

MAINLINE

MAINTenance, renewal and Improvement of rail transport iNfrastructure
to reduce Economic and environmental impacts

Collaborative project (Small or medium-scale focused research project)

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CO	Confidential, only for members of the consortium (including the Commission Services)	

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Glossary

Abbreviation/ acronym	Description
DoW	Description of Work
EB	Executive Board
EC	European Commission
AC	Advisory Committee
GA	General Assembly
IPR	Intellectual Property Right
S&T	Scientific and Technical
WP	Work Package

1. Introduction

This report is the second deliverable of WP7 Project management in MAINLINE.

It presents the public parts of the reports provided after the end of the project (30 September 2014).

From the Second Periodic report, the publishable summary is available in this deliverable.

From the Final report, the following sections are included:

- A final publishable summary report covering results, conclusions and socio-economic impact of the project
- A plan for use and dissemination of foreground, including the list of publications, dissemination activities and exploitable foreground.

2. Second Periodic report – publishable summary



Project context and objectives

Growth in demand for rail transportation across Europe is predicted to continue. Much of this growth will have to be accommodated on existing lines that contain elderly infrastructure and will increase both the rate of deterioration of these elderly assets and the need for shorter line closures for maintenance or renewal interventions. However, interventions on elderly infrastructure will also need to take account of the need for lower economic and environmental impacts. This means that new interventions will need to be designed. In addition, tools will need to be developed to inform decision makers about the economic and environmental consequences of different intervention options being considered.

MAINLINE proposed to address all these issues through a series of linked Work Packages that targeted at least €300m per year savings across Europe coupled with a reduced environmental footprint, principally measured in terms of embodied carbon and other environmental benefits.

The main objective of the MAINLINE project was to develop methods and tools that will contribute to a more cost efficient and effective improvement of European railway infrastructure based on whole life considerations.

In view of the scale of renewal dictated by conventional methods in the future, the specific objectives of the project were to:

- facilitate the utilisation of improved assessment and life extension without increasing risk,
- improve existing knowledge on damage and deterioration mechanisms in order to reduce significantly their effect on asset performance,
- identify and implement new cost effective replacement/renewal construction methods and logistics, bearing in mind the logistics and operational constraints across an expanding railway network, and the associated political aspirations towards a sustainable low carbon society,
- identify and compare new surveying and monitoring technologies in order to complement or replace existing techniques,
- develop methods to determine the whole life environmental and economic impact from track and infrastructure maintenance and renewal through the use of various scenarios and management policies and to create a tool that can compare different maintenance and replacement strategies for track and infrastructure based on traffic situation and whole life evaluation.

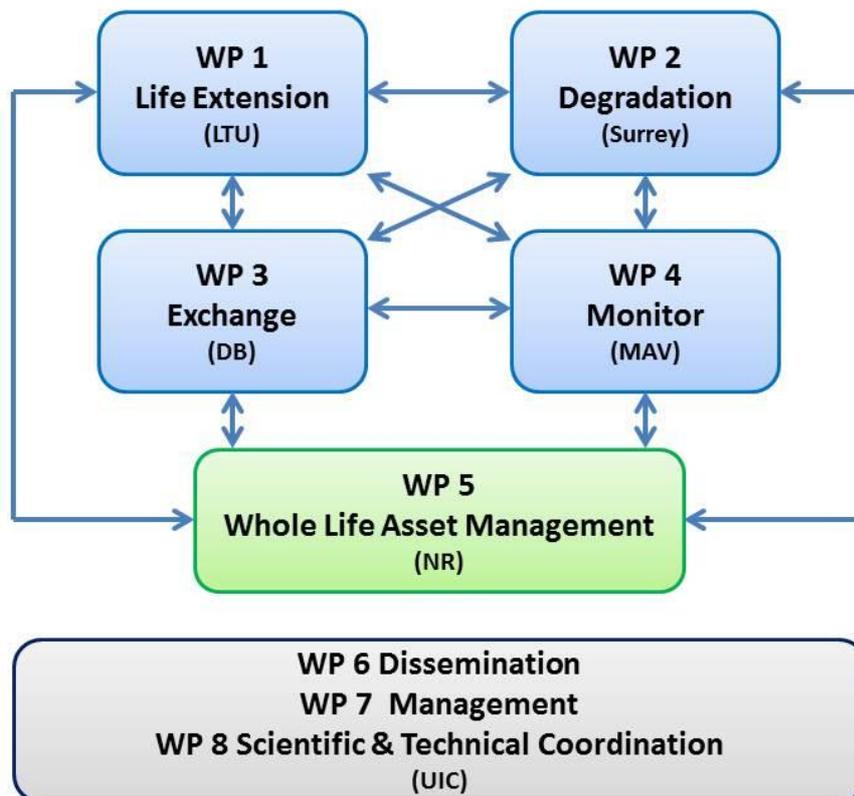
As a result, Infrastructure Managers will be better able to analyse and plan their infrastructure maintenance programs since they will have access to new and improved renewal/ strengthening/refurbishment solutions and an evaluation tool that is capable of accurately comparing cost-efficiency on a whole life basis, taking into account operational, environmental and economic criteria.

The project has quantified the needs arising from emerging freight and passenger demands across Europe with special emphasis being placed on Eastern Europe in order to develop

client options and preferred solutions that are affordable, whilst maintaining operational safety.

The project has drawn on the considerable progress made within recently completed European projects regarding the maintenance and renewal of both track and switches & crossings (INNOTRACK) and bridges (Sustainable Bridges), and has also benefited from partners' expertise in other infrastructure networks.

The overall structure and interactions of the Work Packages (WPs) are demonstrated in the following figure.



List of partners

The 19 partners of MAINLINE have been chosen to bring a mix of competencies and experiences into the consortium as well as to ensure a suitable geographical coverage across Europe (11 countries are represented):

- Infrastructure Managers:
 - The International Union of Railways (UIC), France;
 - Network Rail Infrastructure Limited (NR), United Kingdom;
 - Deutsche Bahn (DB), Germany;
 - MÁV Magyar Államvasutak, Hungary;
 - TCDD, Turkey;
 - TRAFIKVERKET (TrV), Sweden
- Industry partners:
 - COWI, Denmark;

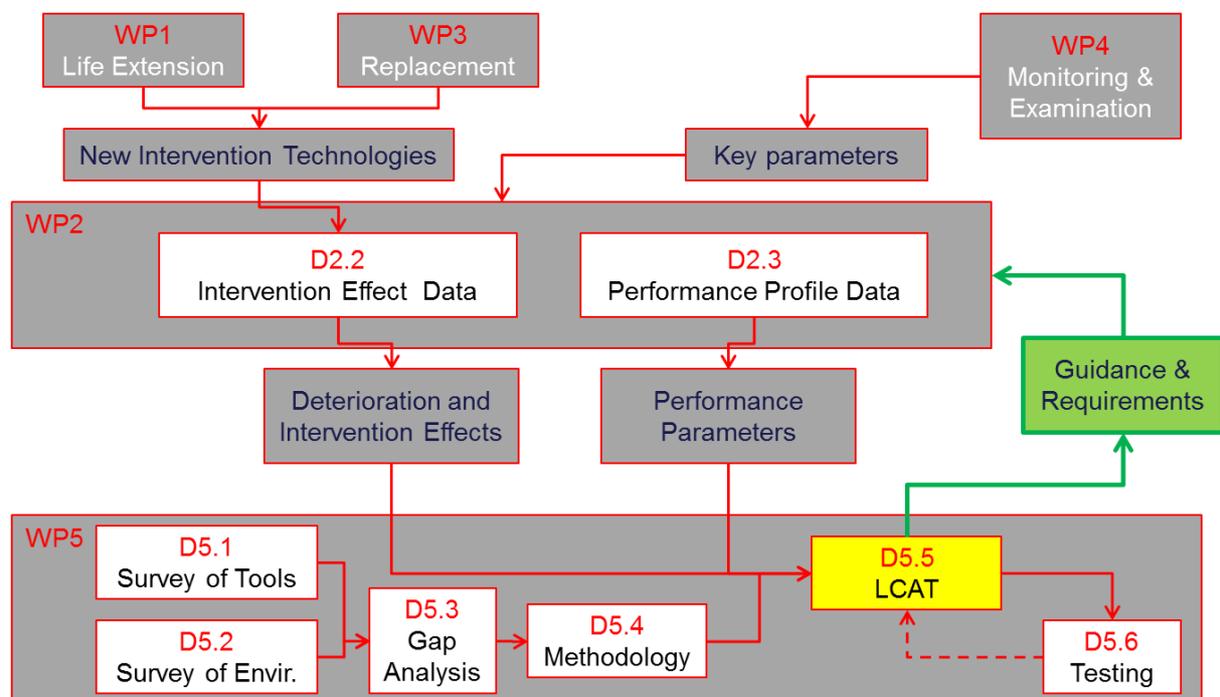
- TWI, United Kingdom;
- COMSA, Spain;
- SKANSKA, Czech Republic;
- Jacobs/Sinclair Knight Merz (SKM), United Kingdom
- Universities:
 - University of Surrey, United Kingdom;
 - University of Minho, Portugal;
 - Luleå University of Technology(LTU), Sweden;
 - Polytechnic University of Catalonia (UPC), Spain;
 - Graz University of Technology, Austria
- SMEs:
 - ARTTIC, France;
 - DAMILL, Sweden
- A governmental organisation: Cerema, France.

