of the latter is very much affected also by the exact location regarding the rails and sleepers. There is a noticeable impact of tamping upon the lateral deformation of the ballast or sub-ballast layer, while tamping affects only longitudinal deformation of the shallow geogrid (at the bottom of ballast layer). As expected, horizontal deformation of the unreinforced section is noticeable larger than horizontal deformation in the reinforced section. Due to interaction of the geogrid with the ballast and sub-ballast aggregate, lateral deformation is efficiently reduced.

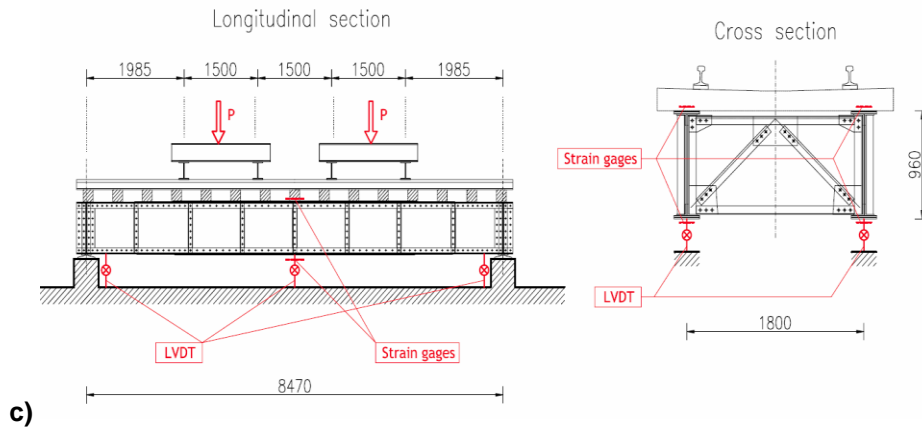


Figure 16: a) Load distribution - testing frame; b) Load testing; c) Test set-up.

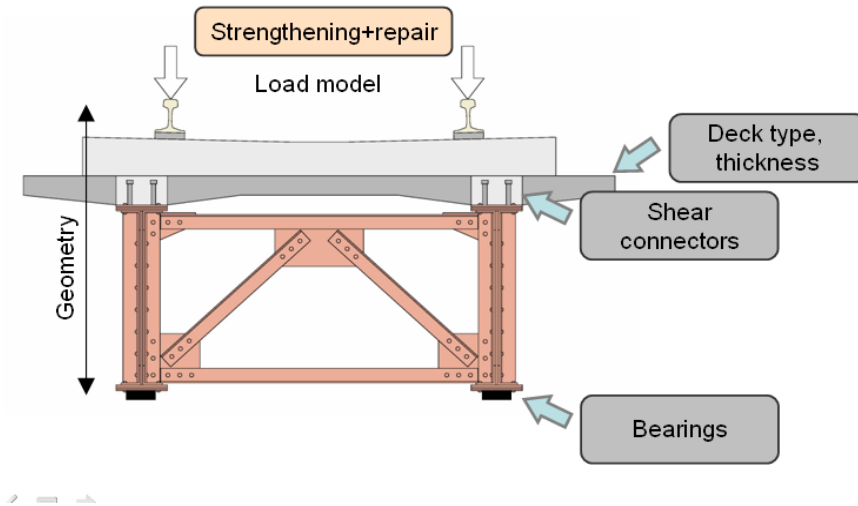


Figure 17: Possible options for bridge rehabilitation

Design of UHPFRC was developed by ZAG, results of mechanical properties testing can be seen in Figure 19.

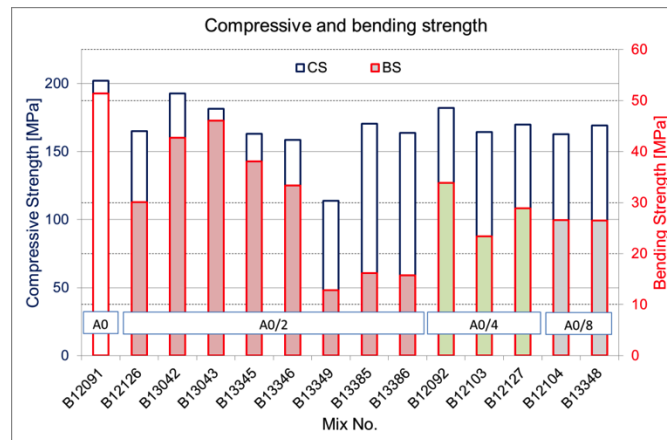


Figure 18: Compressive and bending strength

2.4.3 Validation of the model

Different field measurements and modelling were carried out for the evaluation of the constructed transition zones for Buna Bridge. Vehicle – track superstructure – track substructure interaction is modelled using Multi-Body- Simulations (MBS) in combination with the Finite Element Method (FEM) approach. Verification of this tool has been achieved by measurements recorded at the demonstration/pilot sections of the track based on the behaviour of the super and substructure in the response loads imposed by trains, see Figure 19 & Figure 20. After the execution of the rehabilitation work of the Buna Bridge measurements of vehicle / track behaviour and track substructure was performed to demonstrate improved response and to validate the material and structural models.



Figure 19: Benkelman beam for the measurement of track elastic deflection

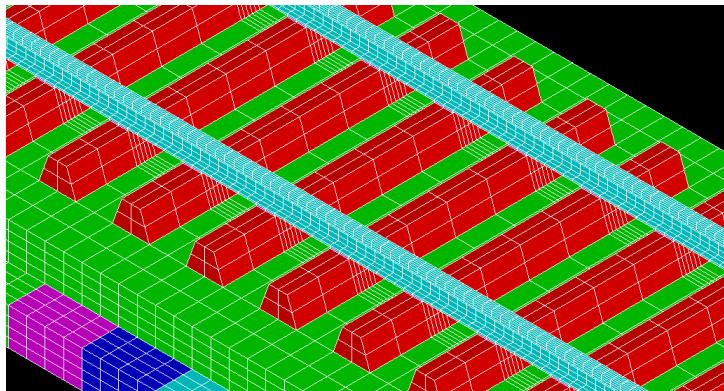


Figure 20: The ANSYS model with 95 rail seats

The general track geometry and elasticity were measured for both transitions. Operational trains with normal speed were also recorded for understanding the track dynamics. Various numerical simulation models including FEM and MBS were constructed for a systematic co-simulation for both vehicle and track, see Figure 18. A real-time illustration of the dynamic vehicle-track interaction was realized for the best view of the counterproductive effect from track side parameters to the vehicle, as well as the other way back. Results of the measurement and simulations were documented (Deliverable 3.4) and suggestions on inclusion of modern superstructure materials like sub-ballast-mat were also included. Comparisons with different scenario studies were made in the simulation environment providing guidelines for the future perspectives.

2.5 LCA/LCC model and SMARTRAIL LCA/LCC tool

The overall objective of the SMARTRAIL project was to create a model and the LCA/LCC tool by which the rail industry will be able to assess railway infrastructure rehabilitation techniques economically and environmentally, leading them to make informed investment decisions optimized on the basis of cost and potential environmental impact.

In the SMARTRAIL project research is focused on the construction part of the railway and maintenance of it with new technologies developed in the SMARTRAIL project.

Three case studies were selected for environmental and cost assessment. These were:

- Open track sub-ballast rehabilitation in Slovenia.
- Bridge transition zone rehabilitation with two novel designs in Croatia.
- Bridge rehabilitation in Croatia.

The goal of the first analysis was to compare conventional construction and remediation work with and without the use of geosynthetics for the case of open track and transition zone, considering the requirement for routine maintenance before and after remediation. The boundary for LCA tool is presented in Figure 21.

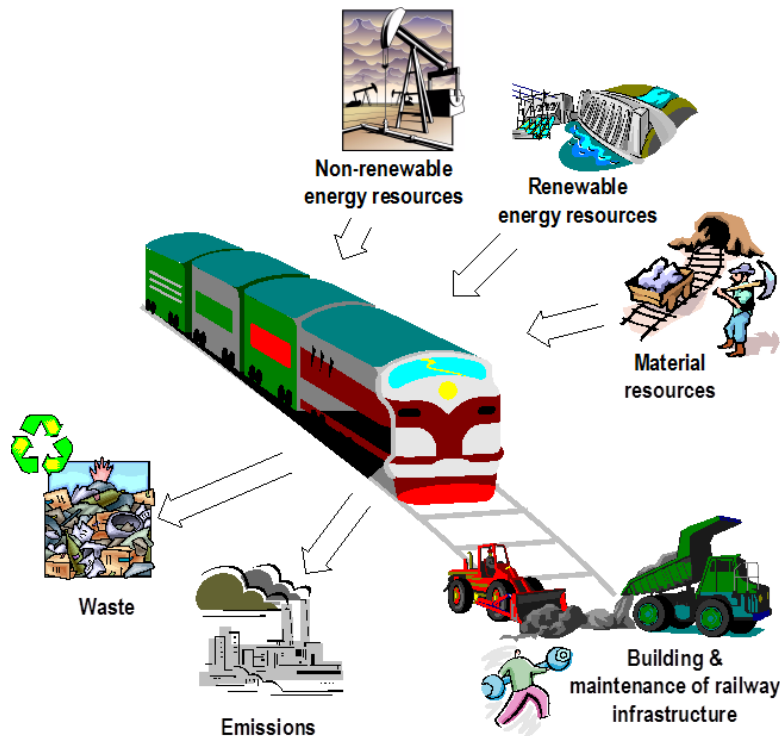


Figure 21: The boundary for LCA tool

For the demonstration site of Buna Bridge in Croatia, a traditional precast bridge was used to replace the pre-existing expired steel bridge. In doing so, the opportunity arise to remediate the old steel bridge ex-situ and replace the bridge deck with an UHPFRC plate; giving scope for a potential future alternative for the precast solution to be investigated. The two transition zones on the bridge approaches were remediated with novel engineering solutions at the time of bridge replacement.

2.5.1 Results for the demonstration sites

The results of the LCA for **open track** (demonstration site in Slovenia) show that the primary energy and gas emissions are lower for the railway constructed with geocomposite (Figure 22). These lower impacts mainly result from the enhanced lifetime of the other components which results from the use of the geocomposite and the added stability that it brings to the ballast.

Analyses by LCC showed support economically for the decision to use geocomposite under the ballast. Several variants were calculated with different maintenance regime and cost variants to test this hypothesis and all suggested the same conclusion (Figure 23).

Because it is at this stage difficult to predict how much the lifetime of the ballast increased due to the use of geocomposite, we calculated several scenarios, but all of them indicate that the construction with the geocomposite is cheaper and more environmentally sound.

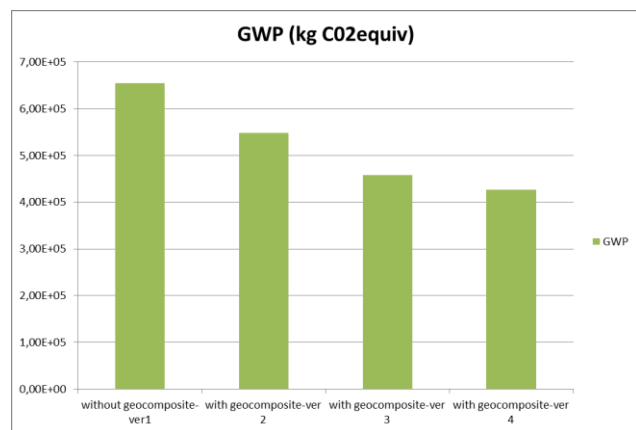


Figure 22: Emission contributing to GWP

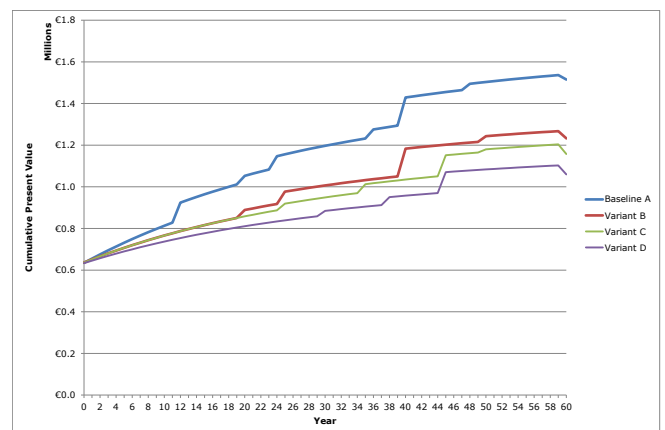


Figure 23: Open track scenarios A-D graphical representation

The results of LCA analysis for **transition zone** (demonstration site in Croatia) show that the primary energy and gas emissions are lower for the transition zone with anchors and geocomposite. Lower values are mainly due lower quantity of material for embankment.

For the LCC analysis the interpretation of the results are not so straightforward. When comparing the two types of transition zone remediation, little can be deduced about the merits of one choice of remediation over another. This is primarily due to the absence of long term performance data for either type of treatment. To achieve beyond break-even and obtain a positive economic indicator for a scenario, transition zone remediation would have to offer quite

considerable benefits in terms of reduced routine maintenance post-remediation, since routine maintenance is relatively cheap in Croatia. This is required to offset the delay costs of the remedial treatment. Delay costs are quite crucial to determining whether remediation is economically beneficial. It is only when remedial delay costs are negligible that transition zone remediation is truly economically viable in life cycle cost terms.

For the **Buna Bridge** in Croatia the boundary conditions are defined in such a way as to find the difference between the construction of the new concrete bridge and strengthening the old bridge with the UHPFRC plate. The results of LCA analysis show that the primary energy and gas emissions are lower for the solution with UHPFRC plate. Lower values are mainly due lower quantity of material for ballast and concrete.

From different scenario of LCC calculations, it can be concluded that the UHPFRC plate solution is very favourable economically. Only if it proved to be significantly less durable in the long term would it prove to be less economically viable than the conventional pre-cast solution.

2.5.2 SMARTRAIL LCA/LCC tool

The LCA calculation for open track, transition zone, and bridge is performed. For the calculation the general information about the geometry of the railway construction, used material, transport , operating machines and life-time of the material have to be included (Figures 24 to 29). The results of the calculation could be presented in the graphic view and in tables.