Work performed since the beginning of the project and results achieved

During the first 18-month period two benchmark reports have been published, one on new technologies to extend the life of elderly rail infrastructure and one on methods to replace obsolete infrastructure, based on questionnaires sent to European Infrastructure Managers. Degradation models and monitoring techniques have been examined as input to a Life Cycle Assessment Tool (LCAT), which is being developed. So far a methodology has been worked out and tested.

During the second 18-month period several reports have been published. They are further described below.

In the figure below the interface between the different WPs of MAINLINE and the final Life Cycle Assessment Tool (LCAT) is illustrated. The added value of MAINLINE resides in how all the research and findings from the individual WPs are added up into the LCAT.



Progress of the technical Work Packages (WPs) was as follows:

WP1 – Life Extension - Application of new technologies to elderly infrastructure

Work in the exploration and evaluation of new technologies to extend life length has been finished, which resulted in the production of the report D1.1 “Benchmark of new technologies to extend the life of elderly rail infrastructure”. Work was also completed on two other aspects: the development of accurate assessment methods, resulting in the report D1.2 “Assessment methods for elderly rail infrastructure” and the development of new technologies to extend life, resulting in the report D1.3 “New technologies to extend the life of elderly infrastructure”. Meanwhile, the outcome of the WP was achieved with the production of a guideline for the application of those new technologies, corresponding to the report D1.4 “Guideline for application of new technologies to extend life of elderly rail infrastructure”.

WP2 – Degradation and structural models to develop realistic life cycle cost and safety models

During this second period, the work was focused, as per the DoW on tasks 2.4 and 2.5. For the selected asset types which were chosen on the basis of earlier research (described in D2.1 and D2.2), and for which agreement had been reached at the mid-term meeting, a range of performance profiles taking account of possible deterioration mechanisms and intervention actions were produced and validated. The validation involved both the use of new data from infrastructure managers and sensitivity analyses. Two reports were delivered, D2.3 and D2.4, and close contact was maintained with the other work packages, in particular WP5 for which the results from WP2 were directly relevant.

WP3 – Replacement of obsolete infrastructure – New construction methods and logistics

In the second period of the project work was focused on the development and improvement of new technologies for construction for both bridges and track. Partners aimed to find advanced construction methods that minimise the time and cost required for replacement of old infrastructure. In the track sector a survey was made that showed European maintenance strategies and with the production of deliverable D3.2 and D3.3 “the final output was prepared. Then the work ended with the preparation of the guideline on the application of the most effective methods for use on railway infrastructure. In D3.4 “Guideline for Replacement of elderly rail infrastructure” infrastructure managers find suitable guidance on how to manage a replacement project and how to find the best methods for their network and individual situation.

WP4 – Monitoring and examination techniques

Task 4.2 was completed and deliverable D4.2 entitled “Solutions to gaps in compatibility between monitoring and examination systems and degradation models” submitted.

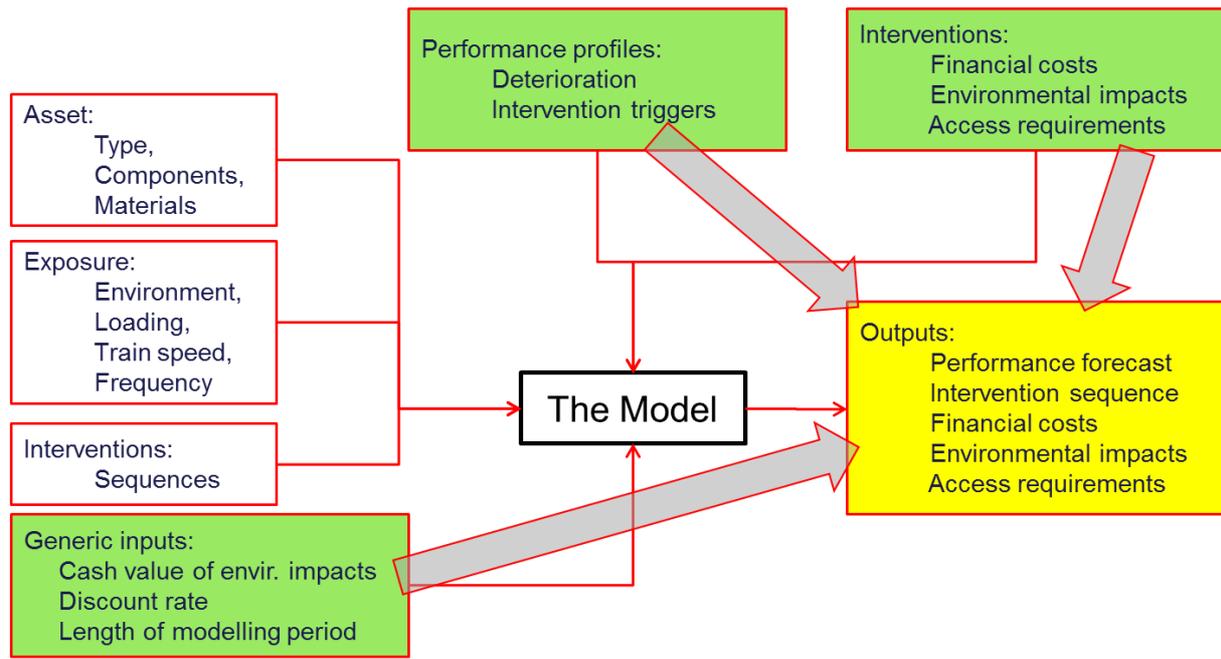
Task 4.3 was on conducting Case Studies showing appropriate monitoring and examination techniques in the management of selected types of assets – Bridges and Earthworks. This work was submitted as D4.3 titled “Report on Case Studies”.

WP5 – Whole life environmental and economic asset management

WP5 is the WP where the concluding result has been produced.

The first four deliverables (D5.1 to D5.4) have been the basis for the development of the LCAT tool (D5.5 and D5.7), together with input from the other WPs.

The model is illustrated in the figure below, where it can be seen how the output is based on input regarding Assets, Exposures, Interventions, Performance profiles and Generic Inputs.



WP8 – Scientific and technical coordination

Work was focused on the technical and scientific follow-up of the project.

It also consisted in common activities with the sister FP7 project SMARTRAIL, among which the organisation of a common Workshop in May 2013.

Several meetings of the Advisory Committee (AC) took place; the second physical meeting provided input for D8.3 “First Report on Advisory Committee Recommendations”.

The choice of guidelines was implemented and reported in D8.4 “Second analysis and identification of potential guidelines from MAINLINE R&D”.