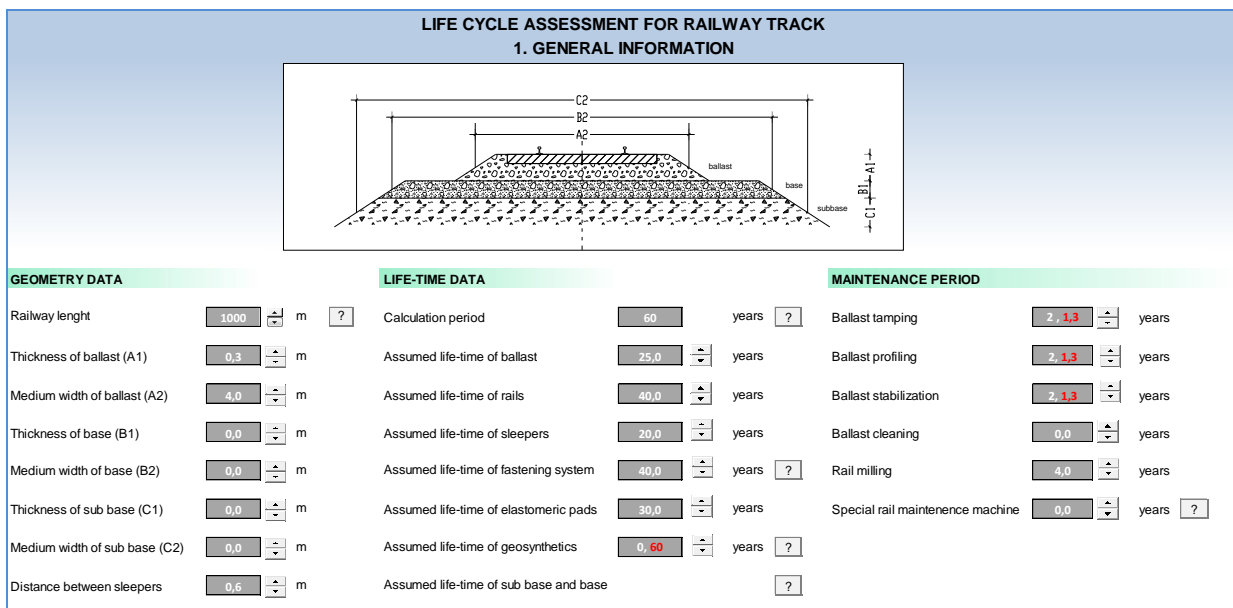


Figure 24: LCA tool for open track

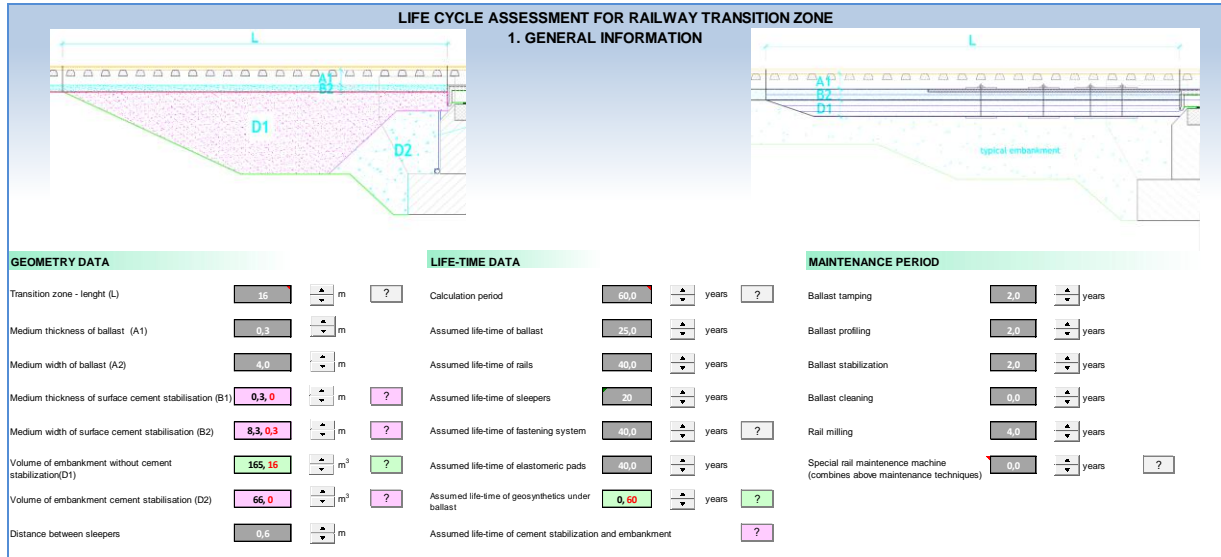


Figure 25: LCA tool for transition zone

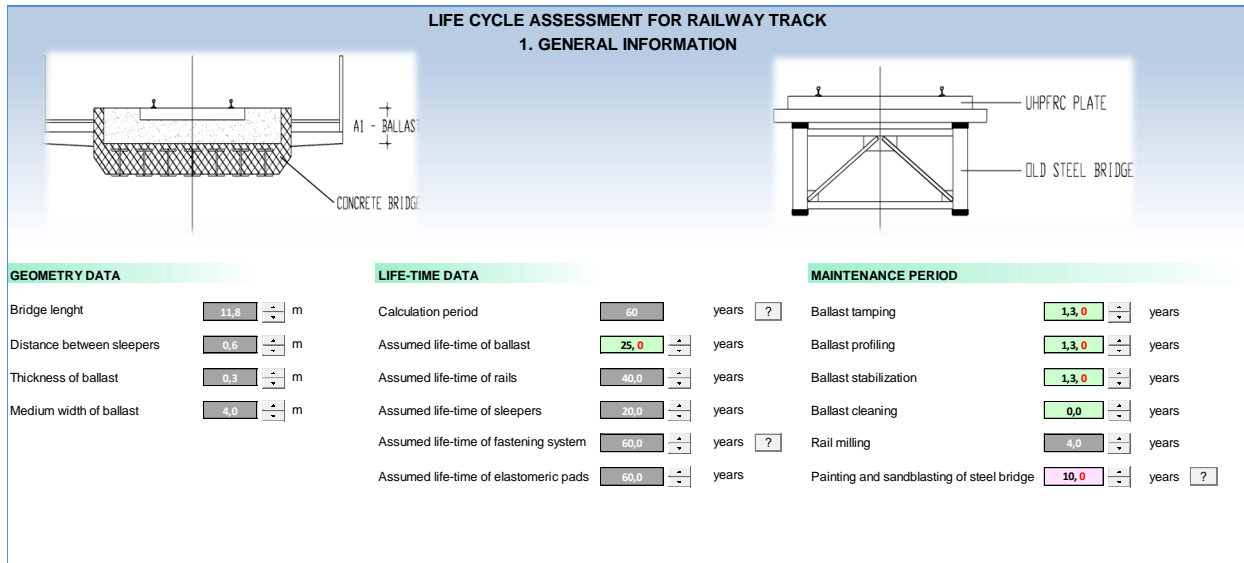


Figure 26: LCA tool for bridge

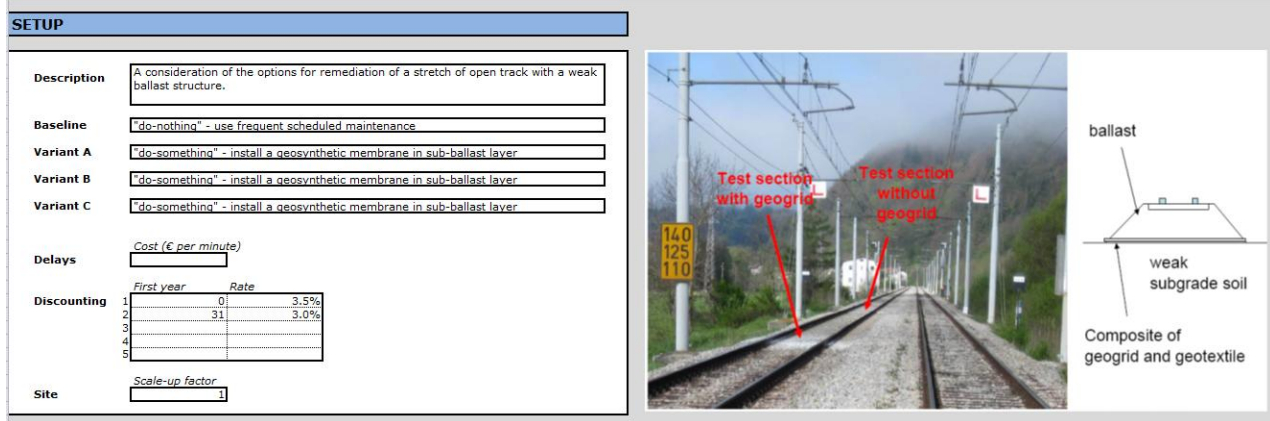


Figure 27: LCC tool for open track

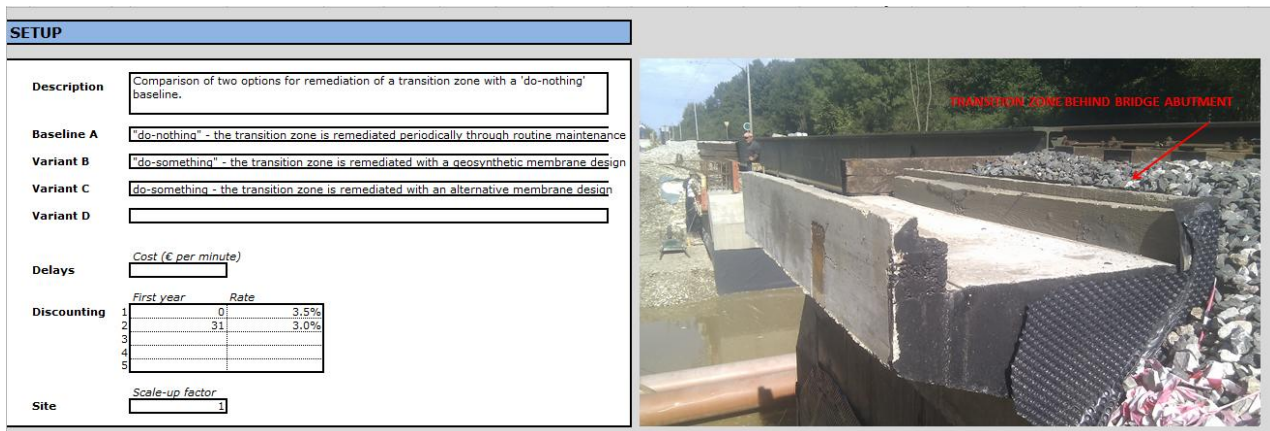


Figure 28: LCC tool for transition zone

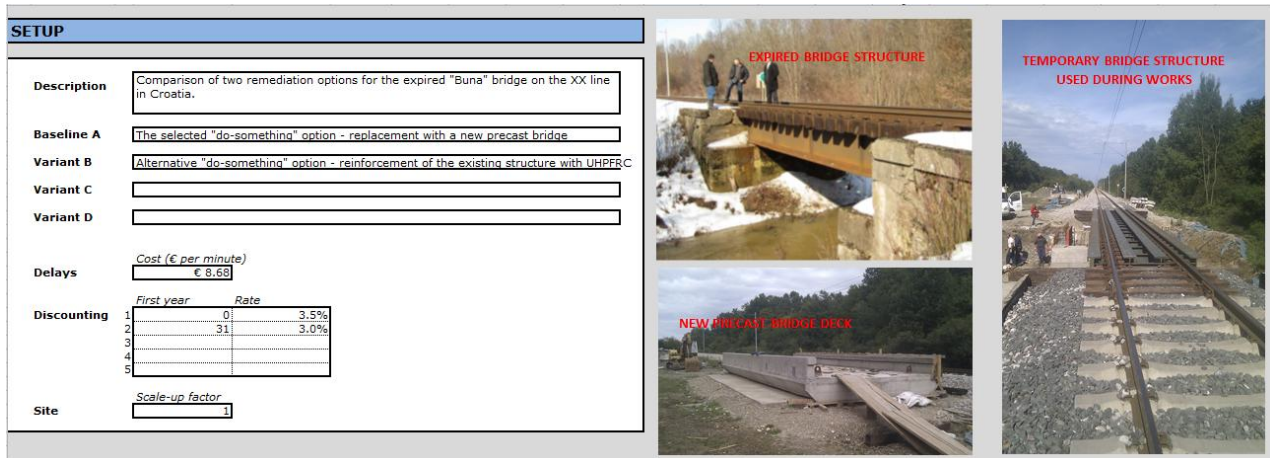


Figure 29: LCC tool for bridge

3 Potential impact and main dissemination activities and exploitation results

3.1 Potential Impact

The SMARTRAIL project set-out to achieve impact in a number of areas, these included;

3.1.1 Adaptation to evolving needs and opportunities

Many of the elements of rail infrastructure required to provide links from the EU to the East were constructed more than 150 years ago. In order to ensure the continued safety and reliability of this infrastructure and reduce the use of resources required in unnecessary maintenance and replacement, a number of key achievements were required from the SMARTRAIL project. These included;

- (i) Demonstration of advanced monitoring and assessment techniques for determining the current condition of infrastructure assets. These techniques included embedded sensors which monitor the condition of slopes during rainfall events, train speed GPR as a method of identifying hot-spots, accelerometers used to monitor the occurrence of bridge scour, the first use of bridge weigh in motion for the rail sector and corrosion monitoring of concrete and steel bridges.
- (ii) The development of theoretical models to provide real-time information on slope stability and bridge scour vulnerability.
- (iii) A probability based framework for optimised whole life management of infrastructural elements/networks. The models developed within this framework will greatly improve the ability of track owners to predict the future condition of the infrastructure and hence to greatly improve the efficiency of maintenance programmes. The framework encompasses not just rail structures (bridges) but also all aspects of rail infrastructure such as track settlement (derailment risk) and slope stability (landslide risk). The models developed can be applied to optimise the decision making process by helping to define a repair/rehabilitation strategy for any aspect of the railway infrastructure. In addition, a simplified approach to reliability-based assessment was also developed, incorporating probabilistic methods into the optimisation of Load and Resistance Factor Design (LRFD). This approach will enable engineers who may only have a basic knowledge of reliability-based assessment to apply the framework.
- (iv) Full-scale demonstration of novel techniques for remediating ageing infrastructure were performed on live railways. Contributions to advancing the state of the art were concentrated in the areas of open-track, transition zones, and bridges. The techniques are low-cost remediation measures that are region-specific, provide minimal disruption and are environmentally friendly. Novel methods included the on design of transition zones implementing anchoring, geotextiles and geogrids. In addition sections of open track with problematic substructure were remediated.

- (v) The use of advanced multi-body simulations and finite element analyses for the design of track systems.
- (vi) A Life Cycle Analysis / Whole Life Cycle (LCA/LCC) tool was developed to assist engineers, researchers and managers to find the optimal solution for renovation and the maintenance of the railway track.

3.1.2 SME Participation

The project consortium contains two SME's (RODIS and Adaptronica) as full partners. The core integration of these SME's was demonstrated through RODIS leading WP2. These organisations are at the cutting-edge of bridge weigh in motion and the application of reliability based theory to major bridges. By demonstrating the first BWIM system for rail bridges through the SMARTRAIL project, these partners made a significant advance in the state of the art in properly quantifying the current condition and future performance of railway bridges across Europe,

3.2 Dissemination

A key feature of achieving impact through dissemination of the project findings was User Involvement from the very beginning of the project. EURNEX as the project partner responsible for dissemination followed the new culture of cooperation involving the major stakeholders, including infrastructure managers, rail operators, engineers, researchers, regulatory bodies and to some extent policy makers from the very beginning of the SMARTRAIL project.

A user platform was formed which considered the project from definition to exploitation with a focus on reflecting the objectives and achievements towards the customer point of view. This included setting needs and requirements, matching and validating results with infrastructure managers to ensure that the research was useful and relevant, that it could be implemented and will be of use in reducing costs, improving performance and safety.

Widespread engagement with industry was undertaken, which included; questionnaires, face to face interviews, workshops and bilateral meeting which directly validated practical solutions at pilot sites.

At an early stage of the project user requirement were assessed to allow the work to be focussed towards solving problems. These were identified as:

- Safety and Performance: this covered a reduction in risks associated with catastrophic failure i.e. bridge collapse, slope failure, removing temporary speed restrictions due to the condition of the infrastructure leading to improved performance and higher customer satisfaction.
- Capacity Improvement, including improved maintenance techniques leading to less downtime on the network with the consequent improvement of availability and capacity. Fewer temporary speed restrictions leading to improved end to end section running times generating more capacity for the same amount of infrastructure.

- Environmental benefit: by moving from “find and fix” to “predict and prevent” and using different techniques the total amount of materials used will be reduced with a consequent improvement in environmental pollution. As an example the elimination of catastrophic bridge collapse and the consequent severe disruption, high cost and potential loss of life arising from such an event will also bring environmental benefits.
- Cost reduction: Predict and Prevent type lead to improved levels of productivity, better quality of work and Lower Life Cycle Costs.

The results were also prioritised and risk assessed using a simple 3x3 matrix of (High, Medium, Low probability) x (High, Medium, Low cost). In addition, by compiling the spreadsheet it was also possible to easily identify any areas of research in the work packages, which were important and not included, and similarly those, which were not important and were included.