Expected final results and their potential impact and use (including the socio-economic impact and the wider societal implications of the project so far)

The results from the MAINLINE project will facilitate longer service lives for existing railway infrastructure, which will bring about great savings for rail administrations in Europe. This will be done by providing improved life extension methods (WP1), understanding of infrastructure degradation (WP2) and enhanced monitoring and examination techniques (WP4). MAINLINE has also provided methods to optimize replacement of obsolete structures (WP3), and developed a tool for evaluating all these options (WP5), in a transparent economic cost and environmental impact framework. A modest 10 year increase in the service life of 2% of the bridges due to the outputs from the MAINLINE project implies that the replacement of 10,000 bridges could be postponed for 10 years.

Similar savings will be available for other kinds of infrastructure;. The project showed that there is potential to enhance replacement methods of Switches & Crossings (S&C) by reducing replacement time, ensuring good track alignment and reducing varying track stiffness. This is one of the principal focus areas for MAINLINE. Hence, just from savings on bridges and switches & crossings, MAINLINE may reduce costs by more than 300 M€ per year. Added to these estimates, savings will be realised due to MAINLINE results for earthwork, tunnels and other structures.

Besides, the tool will enable railway undertakings to assess the environmental (carbon) impact of various maintenance or renewal interventions under consideration and hence have the opportunity to select the one with the least impact.

The combined impact will thus be an effective and efficient improvement of infrastructure based on whole life considerations. The impact will be especially important in considering the improvement of combined rail freight and passenger networks that require substantial infrastructure upgrading, as is the case within Eastern Europe and developing economies.

Railway lines cross National borders in Europe so the infrastructure ought to be analysed in the same way on the different sides of these borders, particularly as the basic infrastructure types are similar. Hence it is advantageous to study them together as today most countries are too small to support this kind of endeavour in isolation. By carrying out a project such as MAINLINE together it will be easier to implement its results in the different states of Europe. By co-operating on a European level it is also possible to share resources and reach a result in a shorter time, which is necessary in order to meet the demands on the railways, and at a significantly lower overall cost. Additionally, good practice can be promulgated more easily and effectively to achieve the best benefits from project outputs.

The MAINLINE consortium was carefully selected to include MAV (the Hungarian railway) and TCCD (the Turkish railway) as active members in this project. They have brought not only their own expertise but also a view from the eastern and central part of Europe and have been well placed to promote dissemination and exploitation of the MAINLINE results. MAV have very good operational and research activities connected to the former Russian Federation and Eastern European areas. Their solutions and strategies are very interesting and valuable for new research activities in the field of maintenance. On the one hand the project will benefit from this knowledge and on the other hand dissemination of project results will be very much easier having partners of known expertise to spread this information in existing working groups.

Recently technical developments in earlier projects, such as Sustainable Bridges, INNOTRACK and Urban Track have been introduced successfully in many railways and the new ideas of life time extension and LCC developed by the MAINLINE project have been disseminated. However, more examples and tests are needed to show how life cycle

methods and effective maintenance planning can work together. This will, in time, increase the understanding and use of these methods. As this a novel way of planning and managing the maintenance of railway infrastructure no guidelines, rules or standards exist, hence railway administrations themselves might have difficulties in testing and adopting the methodology. However, MAINLINE has undertaken the basic research and development activities and produced guidelines for everyday use. In this way the end users can rely on results and the acceptability of the methods will be higher, so that they can be implemented by the railway owners in their infrastructure management systems, which is a necessity.

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Project public website

A public website on the MAINLINE project is available at: <http://www.mainline-project.eu/>.

- Under the first headline “About MAINLINE project” you can find the final book with the summary of results and a link to the presentations of MAINLINE Final Workshop.
- Under “Work Plan” you can get a short explanation about the different WPs and how they are linked together.
- Under “List of participants” you can see who participates in MAINLINE.
- Under “Publications” you can download all press releases, newsletters and brochures produced by the project.
- Under “Events” you can get information about all events performed and find the presentations of the Final Workshop and the Workshop targeted to Central and Eastern Europe.
- Under “Results” you can download all public deliverables and MAINLINE Life Cycle Assessment Tools (LCATs).
- Under “Information / Contact” you can get information about the contact persons.
- Finally under “Members Area”, there is a link to the project internal collaborative platform where all documents are stored (both administrative and technical files).

3. Final report – final publishable summary report

3.1 Executive Summary

MAIN LINE

The MAINLINE project, funded under the Seventh Framework Programme of the European Commission, has been prepared under the auspices of the International Railways Union (IUC) to address work programme topic SST.2011.5.2-6. “Cost-effective improvement of rail transport infrastructure”. This 3-year project brought together infrastructure managers and railway undertakings from across Europe, contractors and consulting engineers with a wide experience of improving existing rail transport infrastructure and academics widely respected for their understanding of the issues related to elderly infrastructure.

Growth in demand for rail transportation across Europe is predicted to continue. Much of this growth will have to be accommodated on existing lines that contain elderly infrastructure and will increase both the rate of deterioration of these assets and the need for shorter line closures for maintenance or renewal interventions. However, interventions on elderly infrastructure will also need to take account of the need for lower economic and environmental impacts.

MAINLINE proposed to address all these issues through a series of linked activities that targeted at least €300m per year savings across Europe coupled with a reduced environmental footprint, principally measured in terms of embodied carbon, and other environmental benefits: both life extension and replacement techniques have been studied, as well as degradation models and monitoring.

Balancing the economic and environmental costs generated by the maintenance and renewal of existing infrastructure is far more difficult than it is when building new, especially as it is necessary to minimise the risks to the continued safe operation of the transport network. It is also necessary to balance the natural desire for lower first cost solutions, particularly in the current economic downturn, with the real need to achieve the lowest life cycle cost.

The development of a tool to assist railway administrations to balance these various considerations was the principal objective of the MAINLINE project and the work plan was arranged to ensure that this objective was kept central to the project activities. A key feature of the MAINLINE project was not only the development of such a tool, but also the provision of sufficient validation to enable infrastructure managers to adopt it with confidence. Although the LCAT is focused on metallic bridges, plain track and soil cuttings, MAINLINE has studied other assets such as switches & crossings (S&C) and tunnels.

Thanks to the MAINLINE project, Infrastructure Managers will be better able to analyse and plan their infrastructure maintenance programs, since they will have access to new and improved renewal/ strengthening/refurbishment solutions and an evaluation tool that is capable of accurately comparing cost-efficiency on a whole life basis, taking into account operational, environmental and economic criteria.

The project has quantified the needs arising from emerging freight and passenger demands across Europe with special emphasis being placed on Eastern Europe in order to develop client options and preferred solutions that are affordable, whilst maintaining operational safety.

MAINLINE has drawn on the considerable progress made within recently completed European projects regarding the maintenance and renewal of both track and switches & crossings (INNOTRACK) and bridges (Sustainable Bridges), and has also benefited from partners' expertise in other infrastructure networks.

3.2 Description of the Project Context and Objectives

The demand for rail transportation across Europe is continuously increasing, and growth is predicted to continue into the future. Midterm projections by the EC, COM (2006)¹, expect rail freight and passenger traffic to rise by around 13% and 19% respectively between 2000 and 2020. Whilst some of this growth will be met, particularly in Western Europe by the building of new high speed lines, much of it will have to be accommodated on existing lines which contain some of the oldest transportation infrastructure now in regular use for long distance journeys. For instance it is estimated that some 35% of the railway bridges in Europe are in excess of 100 years and major earthworks (cuttings and embankments) and tunnels date back to the original construction of the route, possibly in excess of 150 years.

The predicted increase in traffic on existing elderly rail infrastructure across Europe will result in increased rates of degradation for the civil engineering and track assets utilised, which will then need to be maintained, and when necessary, replaced, in as short time as possible so that disruption to the flow of freight and passengers is kept to a minimum. However, in order to maintain rail's competitiveness, faster maintenance and renewal activities will have to be undertaken without any increase in real costs and preferably at lower cost than traditionally has been the case. In addition, the increasing worldwide importance of environmental considerations in infrastructure maintenance and renewal activities, particularly those related to climate change (generally expressed in terms of carbon emissions) means that new techniques will have to be rigorously evaluated to ensure that their environmental cost is also kept to a minimum. The possibility of safely extending the life of existing infrastructure in order to deal with both historic under investment in railway networks and short term financial constraints can also provide great savings in environmental impact as it will postpone the need for the construction of new assets.

The main objective of the MAINLINE project was to develop methods and tools that will contribute to a more cost efficient and effective improvement of European railway infrastructure based on whole life considerations. In view of the scale of renewal dictated by conventional methods in the future, the specific objectives of the project were to:

- Apply new technologies to extend the life of elderly infrastructure,
- Improve degradation and structural models to develop more realistic life cycle cost and safety models,
- Investigate new construction methods for the replacement of obsolete infrastructure,
- Investigate monitoring techniques to complement or replace existing techniques,
- Develop management tools to assess whole life environmental and economic impact.

Project benefits have also been derived from keeping existing infrastructure safely in service through the application of technologies and interventions based on life cycle considerations. Although MAINLINE has focused on certain asset types, the management tools developed are also applicable across a broader asset base.

The overall structure and interactions of the Work Packages (WPs) are demonstrated in the following figure.

¹ COM (2006): Keep Europe moving. Sustainable mobility for our continent. Midterm review of the European Commission's 2001 White Paper, see: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2006:0314:FIN:EN:PDF> [accessed 19 Nov 2014]

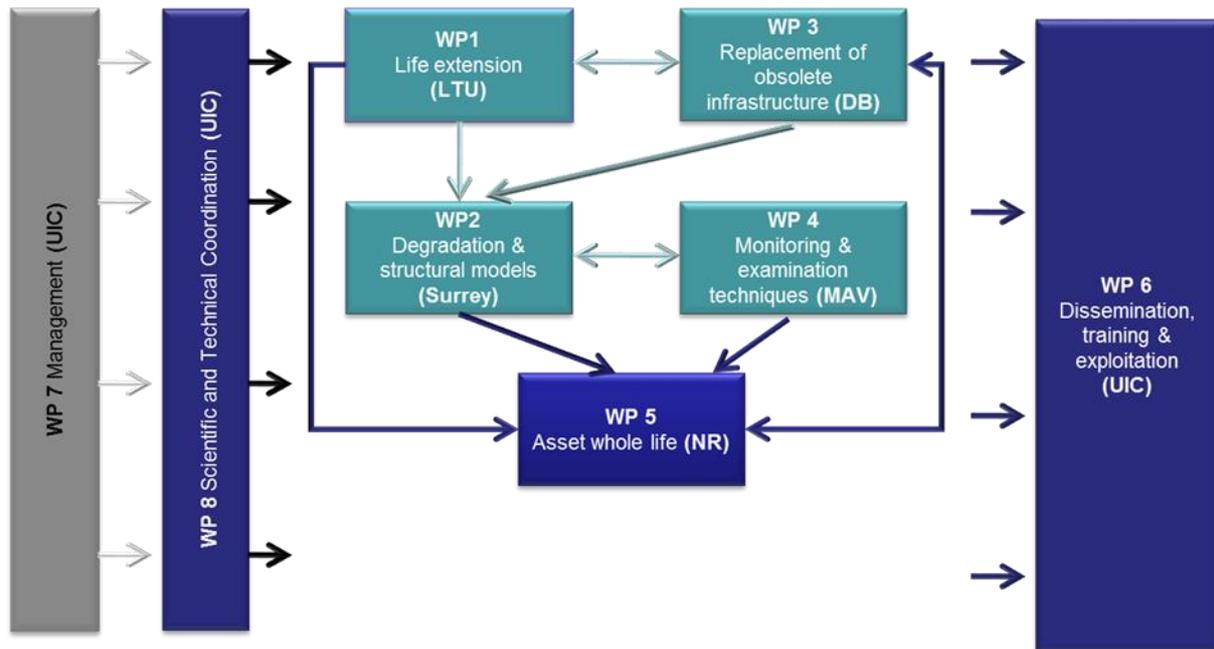


Figure 3-1 MAINLINE project structure

3.3 Description of the main S&T Results/Foregrounds

3.3.1 Life extension of elderly infrastructure

The main objective of this life extension work package was to apply new technologies to extend the life of elderly infrastructure. This can be subdivided as follows:

- to explore and evaluate new technologies to extend the life length,
- to develop new more accurate assessment methods to determine if and when the life can be extended without any interventions (as e.g. strengthening),
- to further develop new technologies that can reduce life cycle costs for repair and strengthen and minimize the necessary traffic interruption,
- to develop a guideline for the application of new technologies to extend the life length,
- to transfer existing knowledge of new technologies to Eastern Europe and developing economies.
- to deliver input regarding data to the development of life cycle cost models and other decision support systems. This includes describing the cost and effect on the environment of applied technologies.

In line with the objectives, the following results have been achieved:

1. New technologies and novel methods to extend the service life of bridges, tunnels, track and earthworks have been explored and described in a guideline (D1.4).
 - For bridges this has included describing the use of both retrospective post tensioning and the application of fibre reinforced polymer (FRP) plates to increase carrying capacity. A cost saving of between 75% and 85% compared with the alternative solution of replacement was achieved for one Swedish case study described in detail in Appendix B to report D1.3 and illustrated in Figure 1.2 where

retrospective post tensioning permitted an increase in permissible axle load from 250kN to 300kN.



Figure 3-2 The Swedish bridge strengthened with retrospective post tensioning

- For tunnels the use of techniques such as sprayed concrete replacement linings and both traditional and proprietary roof support systems (shown in Figure 1.3) to maintain safety are described in case studies in Appendix C to report D1.3.



Figure 3-3 Traditional and proprietary tunnel roof support systems

- For track, life extension by grinding, ballast tamping and cleaning and stone blowing have been examined and recommendations made.
 - For earthworks the use of lime columns and vertical drains to maintain safety and reduce future maintenance needs has been described.
2. More accurate assessment methods have been developed to study if and when the life can be extended for bridges, track and earthworks without any interventions.
- For bridges the use of advanced assessment techniques such as direct reliability, the calculation of system safety, redundancy and robustness criteria and consideration of site specific loading, dynamic amplification factors and temperature effects have been described. Sample calculations are included in Appendix A to D1.3. The benefit of finite element (FE) modelling has been demonstrated through the use of a FE model to compare predictions with the actual results of the test to failure of the Åby River metal truss bridge in northern

Sweden, (see Figure 1.2, which is also discussed in detail in Appendix A to D1.3. This work has enabled a number of similar bridges to be kept in service carrying higher axle loads.

- For track the benefit of refined inspection and assessment techniques such as infrastructure mounted video cameras, high speed inspection of switches using lasers, SIM (Switch Inspection Measurement) wagon and in-service track geometry recoding have been explored.
- For earthworks the benefits from the use of slope stability analysis to identify potential future failure sites has been described and the technique used to help populate the LCAT developed by WP5.



Figure 3-4 The Åby bridge after failure, which was caused by buckling of the top flange of the main truss girders. The failure was quite ductile and the bridge could continue to carry a high load after failure, as predicted by the FEM model of the failure, shown in insert.

3.3.2 Degradation and structural models

The objectives of work package 2 were to:

- identify and model important degradation phenomena and processes for selected railway assets for the purpose of LCC and LCA analysis.
- quantify the influence of intervention strategies on degradation time profiles.
- develop performance time profiles for selected asset types.
- validate the developed degradation and performance models through case studies.

At the start of the MAINLINE project, the available asset management tools for transport networks were largely deficient in the treatment of deterioration and how it impacts on Life Cycle Cost and Environmental Impact analysis. In particular, available models were hampered by simplifying assumptions made in deterioration models, which had been developed from limited laboratory (rather than field) data or simply transferred from allied, yet distinct, industry sectors (e.g. corrosion models from the marine/offshore sector). This work

package was aimed at the development and validation of deterioration models within a railway environment, in order to increase confidence in their predictions, which in turn would improve the capability of LCC estimates for alternative maintenance options.

Given the range and number of possible degradation mechanisms and asset types, research has been undertaken to devise an appropriate taxonomy which can be incorporated in an asset management tool. Thus, effort has been given to categorising degradation mechanisms bearing in mind the requirements of LCC and LCA calculations, and the need to cover assets with both relatively short and very long life-spans. The appropriate framework for performance, cost and environmental impact time profiles for different asset types under a range of degradation mechanisms has been a significant contribution towards the next generation asset management tools. In particular, we have:

- analysed the current models used for predicting the degradation typically found in elderly railway infrastructure to check if the results reflect observations.
- developed those models found to be deficient.
- created new models where no models currently exist.