The Work Package 5 activities included a series of face to face interviews with Infrastructure Managers, notably PLK (Poland), HZ (Croatia), SZDC (Czech Republic), REFER (Portugal), LITH (Lithuania), MAV (Hungary), and questionnaires from ÖBB (Austria), CIE (Ireland) and NRIC (Bulgaria). A series of workshops were also held, notably aiming the countries of South-Eastern Europe as well as events gathering actors of the international railway world, such as TRA (2012 in Athens, 2014 in Paris) and EURNEX Advisory Board meetings. A comprehensive list of these activities is given in the Table of dissemination activities in section 4.2 below.

Interviews and bilateral meetings identified lack of information available on both sides (user & researcher) in the beginning and with further exchanges on the contents and potential outcome the priorities of IM needs could be ranked.

In order to keep IMs updated on progress with the research, various workshops and presentations were held where work package leaders presented the progress of their work. These workshops have also provided an opportunity for IMs to discuss the direction of the research to ensure that it is meeting their needs.

All together with the detailed face to face and Workshop interactions and the Conference presentations (total ca. 40) an audience of over 2500 infrastructure related experts, regulatory bodies and users were informed on the SMARTRAIL project. These interactions with IM's and users allowed a series of priority areas to be identified. These included the areas of:

- Embankment stability.
- Bridge life extension.
- Bridge scour.
- Structural Health Monitoring.
- New Rehabilitation Technologies.
- Track maintenance, e.g. Anchor Rail fastening (ARF).
- LCA/LCC Database.

User Platform continuous feedback: Interim dissemination results and matching of Work Package achievements to the user needs and expectations were assured by a continuous dialogue with the user platform and presentations to various user groups/conferences including

the UIC Structures Group September 2013 in Zagreb, Club Feroviar Wider Black Sea Area conferences held in Bucharest in October 2013 and Sibiu in February 2014, the International Symposium on Bridges held in Brno in April 2014, SMARTRAIL Workshop held in Ljubljana in March 2013, EURNEX Advisory Board meeting held in Berlin in June 2014.

SMARTRAIL flyers and newsletter were produced and distributed widely as well as being available via the website to raise awareness of the project to the target audiences.

Furthermore, the opportunity was taken at the European Railway Awards in January 2014, various Rail Forum Europe events in 2014 and the International Transport Forum held in Leipzig in May 2014 to have informal discussions with key players.

Finally additional deliverables in the form of guidelines for the implementation of practical solutions to meet the user needs were initiated, discussed and made available on the project's web site following the final conference.

Through some of the key dissemination activities listed below, and with the aid of the SMARTRAIL website, the knowledge developed as part of the project is made readily available to infrastructure owners.

CETRA 2012 – Dubrovnik, Croatia. 7th- 9th May 2012

A special session/workshop of the SMARTRAIL project was held during the 2nd International conference on Road and Rail Infrastructure. The session was attended by infrastructure owners and asset managers. A detailed description of the work being undertaken in Work Package 2 was presented by ROD-IS.

<http://master.grad.hr/cetra/ocs/index.php/cetra/cetra2012>

TRA 2012, Athens

TRA is the leading conference for European transport researchers. At the 2012 Conference in Athens SMARTRAIL held a joint special session with the MAINLINE project. The talks included an overview of the SMARTRAIL project and a lecture on bridge modelling. The session included an active Q&A session.

UIC Workshop/ Joint Meeting between SMARTRAIL and MAINLINE, Paris, May 2013

A two-day joint workshop was held as the MAINLINE general assembly in Paris. Each Work Package leader from SMARTRAIL gave a review of objectives and projects for their work.

FERHL/FIRM, Brussels, 4th to the 6th of June 2013

A special combined presentation by SMARTRAIL and MAINLINE was given on the management of ageing rail infrastructure

CETRA 2014, Split, Croatia

A number of SMARTRAIL talks were given covering work from WP1, WP2, WP3 and WP4. In addition the coordinator delivered a keynote lecture on Geotechnical Challenges Facing the TEN-T network based on work from SMARTRAIL WP1.

Opensees @ Bristol 2014 – Bristol, UK. 25th- 26th June 2014

This workshop was jointly organised by University of Bristol, University of Washington and University of California-Berkeley. The aim of the workshop was to share the latest advances in computational techniques in modelling nonlinear behaviour of structural systems. The event, entitled OpenSees@Bristol, was held at the University of Bristol and brought together researchers from the United States, the United Kingdom, and the European Union. A SMARTRAIL poster was presented by ROD-IS focusing on the work undertaken in Work Package 2. The Opensees Finite Element programme was used to carry out a reliability analysis of the Nieporęż bridge in Work Package 2.

<http://www.bristol.ac.uk/engineering/news/2014/25.html>

CERI 2014 – Belfast, Northern Ireland. 28th-29th August 2014

The Civil Engineering Research in Ireland (CERI) conference is the successor to the Bridge and Concrete Research in Ireland (BCRI) conference series. The conference addresses similar topics to the previous BCRI conference. A number of SMARTRAIL papers were presented and the work performed by UCD on bridge scour monitoring was awarded a prize for best paper on geotechnical engineering.

<http://www.cerai.net/>

IALCCE 2014 – Tokyo, Japan. 16th-19th November 2014

The Fourth Symposium on Life Cycle Engineering will be hosted by the International Association for Life Cycle Engineering and Waseda University. The conference will cover all aspects of life-cycle assessment, design, maintenance, rehabilitation and monitoring of civil engineering systems. A paper entitled “*Partial safety factors for an existing single span railway bridge – Case study using an engineering based recalibration process*” was prepared by AIT and will be presented at the conference. The paper gives a detailed description of the procedure involved in applying the simplified approach discussed above.

<http://www.ialcce2014.org/>

SMARTRAIL Final Conference, 25-26th August in Ljubljana, Slovenia.

The SMARTRAIL final conference was held in held on 25-26th August in Ljubljana, Slovenia. Hosted by project partner ZAG, the event was attended by over 60 representatives from the scientific, research, railway and political arena, including infrastructure managers from Ministries of Transport and Infrastructure, SMEs, research institutes, Universities and the Europe-wide organizations United Nations Economic Commission for Europe (UNECE), the European Commission and the Danube Strategy. The agenda featured presentations of the cutting edge science developed during the project within each Work Package, as well as three engaging and salient keynote speeches interspersed throughout the day focused on:

- i) The importance of reducing maintenance costs for the long term viability of railway infrastructure and maximising the social and environmental benefits accruing from investment in railway infrastructure;
- ii) The remediation of ageing rail infrastructure with the results of demonstration projects on the railway networks of Croatia, Slovenia, Poland and Ireland
- iii) Linking advanced meteorological approaches to provide early warning systems for weather-proofing the railway system.

It concluded with a lively round table debate on the future of the project. The second day included a visit to a building site for railway rehabilitation on the Slovenian railway network and a very interesting railway museum.

3.3 Exploitation

The work on vibration based monitoring of bridge scour has been demonstrated at pilot-scale and has been published in three international journal papers to date. A number of major infrastructure managers have shown significant interest in the technique. Work is currently progressing to identify a field test site at which to demonstrate the methodology.

Risk assessment methodologies are widely used for the management of assets, including slopes. The work on slope stability has allowed key variables controlling the safety of slopes to be identified, quantified and described in statistically robust manners. This has allowed Irish Rail, a SMARTRAIL project partner to develop a new decision support tool for the management of over 3,000 slopes assets.

As part of the probabilistic assessment of the Nieporęt bridge, a software tool was created. This tool will be used in the future by RODIS to perform similar assessments and analyses both for research and possibly at a commercial level. The tool can be used to perform a permissible stress-based reliability assessment of any bridge with a 1-dimensional influence line, but was developed for the assessment of steel railway bridges.

In Work Package 3, innovative methods of rehabilitating transition zones were implemented in practice at the Buna Bridge site in Croatia. In addition research on UHPFRC implementation is going to be extended together with railway agencies.

The SMARTRAIL LCA/LCC tool was developed to assist engineers, researchers and managers to find the most optimal solution for renovation and the maintenance of the railway track. The tool is freely available for use and can be downloaded from the SMARTRAIL website (<http://smartrail.fehrl.org/?m=40>). The general form of the tools is Excel workbooks which are presented in the Figure 31.

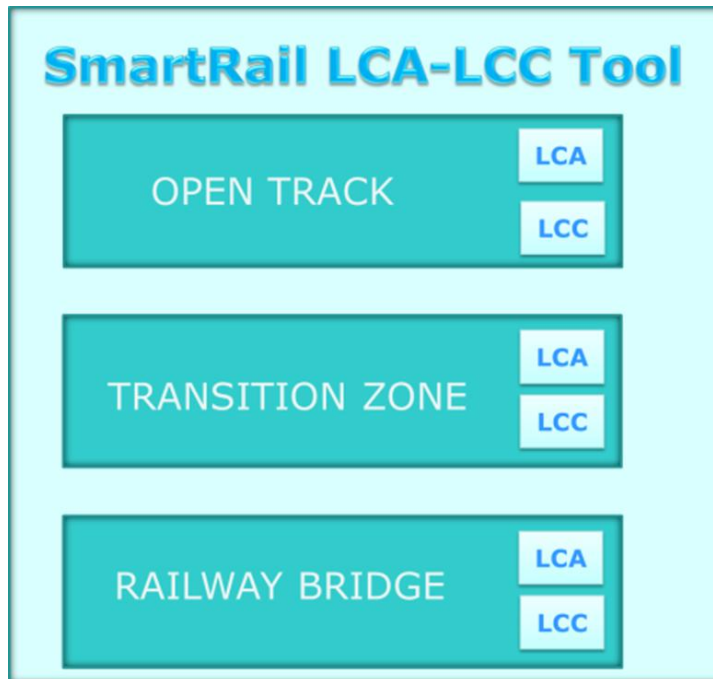


Figure 30: Form of the SMARTRAIL life cycle tool

With the LCA/LCC tool it is possible to compare conventional construction and remediation work with and without the use of geosynthetics for the case of open track sections and transition zones. The user can consider the requirement for routine maintenance before and after remediation. The purpose of the tool is to optimize the maintenance of the rail infrastructure with regard to the environmental requirements, and also in terms of costs.

For the case of replacing steel bridge it is possible to compare the solution with the concrete bridge and the new solution with the UHPFRC plate. For open track sections, transition zones and bridges it is possible to calculate environmental impact and cost for a range of construction types of various scales. The choice of materials, e.g. ballast, rails, sleepers, geosynthetics, can be specified. Transport costs for the materials and machine operating on trucks or rails can be included.

The SMARTRAIL LCA/LCC tool is designed in a way which could be usable designers and rail managers from different regions in Europe who uses different types of material for the rail renovation and maintenance.

In next subsequent years, evolution of the tool will be based on feedback received from users of the programme. The results of the development tools in the coming months, will be published in scientific journals, in which will be discussed in detail the theoretical model of the calculation.

Address of project public website and relevant contact details smartrail.fehrl.org

SMARTRAIL website

The project website can be found at URL <http://smartrail.fehrl.org>. It is presented in English. The website describes the project activities in detail. Its prime objective is the communication of the project concept, its outcomes and events realized in its context as well as provision of the contact details of project partners to the interested users to promote communication and possible collaborations with other companies and organisations outside the consortium.

The website is considered a very important dissemination tool, since it connects SMARTRAIL integrated project with the wider publics (experts, related projects and research programmes, relevant authorities, policy makers, industry as well as the general public) via the internet.

4 Use and dissemination of foreground

Section A (public)

Publications

LIST OF SCIENTIFIC PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
No.	Title / DOI	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Date of publication	Relevant pages	Is open access provided to this publication?	Type
1	A review of bridge scour monitoring techniques	Prendergast, L.J., Gavin, K.	Journal of Rock Mechanics and Geotechnical Engineering	6/2	Elsevier BV		01/04/2014	138-149	Yes	Peer reviewed
2	An investigation of the changes in the natural frequency of a pile affected by scour 10.1016/j.jsv.2013.08.020	L.J. Prendergast, D. Hester, K. Gavin, J.J. O'Sullivan	Journal of Sound and Vibration	Vol. 332/Issue 25	Academic Press Inc.	United States	01/12/2013	6685-6702	Yes	Peer reviewed
3	Predicting permanent deformation behaviour of unbound granular materials 10.1080/10298436.2014.943209	Mohammad Shahfiqur Rahman, Sigurdur Erlingsson	International Journal of Pavement Engineering	0	Taylor and Francis Ltd.	United Kingdom	16/09/2014	1-15		Peer reviewed
	Sustainable Maintenance and Analysis of Rail Transport Infrastructure (SMART rail)	O'Connor, A., O'Brien, E., Arrigan, J.	bridge and concrete research in Ireland conference, Dublin, Ireland, 2012		BCRI		01/09/2012		Yes	Conference
	Probabilistic -Based Modelling and Assessment of a Steel Truss Railway Bridge	Connolly, L., Ni Choine, M., O'Connor, A.	Civil Engineering Research Association of Ireland Conference, Belfast, Northern Ireland 2014		Civil Engineering Research Association of Ireland		01/09/2014		Yes	Conference
	Partial safety factors for an existing single span railway bridge - Case study using an engineering based recalibration process	Lachinger, S., Strauss, A.	International Association of Life Cycle Civil Engineering 2014		IALCCE2014		16/11/2014		Yes	Conference

Non-intrusive bridge scour analysis technique using laboratory test apparatus	Prendergast, L.J., Gavin, K., O'Sullivan, J.J.	Proceedings of the bridge and concrete research in Ireland conference, Dublin, Ireland, 2012	http://www.bc ri.ie/	06/09/2012	Yes	Conference
Monitoring of bridge scour using changes in natural frequency of vibration - A field investigation	Prendergast, L.J.	Proceedings of the International Young Geotechnical Engineer's Conference, Paris, France, 2013	ISSME2013	02/09/2013	Yes	Conference
Monitoring of scour critical bridges using changes in the natural frequency of vibration of foundation piles – a field investigation	Prendergast, L.J., Gavin, K.	Transport Research Arena 2014	TRA2014	14/04/2014	Yes	Conference
Bridge scour monitoring using accelerometers placed on bridge piers – a numerical investigation	Prendergast, L.J., Gavin, K.	CETRA 2012, Proceedings of the 3rd International Conference on Road and Rail Infrastructure, Split, Croatia, 2012	CETRA 2012	07/05/2012	Yes	Conference
Laboratory experiment to measure soil matrix suction and examine the effect of infiltration	C.Reale, K.Gavin, A.O.Connor	BCRI DIT September, 2012	http://www.bc ri.ie/	06/09/2012	Yes	Conference
Laboratory experiment to measure soil matrix suction and examine the effect of infiltration	C.Reale, K.Gavin, A.O.Connor	BCRI DIT September, 2012	BCRI 2012	06/09/2012	Yes	Conference
Stability charts for unsaturated soil slopes	C.Reale, J.F.Xue, K. Gavin	Transport Research Arena 2014	TRA2014	14/04/2014	Yes	Conference
Transition zones on the railway track - overview	M. Vajdi#, I. Stipanovi#, Oslakovi #, S. Kralj	CETRA 2012, Proceedings of the 2nd International Conference on Road and Rail Infrastructure, Dubrovnik, Croatia, 2012	CETRA 2012	07/05/2012	Yes	Conference
Smart Maintenance and Analysis of Railway Transport Infrastructure (SMART Rail)	K. Gavin, I. Stipanovic Oslakovic, M. Vajdic, G. Puz, V. Sporic	CETRA 2012, Proceedings of the 2nd International Conference on Road and Rail Infrastructure, Dubrovnik, Croatia, 2012	CETRA 2012	07/05/2012	Yes	Conference
Application of different methods for rehabilitation of existing transition zones on the old railway lines	M. Vajdi#, D. Liu, S. Lenart, I. Stipanovi#, Oslakovi #	Transport Research Arena 2014	TRA 2014	14/04/2014	Yes	Conference
Rehabilitation of steel railway bridges by implementation of UHPFRC deck	I. Dzajic, A. Sajna, I. Stipanovic Oslakovic	CETRA 2014, Proceedings of the 3rd International Conference on Road and Rail Infrastructure, Split, Croatia, 2014	CETRA 2014	28/04/2014	Yes	Conference