The work first identified groups of railway assets, based on a ranking strategy that considered the potential to increase knowledge within the project's lifetime and the availability of field data for validation purposes. Additional considerations included the desire to cover asset types managed on the basis of their condition as well as those managed on a capacity basis, and the opportunity to demonstrate the development of deterioration models either from empirical data/observations or from physical laws and mechanical relationships (see Deliverable D2.1).

Particular attention was directed towards formulating the models so that they could be integrated within asset management tools that depend on both LCC and LCA algorithms. The modelling effort was complemented with targeted validation studies, which was carried out using knowledge and field experience from the participating consulting organisations and infrastructure managers. These activities led to improved and validated degradation and structural models, thus allowing infrastructure owners to examine and predict the performance of their assets with higher confidence. In turn, this led to more robust estimates of maintenance plans and budgets under a range of operational scenarios. Four distinct asset types, covering both condition and capacity related performance, were addressed: plain line track, soil cuttings, metallic bridges and concrete lined tunnels.

For all four asset types, available deterioration models were analysed and compared, and specific recommendations were made as to how they could be adapted for use in a railway context. Moreover, a number of improvements and insights were introduced in order to create complete and robust deterioration models (see Deliverable D2.2) that are compatible with the Life Cycle Cost methodology described in section 1.3.5. Specific examples of typical railway assets from each of the above four groups were presented in full, quantifying the influence of deterioration on the basis of changes in performance over time (see Deliverable D2.3). For plain line track and soil cuttings, the adopted approach was based on the analysis of large historical datasets pertaining to asset performance over a period of more than ten years. On the other hand, for metallic bridges and concrete lined tunnels, analytical modelling was preferred, partly based on test and field data but also relying to a considerable extent on physical understanding of the underlying deterioration mechanisms and structural behaviour. Finally, significant effort was directed towards scrutinising all the proposed models through comparisons with real data and targeted sensitivity analyses (see Deliverable D2.4).

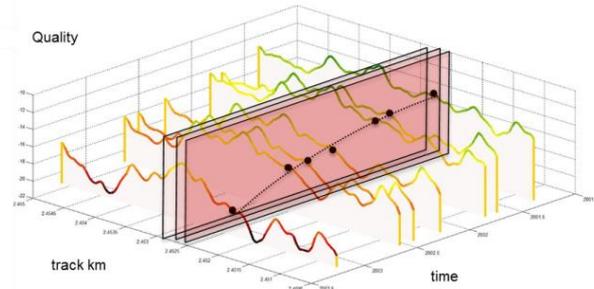
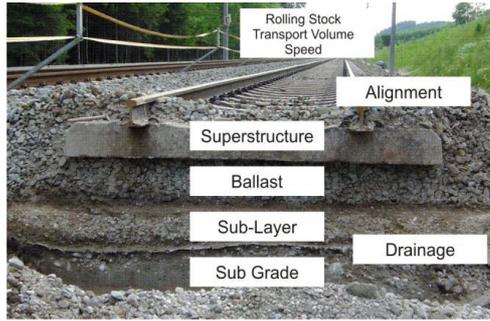


Figure 3-5 Generation of track deterioration profiles.

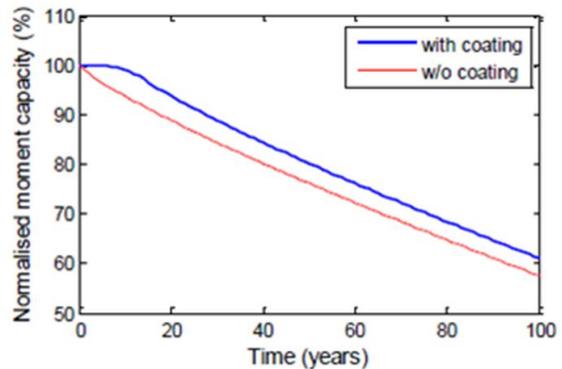
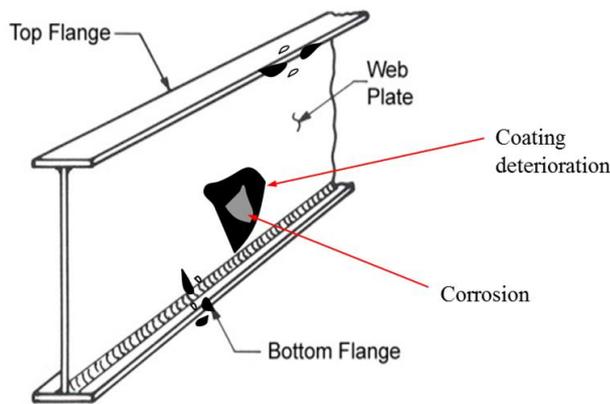
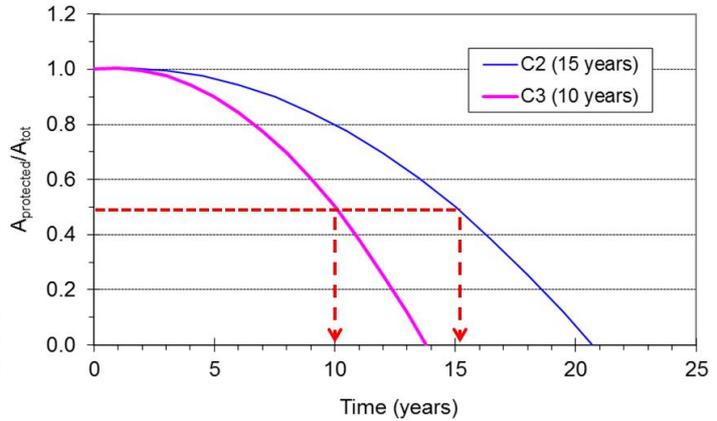


Figure 3-6 Generation of metallic bridge deterioration profiles.

The main outcomes from the activities related to degradation and structural models have been fed into the project methodology leading to integrated asset management tools. In this respect, an important research performance indicator was the readiness and user friendliness with which this task could be accomplished. The consortium has benefited from a broad spectrum of infrastructure owners and consultants, who were able to assess this aspect of the work directly and progressively during the project. In addition, the project advisory group, drawn from industry focused bodies directly involved with structure and track research and development, were able to assess the intrinsic quality and potential impact of the progress achieved with respect to the characterization of degradation mechanisms and their effect on structural models. The introduction of validated performance models for deteriorating assets into the LCAT tool is an important contribution to railway asset management practice, promoting the use of refined asset management strategies. With respect to wider dissemination, the outcomes from this activity have been presented at

international conferences (such as IABMAS etc) and will be submitted for publication in relevant scientific and technical journals. In this way, the outcomes have been subjected to wide peer review and professional scrutiny, which is based on quality, innovation, rigour and practicality.

To summarise, the main achievements are as follows:

- A deterioration model for Soil Cuttings which considers a number of time-invariant (such as soil type) and time-variant (such as vegetation and drainage) factors that predicts on the basis of historical trends captured through inspection cycles.
- A deterioration model for Track (Plain Line) that explicitly quantifies track quality as a function of time on the basis of initial conditions and a deterioration rate estimated considering line-specific factors (such as sleeper types, transport loads and track alignment)
- A deterioration model for metallic bridges susceptible to atmospheric pollution and corrosion, focusing first on the degradation of any available coating and the ensuing evolution of corrosion as coating becomes ineffective; the change of performance with time is captured under both condition criteria (such as percentage of unprotected area or fraction of thickness lost) and strength criteria (such as bending, shear or buckling capacity).
- A deterioration model for tunnels with concrete linings subject to chemical attack on reinforcing steel by carbon dioxide or by chloride ions, bearing in mind the specificities of tunnel geometry and availability of aggressive substances in a railway environment.

3.3.3 New construction techniques - Replacement of old infrastructure

Replacement is an important part when infrastructure assets have reached the end of their service life and are functionally obsolete. It should be carried out with minimum traffic disruption. Traffic disruption can be minimised through the clustering of different work items between the same closure points together, provided that there is no logistical clash between work sites. This can be achieved through careful preplanning. Work has been focussed on bridge structures and track systems as these are the infrastructure assets within the overall MAINLINE work plan that are most frequently replaced.

The objectives of work package 3 were:

- to investigate new construction methods and logistics for transport that minimize the time and cost required for the replacement of obsolete infrastructure. The focus here is on cost effective and environmentally sound methods that are easy to implement with low impact on the rail traffic and a short down time of the network.
- to plan and optimise the construction processes on existing lines where replacement of existing infrastructure is an alternative. Here the systematic approach is extremely important and should always be connected to LCCA. The results will help the infrastructure manager to decide for the most favourable measure from technical, social, environmental or cost demands.
- to deliver input regarding data to the development of life cycle cost models and other decision support systems for infrastructure managers. This includes taking into account construction time and logistics, short- and long-term impact on the network,

future maintenance issues but also environmental aspects such as emissions of greenhouse gases from temporary transport services.

A comparison of the techniques identified has been undertaken through detailed reviews to determine which are the most likely to offer benefit to the majority of railways in Europe. The most appropriate techniques discovered have been summarised in a series of guides analysing the advantages and disadvantages of each technique. These guides were supported by relevant case studies drawn from projects undertaken by the project partners or our international contacts.

Planning

A survey of railway infrastructure managers across Europe showed that, in those countries where there is a regime for compensating train operators when lines are not available to them, the longer notice of disruptive activities that is given the lower the compensation payment. In some cases lead times of several years are necessary when very long disruptive possessions are needed, even when these are usually only made available over the Easter and Christmas holiday periods. As a result, advice has been given on how to undertake long term planning by comparing the strategies and methods used across Europe. This could lead to a reduction of up to 60% in disruption costs.

Since not all countries have established regimes for charging disruption costs, a number of regimes were studied and a simplified method devised to assist those countries without a method. This will allow such countries to populate the relevant parts of the LCAT models with consistent data.

The survey also showed that the clustering of maintenance and renewal activities within disruptive possessions would lead to cost savings for individual projects as the disruption costs could be shared and productivity was likely to increase due to a higher efficiency of machinery use. An example quoted showed a productivity increase of 15% following the introduction of clustering.

Another important part of the planning process is the consideration of the environmental impact of the work proposed. The MAINLINE LCAT tool will be of assistance to this when looking in detail at individual construction activities but it is designed to deliver the impact in terms of CO₂ output or Euro equivalent. This means that other less easily quantified environmental impacts such as noise, which is becoming a more important issue in parts of Europe, are not addressed by the tool. Hence advice is given in D3.4 about how to reduce both the generation of noise and its export to neighbouring communities, with different solutions being offered for both bridgeworks and track works.

The application of the methodology of Reliability, Availability, Maintainability and Safety (RAMS) to new and existing structures has also been introduced by MAINLINE to the rail infrastructure sector.

Main focus is on the guidelines: MAINLINE has delivered “ready to use solutions” in the guideline for replacement of elderly infrastructure including

- state of the art,
- decision help for certain site conditions
- construction details, technical / engineering data to use the method developed or evaluated in MAINLINE.

Bridges

Most railway administrations across Europe have their own standard designs of bridges. A selection of these have been described and compared so that good or novel solutions from one railway can be adopted by others.

A Eurocode compliant design for a relatively simple concrete bridge, which could be considered as a future standard pan-European design, has been undertaken to compare the requirements of the Swedish and Spanish National Annexes. This has shown that there are only minor differences between the two designs and hence little practical difficulty in developing standardised products that could be offered commercially to the whole of Europe, with the potential for savings based on a larger scale of production.

The aim was not only to propose efficient methods to replace bridges but also to optimise procedures for different site situations. MAINLINE proposed and explained a project management system for infrastructure managers and also introduced strengths and weaknesses of different procurement processes. Installation methods also vary across Europe. The most popular method is by the use of either road or rail mounted cranes but this can lead to additional time and cost where lines are electrified as overhead equipment may need to be removed. To counteract this some countries possess special rail mounted bridge carriers and others rely more on multi wheel road based bridge carriers. In other cases replacement bridges are built alongside the existing bridge and then slid (or launched) laterally into position during a relatively short track closure. For long bridges, particularly over water, this method can be combined with the sequential longitudinal launching of individual spans constructed on dry land onto temporary supports prior to lateral movement. A table has been produced to compare the merits of each solution to assist infrastructure managers in the selection of the best option.

	Mobile Cranes	Rail Mounted Crane	Rail Mounted Bridge Carrier	Longitudinal Launching	Horizontal Launching	Deck Replacement
++ = yes + = may work - = no						
1. Bridge length						
1.1 Less than 5 m	++	++	++	++	++	++
1.2 5-20 m	++	++	++	++	++	++
1.3 More than 20 m	+	+	+	+	++	++
2. Bridge type to be exchanged						
2.1 Reinforced concrete beam bridge Proposed for deletion	+	+	++	++	++	++
2.2 Steel truss	++	++	+	++	++	++
2.3 Steel beam	++	++	++	++	++	++
2.4 Arch	+	+	+	+	+	+
2.5 Other	+	+	+	+	+	+
3. Track possession time						
3.1 Between 6-12 h	+	+	+	-	+	+
3.2 Between 12-24 h	++	++	++	+	++	+
3.3 Between 24-60 h	++	++	++	++	++	++
3.4 More than 60 h	++	++	++	++	++	++
4. Available funding						
4.1 Very restricted funding	+	+	+	+	++	++
4.2 Normal funding	++	++	++	++	++	++
4.3 Money is not the problem	++	++	++	++	++	++
6. The bridge runs over						
6.1 Water	++	++	++	++	+	++
6.2 A rural route	++	++	++	++	++	++
6.3 A highway	++	++	++	++	++	++
6.4 A street in a city	++	++	++	++	++	++
6.5 Agricultural land	+	++	++	++	++	++
7. Available working site						
7.1 Small	++	++	++	+	+	+
7.2 Normal	++	++	++	++	++	++
8. Electrified line						
8.1 Electrified line	+	++	++	+	++	+
8.2 No electricity	++	++	++	++	++	++

Figure 3-7: Recommendations for methods for replacement of the superstructure of short span bridges.

Finally, there are new techniques available to use prefabricated bridge units. They can be assembled on site and thus reduce the time for closure of rail traffic. MAINLINE has further developed these innovative methods and provided guidelines for how the assembly work can be performed in an efficient way. A special kind of bridge is the so called soil-steel bridge, which consists of a steel shell supported on a foundation and by soil backfill. This type of bridge, or culvert, is mostly used for small spans.

MAINLINE has explored the use of different installation techniques including open cut (trenched) and thrust boring & pipe jacking (trenchless) technologies.

The use of novel materials for bridge construction, principally high performance concrete and fibre reinforced polymers (FRP), also known as advanced composites, has been investigated. This has shown that both materials have seen limited use worldwide in railway bridge applications and that they offer considerable promise in the future. Two notional designs have been produced:

- a replacement FRP deck on pre-existing metallic main girders which could produce weight savings of up to 50% when compared with the more traditional concrete alternative.
- a fully FRP composite railway bridge with a span capability of up to 50m which are expected to offer cost savings on both initial construction (due to their relative lightness) and through life (due to lower maintenance requirements).

Nevertheless the absence of a Eurocode covering the use of FRP material is likely to inhibit the take up of these solutions in the short term, although design guidance, without the formal status of codes, is available in a number of European countries.