European existing railway tracks: overview of typical problems and challenges	I. Stipanovic Oslakovic, X. Tan, K. Gavin	CETRA 2014, Proceedings of the 3rd International Conference on Road and Rail Infrastructure, Split, Croatia, 2014	CETRA 2014	28/04/2014	Yes	Conference
Optimization of Geotechnical Investigation Works during the Reconstruction of the Transition Zones on the Old Railway Lines	M. Bišan, M. Vajdiš, I. Matković, L. Bolfan	CETRA 2014, Proceedings of the 3rd International Conference on Road and Rail Infrastructure, Split, Croatia, 2014	CETRA 2014	28/04/2014	Yes	Conference
Transition zones - connection between the structure and open track (in Croatian, Prijelazno područje - spoj objekta i trase)	M. Vajdiš, G. Puž, S. Kralj, N. Popovac	Dani prometnica 2012: Građenje prometne infrastrukture, Zagreb, Croatia, 2012	NA	01/03/2012	Yes	Conference
Implementation of transition zones before and after the bridge on the existing railway track: case study "Buna" bridge	M. Vajdiš, S. Lenart, I. Stipanović, D. Liu	submitted Special Issue TC202 ASCE Journal	TC202 ASCE	01/09/2014	Yes	Conference
An environmental analysis of rehabilitation options for an open track section of railway in Slovenia	Karmen Fifer Bizjak, Matthew Wayman, Katja Slanc, Friderik Knez, Adewole Adesiyun, Alan O'Connor, Irina Stepanoviš, Marko Vajdiš, Wolfgang H. Steinicke, Darko Kokot	Transport Research Arena 2014	TRA 2014	14/04/2014	Yes	Conference

LIST OF DISSEMINATION ACTIVITIES								
No.	Type of activities	Main Leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
1	Oral presentation to a scientific event	UNIVERSITY COLLEGE DUBLIN, NATIONAL UNIVERSITY OF IRELAND, DUBLIN	SMARTRAIL Special Session, Transport Research Arena, 2012	26/04/2012	Athens, Greece	Scientific community (higher education, Research) - Industry - Civil society - Policy makers	100	International
2	Media briefings	UNIVERSITY COLLEGE DUBLIN, NATIONAL UNIVERSITY OF IRELAND, DUBLIN	FEHRL Infrastructure Research Magazine (FIRM)	01/02/2012	FEHRL, Brussels	Scientific community (higher education, Research) - Industry - Policy makers	2000	International
3	Oral presentation to a scientific event	UNIVERSITY COLLEGE DUBLIN, NATIONAL UNIVERSITY OF IRELAND, DUBLIN	SMARTRAIL Overview	01/06/2013	FEHRL Infrastructure Research Meeting 2013	Scientific community (higher education, Research) - Industry	50	International
4	Media briefings	UNIVERSITY COLLEGE DUBLIN, NATIONAL UNIVERSITY OF IRELAND, DUBLIN	FEHRL Infrastructure Research Magazine (FIRM)	01/06/2013	FEHRL, Brussels	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias	2000	International
5	Oral presentation to a scientific event	UNIVERSITY COLLEGE DUBLIN, NATIONAL UNIVERSITY OF IRELAND, DUBLIN	Bridges 2014 Conference	01/04/2014	Dublin, Ireland	Scientific community (higher education, Research)	500	Ireland and UK
6	Oral presentation to a scientific event	UNIVERSITY COLLEGE DUBLIN, NATIONAL UNIVERSITY OF IRELAND, DUBLIN	IYGEC 2013	31/08/2013	Ecole des Ponts Paris Tech, Paris	Scientific community (higher education, Research)	200	International
7	Oral presentation to a scientific event	UNIVERSITY COLLEGE DUBLIN, NATIONAL UNIVERSITY OF IRELAND, DUBLIN	LARAM 2012	12/11/2012	Chengdu, China	Scientific community (higher education, Research)	50	International

		UBLIN, NATIONAL UNIVERSITY OF IRELAND, DUBLIN				ion, Research)		
8	Oral presentation to a scientific event	UNIVERSITY COLLEGE DUBLIN, NATIONAL UNIVERSITY OF IRELAND, DUBLIN	BCRI 2012	06/09/2012	Dublin, Ireland	Scientific community (higher education, Research)	100	Ireland and UK
9	Oral presentation to a scientific event	UNIVERSITY COLLEGE DUBLIN, NATIONAL UNIVERSITY OF IRELAND, DUBLIN	Transport Research Arena, 2014	14/04/2014	Paris, France	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias	70	International
10	Oral presentation to a scientific event	ROUGHAN & O'DONOVAN LIMITED	BCRI 2012	06/09/2012	Dublin, Ireland	Scientific community (higher education, Research)	100	Ireland & UK
11	Posters	ROUGHAN & O'DONOVAN LIMITED	Opensees@Bristol	02/06/2014	Bristol, UK	Scientific community (higher education, Research)	50	International
12	Oral presentation to a scientific event	ROUGHAN & O'DONOVAN LIMITED	CERAI 2014	28/08/2014	Belfast, Northern Ireland	Scientific community (higher education, Research)	100	Ireland and UK
13	Oral presentation to a scientific event	FORUM DES LABORATOIRES NATIONAUX EUROPEENS DE RECHERCHE ROUTIERE	IALCCE 2014 Conference	01/11/2014	Tokyo, Japan	Scientific community (higher education, Research)	100	International
14	Oral presentation to a scientific event	ZAVOD ZA G RADBENISTVO SLOVENIJE	Danube Region Transport Days 2013	01/10/2013	Belgrade,	Scientific community (higher education, Research)	120	International
15	Oral presentation to a scientific event	ZAVOD ZA G RADBENISTVO SLOVENIJE	First Transport & Research in the Danube Region Conference	01/04/2014	Ljubljana, Slovenia	Scientific community (higher education, Research)	50	International
16	Oral presentation to a scientific event	ZAVOD ZA G RADBENISTVO SLOVENIJE	EURNEX Advisory Board Meeting	01/06/2014	Berlin, Germany	Industry	20	International

17	Oral presentation to a scientific event	ZAVOD ZA G RADBENISTVO SLOVENIJE	ERRAC Permanent Advisory Group	02/07/2014	Brussels	Scientific comm unity (higher educat ion, Research) - Ind ustry - Policy makers	30	International
18	Oral presentation to a scientific event	ZAVOD ZA G RADBENISTVO SLOVENIJE	Transport Research Arena, 2014	14/04/2014	Paris, France	Scientific comm unity (higher educat ion, Research)	70	International
19	Oral presentation to a scientific event	ZAVOD ZA G RADBENISTVO SLOVENIJE	ERRAC Permanent Advisory Group	01/07/2014	Brussels, Belgium	Scientific comm unity (higher educat ion, Research) - Pol icy makers	30	International
20	Interviews	EURNEX e. V.	Face-to-face intervi ew	03/11/2011	Warsaw, Poland	Industry	6	Poland
21	Interviews	EURNEX e. V.	Face-to-face intervi ew	01/11/2011	Zagreb, Croatia	Industry	6	Croatia
22	Interviews	EURNEX e. V.	Face-to-face intervi ew	01/05/2012	Prague, Czech R epublic	Industry	8	Czech Republic
23	Organisation of Workshops	EURNEX e. V.	Wider Black Sea Summit	03/10/2011	Bucharest	Industry - Policy makers	250	International
24	Oral presentation to a scientific event	EURNEX e. V.	Mittelstandsfruehstu eck BWG	02/04/2012	Berlin, Germany	Industry	40	Germany
25	Organisation of Workshops	EURNEX e. V.	Face-to-face intervi ew	01/06/2012	Riga, Latvia	Industry	10	Latvia
26	Organisation of Workshops	EURNEX e. V.	Face-to-face intervi ew	01/05/2012	Budapest	Industry	6	Hungary
27	Organisation of Workshops	EURNEX e. V.	Face-to-face intervi ew	01/07/2014	Warsaw, Poland	Industry	6	Poland
28	Oral presentation to a wider public	EURNEX e. V.	Club Feroviar	03/02/2014	Bucharest, Roma nia	Industry - Policy makers	200	Romania
29	Oral presentation to a wider public	EURNEX e. V.	Bridges 2014 Co nference	01/04/2014	Brno, Czech Rep ublic	Scientific comm unity (higher educat ion, Research) - Ind ustry	150	International
30	Organisation of Conference	UNIVERSITY COLLEGE D UBLIN, NAT IONAL UNIV ERSITY OF IRELA	1st Smartrail Region al Conference	05/05/2012	Dubrovnik, Croatia	Scientific comm unity (higher educat ion, Research) - Ind ustry - Policy makers	40	International