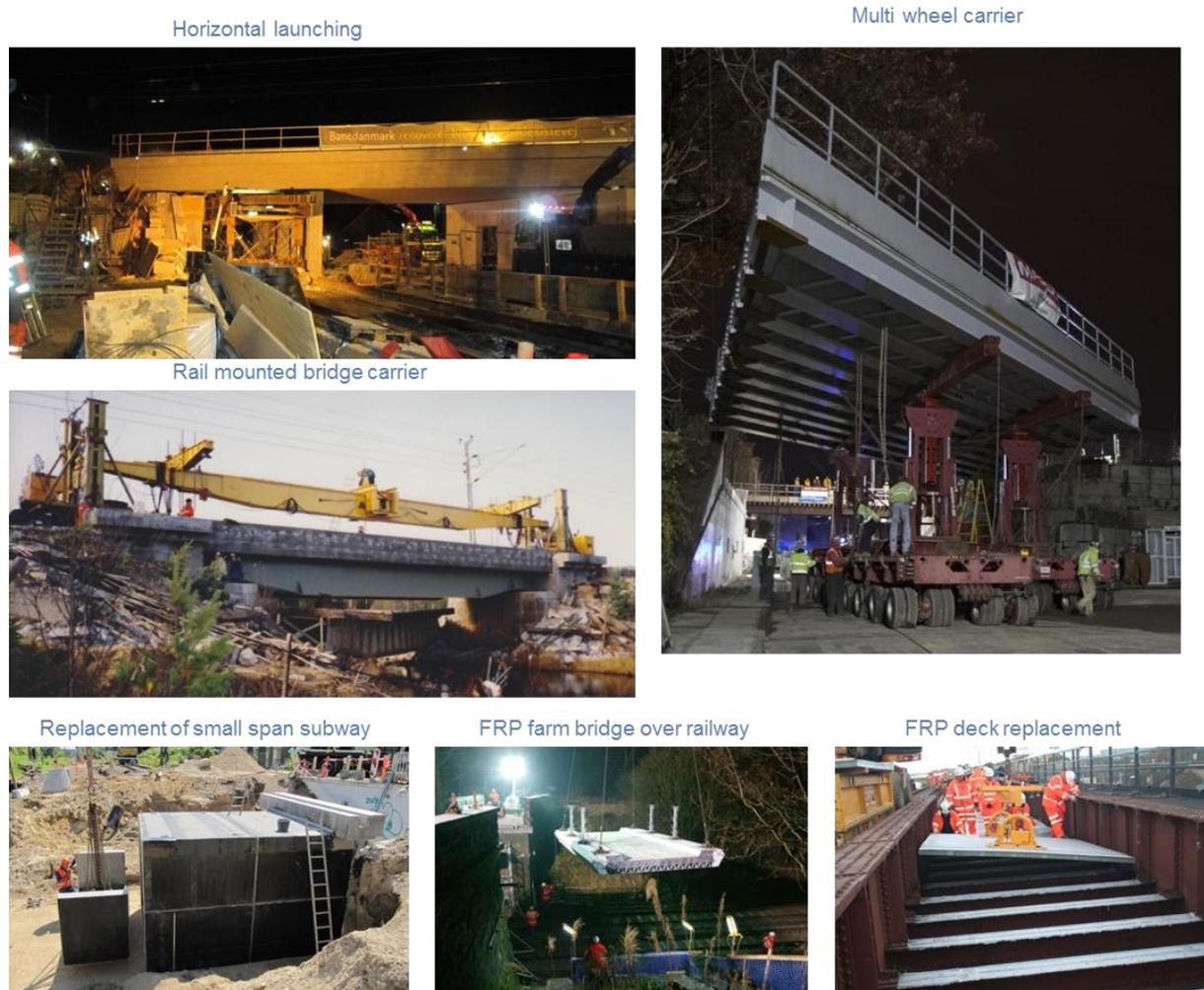


Figure 3-8 Example of bridge replacement methods

Track

Track replacement falls into two distinct categories, plain line and switches and crossings (S&C), each of which has different logistical and engineering requirements. The total replacement of a complicated junction can take several days. Plain line can be done in short track possessions in order not to affect train operation but with very low output and high costs or on the contrary, the line can be closed during several weekends -or even weeks- depending on the line, available alternative routes and the country. The latter enables higher output and lower costs (see also LCAT). Therefore the length of track possession for track activities depends strongly on the requirements/demands of the IMs, which affects directly cost and output of the works.

Plain line renewal can vary from the use of manual labour with minimal assistance from plant such as cranes or excavators to the deployment of a modern fully automatic track relaying machine with the choice of system being dictated in part by the length of line to be replaced and the time available for the work. The manual method can be made less weather dependent by the use of mobile workshops (which can also be used when routine maintenance is undertaken) in which case the adjacent line can be kept open without restriction. The merits of each approach are discussed so that infrastructure managers can decide on the best approach for their own specific requirements. Major cost savings can usually only be achieved through the use of modern high output machines which have a high capital cost and thus need to be used intensively to justify the initial outlay.

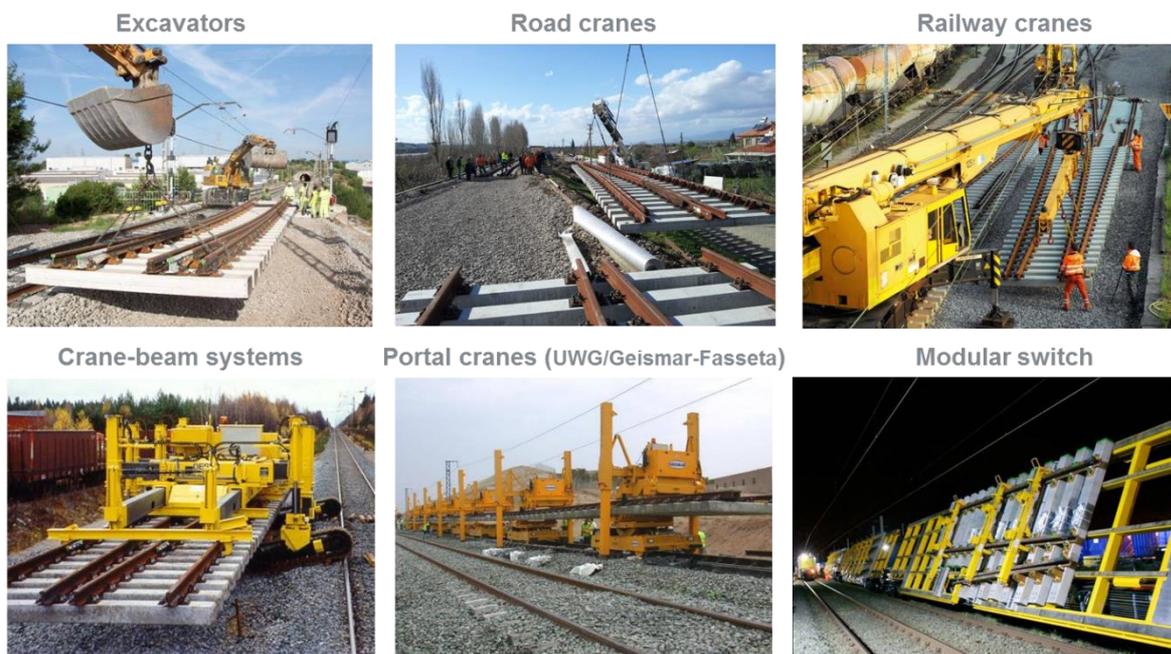


Figure 3-9 Different techniques for track renewal.

Switch & crossing renewal, as outlined above, can vary from the replacement of a single lead turnout to the total replacement of a complicated junction. There are many methods available, ranging from hand build up on site to the transportation and installation of large components fabricated offsite. There are also a number of commercially available machines to assist the installation of S&C, such as the Automated Ballast Collector which efficiently removes the old ballast and compacts the subgrade to avoid future differential settlements.

It has been shown in INNOTRACK that there is a potential to improve replacement methods. This relates to two items, the first is to reduce replacement time, while the other is to assure track alignment and to reduce varying track stiffness. Starting from this MAINLINE has developed methods further to increase the quality of the work at site in order to make the switches and crossings last longer.

Additionally the use of modular S&C is becoming more popular as it can give time savings of up to 80% and a 33% reduction in work force on site. All these options are discussed in detail in terms of required machinery, output and labour and compared in specially produced tables so that the most appropriate system can be chosen for each particular site. Moreover, additional recommendations are provided in order to achieve higher initial quality after the renewal (such as avoiding provisional clamping in favour of welding or always removing the complete layer of old ballast layer), which is essential to minimize future track degradation.