ND, DUBLIN								
31	Organisation of Workshops	EURNEX e. V.	Innotrans	05/09/2012	Berlin, Germany	Scientific community (higher education, Research) - Industry	30	International
32	Organisation of Workshops	EURNEX e. V.	Wider Black Sea Summit	01/10/2013	Bucharest, Romania	Industry - Policy makers	250	International
33	Organisation of Conference	EURNEX e. V.	2nd Smartrail Regional Conference	03/12/2012	Moscow-Sherbinka	Industry - Policy makers	60	International
34	Oral presentation to a wider public	EURNEX e. V.	UNECE-TER	01/10/2013	Bad Gastein, Austria	Industry - Policy makers	60	International
35	Oral presentation to a scientific event	EURNEX e. V.	ETR	02/09/2013	Prague, Czech Republic	Scientific community (higher education, Research) - Industry - Policy makers	180	International
36	Organisation of Workshops	EURNEX e. V.	EURNEX Advisory Board Meeting	01/07/2013	Berlin, Germany	Scientific community (higher education, Research) - Industry	25	International
37	Organisation of Conference	ZAVOD ZA GRAĐBENISTVO SLOVENIJE	SMARTRAIL FINAL CONFERENCE	25/08/2014	Ljubljana, Slovenia	Scientific community (higher education, Research) - Industry - Policy makers	70	International

Section B (Confidential or public: confidential information marked clearly)

LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, UTILITY MODELS, ETC.					
Type of IP Rights	Confidential	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant(s) (as on the application)

OVERVIEW TABLE WITH EXPLOITABLE FOREGROUND								
Type of Exploitable Foreground	Description of Exploitable Foreground	Confidential	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use or any other use	Patents or other IPR exploitation (licences)	Owner and Other Beneficiary(s) involved

ADDITIONAL TEMPLATE B2: OVERVIEW TABLE WITH EXPLOITABLE FOREGROUND	
Description of Exploitable Foreground	Explain of the Exploitable Foreground

Report on societal implications

4.3 Report on societal implications

B. Ethics

1. Did your project undergo an Ethics Review (and/or Screening)?	No
If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final reports?	
2. Please indicate whether your project involved any of the following issues :	
RESEARCH ON HUMANS	
Did the project involve children?	No
Did the project involve patients?	No
Did the project involve persons not able to consent?	No
Did the project involve adult healthy volunteers?	No
Did the project involve Human genetic material?	No
Did the project involve Human biological samples?	No
Did the project involve Human data collection?	No
RESEARCH ON HUMAN EMBRYO/FOETUS	
Did the project involve Human Embryos?	No
Did the project involve Human Foetal Tissue / Cells?	No
Did the project involve Human Embryonic Stem Cells (hESCs)?	No
Did the project on human Embryonic Stem Cells involve cells in culture?	No
Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	No
PRIVACY	
Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	No
Did the project involve tracking the location or observation of people?	No
RESEARCH ON ANIMALS	

Did the project involve research on animals?	No
Were those animals transgenic small laboratory animals?	No
Were those animals transgenic farm animals?	No
Were those animals cloned farm animals?	No
Were those animals non-human primates?	No
RESEARCH INVOLVING DEVELOPING COUNTRIES	
Did the project involve the use of local resources (genetic, animal, plant etc)?	No
Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	No
DUAL USE	
Research having direct military use	No
Research having potential for terrorist abuse	No

C. Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	0	1
Work package leaders	2	5
Experienced researchers (i.e. PhD holders)	10	24
PhD student	1	7
Other	2	1

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	14
Of which, indicate the number of men:	2

D. Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project ?	No
6. Which of the following actions did you carry out and how effective were they?	
Design and implement an equal opportunity policy	Not Applicable
Set targets to achieve a gender balance in the workforce	Not Applicable
Organise conferences and workshops on gender	Not Applicable
Actions to improve work-life balance	Not Applicable
Other:	
7. Was there a gender dimension associated with the research content - i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?	No
If yes, please specify:	

E. Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?	Yes
If yes, please specify:	TRA Visions Project
9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?	Yes

F. Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?	
Main discipline:	2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)
Associated discipline:	2.3 Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining,

	textile technology and other applied subjects)
Associated discipline:	

G. Engaging with Civil society and policy makers

11a. Did your project engage with societal actors beyond the research community? (if 'No', go to Question 14)	Yes
11b. If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?	Yes - in determining what research should be performed
11c. In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	Yes
12. Did you engage with government / public bodies or policy makers (including international organisations)	Yes- in framing the research agenda
13a. Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?	Yes - as a primary objective (please indicate areas below multiple answers possible)
13b. If Yes, in which fields?	
Agriculture	No
Audiovisual and Media	No
Budget	No
Competition	No
Consumers	No
Culture	No
Customs	No
Development Economic and Monetary Affairs	No
Education, Training, Youth	Yes
Employment and Social Affairs	No
Energy	No
Enlargement	No
Enterprise	No
Environment	Yes
External Relations	No
External Trade	No
Fisheries and Maritime Affairs	No
Food Safety	No

Foreign and Security Policy	No
Fraud	No
Humanitarian aid	No
Human rightsd	No
Information Society	No
Institutional affairs	No
Internal Market	No
Justice, freedom and security	No
Public Health	No
Regional Policy	No
Research and Innovation	No
Space	No
Taxation	No
Transport	Yes
13c. If Yes, at which level?	European level

H. Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	22
To how many of these is open access provided?	21
How many of these are published in open access journals?	21
How many of these are published in open repositories?	21
To how many of these is open access not provided?	0
Please check all applicable reasons for not providing open access:	
publisher's licensing agreement would not permit publishing in a repository	Yes
no suitable repository available	No
no suitable open access journal available	No
no funds available to publish in an open access journal	No
lack of time and resources	No
lack of information on open access	No
If other - please specify	
15. How many new patent applications	0

("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).

Trademark

0

Registered design

0

Other

0

17. How many spin-off companies were created / are planned as a direct result of the project?

1

Indicate the approximate number of additional jobs in these companies:

10

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

Increase in employment, In small and medium-sized enterprises

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (FTE = one person working fulltime for a year) jobs:

10

I. Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

Yes

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

No

22. Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

Press Release

No

Media briefing

Yes

TV coverage / report

No

Radio coverage / report

No

Brochures /posters / flyers

Yes

DVD /Film /Multimedia

No

Coverage in specialist press

Yes

Coverage in general (non-specialist) press

No

Coverage in national press	No
Coverage in international press	No
Website for the general public / internet	Yes
Event targeting general public (festival, conference, exhibition, science café)	No
23. In which languages are the information products for the general public produced?	
Language of the coordinator	Yes
Other language(s)	Yes
English	Yes

Attachments	Smartrail final report_211014_final_edited.pdf
Grant Agreement number:	285683
Project acronym:	SMART RAIL
Project title:	Smart Maintenance and Analysis of Transport Infrastructure
Funding Scheme:	FP7-CP-FP
Project starting date:	01/09/2011
Project end date:	31/08/2014
Name of the scientific representative of the project's coordinator and organisation:	Dr. Kenneth Gavin UNIVERSITY COLLEGE DUBLIN, NATIONAL UNIVERSITY OF IRELAND, DUBLIN
Name	
Date	

This declaration was visaed electronically by Ken GAVIN (ECAS user name ngavinke) on