Comparisons have been undertaken between the use of under rail pads, under sleeper pads and under ballast mats for homogenising track stiffness through S&C, which is now believed to be an important factor in long term track behaviour. The results are presented in a series of graphs and the following conclusions drawn:

- soft rail pads are the most efficient system to minimize track stiffness variation and hence, impact load on the crossing, while under ballast mats have very little effect.
- the combined use of rail pads and under sleeper pads can bring additional benefits, and should be considered. However, the stiffness of rail pads and under sleeper pads should be revised if used together.
- further studies should be carried out on under sleeper pads.

It is well known that the use of wood sleepers in S&C improve the dynamic behaviour to a similar degree as the use of under sleeper pads. The disadvantage of wooden sleepers is that they need to be preserved to prevent rot using creosote, which is no longer environmentally acceptable. Hence the use of synthetic sleepers manufactured from fibre-reinforced foamed urethane (FFU) has been investigated. These are extensively used in Japan and have been used in a number of European countries. Whilst more expensive than comparative wooden sleepers, FFU sleepers should have a longer life (up to 50 years is suggested) so are likely to prove to be cheaper on a whole life cost basis.

Cleaning of ballast and exchange of sleepers is usually achieved through mechanised procedures. MAINLINE has examined and compared different methods to be able to propose further development and give guidance.

3.3.4 Monitoring and examination techniques

Monitoring and Examination (M&E) techniques are applied to assets so that timely action can be taken for these assets to remain fit for service. M&E systems thus form a crucial part of asset integrity management. They also provide valuable support in through life cycle management decision making by enabling asset managers to assess the remaining life of their assets and plan for life extension or decommissioning

M&E systems range from the very basic visual inspection by trained personnel to the remotely operated real-time continuous monitoring systems employing electronics for sensing and wireless communication. The M&E techniques used must be compatible with other parts of the asset management system, particularly the degradation assessment models that necessarily require appropriate inputs from such techniques. The issues that MAINLINE has sought to investigate include state of the art M&E techniques and the interface between such techniques and degradation assessments.

The main objectives of work package 4 were to:

- clarify what inputs the degradation models require from advanced monitoring techniques and examination systems, investigate their use and identify how these can operate in the most cost-effective and reliable way to complement or replace existing examination techniques for elderly infrastructure. Such monitoring and

examination systems, together with the degradation models, are crucial for the effective and efficient integrated whole life asset management system described in section 1.3.5,

- provide case study/validation evidence so as to promote take-up of the proposed approaches by infrastructure managers.

The work package includes: assessment of currently used and promising M&E techniques, given the information provided regarding the degradation models in use; identification of gaps and recommendations to address the gaps between M&E and degradation assessment procedures; and, reports from Case Study applications.

The project has taken a broad, pragmatic view of the monitoring and examination requirements.

The main outcomes of WP4 are the three deliverables (D4.1-D4.3). These deliverables have provided:

- a realistic overview on currently available monitoring and examination techniques in relation to modelling the degradation process of railway assets,
- successful solutions to gaps in compatibility between monitoring and examination systems and degradation models,
- convincing validation of the improved methodologies via case studies.

The criteria and performance/research indicators that were used to measure the results, progress and impact of the project are as follows:

D4.1) Report on assessment of current monitoring and examination practices in relation to the degradation:

- The quality and comprehensiveness of assessment.
- Is the evaluation of monitoring and examination techniques sufficiently comprehensive to understand the efficiency and effectiveness of the methods in relation to their ability to provide input parameters for the degradation models?

Deliverable D4.1 provides an overview of currently available M&E techniques in relation to modelling degradation processes in a selection of railway assets – Cuttings, Metallic Bridges, Tunnels, Plain line, and Retaining Walls. This Deliverable summarises the pros and cons of each technique, draws on the suitability of these methods according to the degradation mechanism and the railway asset they apply to, and identifies gaps and issues to be addressed in the next stage in this work package.

D4.2) Solutions to gaps in compatibility between monitoring and examination systems and degradation models:

- Are the proposed solutions a step forward from the current state-of-the-art?
- Can the new approaches be used in practice? Have guidelines for practical use been developed? Will it be accepted and put into use by infrastructure managers?

Deliverable D4.2 is a report on the range of potential solutions to address the gaps identified in an efficient and cost-effective way. A suitable geographical coverage across Europe was ensured through the involvement of experts from both Western and Eastern European countries in the preparation of the document. A comparison of European best practice methods has been carried out to offer reliable conclusions in regard to solutions to compatibility gaps between monitoring and examination systems and degradation models.

D4.3) Report on case studies:

- Have at least two case studies and the relevant tests been completed?

- Do the case studies performed provide a convincing validation of the improved methodologies?
- Can the case studies performed contribute to the industry understanding of the proposed methodologies and help implement them into the practice of end users?

Deliverable D4.3 is a report on Case Studies showing the application of appropriate M&E techniques in the management of assets.

- Bridge Case Studies:

The Retszilas Bridge Case Study in Hungary illustrates how monitoring can be used to follow fatigue cracking and strengthening in a full scale test on a real bridge.



Figure 3-10 Retszilas bridge case study, Hungary.

The Åby Bridge Case Study in Sweden illustrates how a photographic strain measurement system can be used. Results from the measurements are compared against traditional assessment of the remaining fatigue life of the bridge and finite element modelling.



Figure 3-11 Aby bridge case study.

These Case Studies have used information from the previous deliverables. In particular regarding fatigue in metallic bridges, optical sensors, photographic strain monitoring and full-scale testing are the proposed solutions to enable the measurement at points with maximum damage and calibrate fatigue models to improve their reliability.

- Earthworks Case Study:

Another Case Study is the Sligo Line Cutting in Ireland which is a SMARTRAIL test site too. The cutting is a live railway cutting on the Sligo line in North West Ireland, owned by Irish Rail. State-of-the-art M&E techniques and assessment procedures were used and results compared. This Case Study gained from the results from both MAINLINE and SMARTRAIL projects.

3.3.5 Whole life environmental and economic asset management

The continued growth in rail traffic across Europe will increase both the rate of deterioration of these railway assets and the need for shorter line closures for maintenance or renewal interventions. The impact of these interventions will need to take into account the financial constraints and enhanced environmental requirements as a result of new legislation. Tools to inform decision makers about the economic and environmental consequences of different intervention options are becoming essential to provide confidence and assurance.

The main objective of MAINLINE was to create a tool (Life Cycle Assessment Tool - LCAT) that can compare different maintenance/replacement strategies for track and infrastructure based on a life cycle evaluation quantifying:

- Direct economic costs
- Availability (Delay costs/user cost/benefit from upgrade etc.)
- Environmental impact costs

MAINLINE has gone further than the current state of the art on LCC and LCA for railway infrastructure assets through the setting up of databases for different asset types:

- including life-cycle performance, life-cycle cost and life-cycle environmental analysis;
- incorporating refined LCC and LCA formulae and supporting data inventories,
- sub-divided into parts that address renewal/replacement options and parts that address rehabilitation and strengthening options,
- for both parts, the databases are linked with improved degradation models, which includes possible interaction effects, and have the option of allowing the introduction of field data collected from rail assets,
- the databases also include data on costs and implementation aspects of inspection and monitoring techniques, so that their adoption can be evaluated in terms of LCC and LCA criteria.

MAINLINE's activities have come together in the development of an asset management tool that combines LCA and LCC analysis in order to quantify and reduce environmental and cost impact for the renewal and maintenance of railway infrastructure using a holistic and properly validated methodology.

Emphasis has been given to both integration and transparency, so that the tool can be versatile and applicable to different scenarios across the European rail network. Methods for environmental impact normalisation and weighting have been presented and analysed through case studies. However, it is not the intention to combine both economic and environmental criteria through single score methods, to avoid narrowing down the scope of the tool, and to allow stakeholders from across Europe to exercise their judgement and expertise relevant to national/local conditions.

The initial work was to establish which existing asset management tools could be used for railway assets and whether they provide both life-cycle and environmental outputs. This analysis highlighted positive and negative features of existing software and also found that combining life-cycle and environmental outputs was uncommon.

Questionnaires were issued to Infrastructure Managers to confirm the extent and nature of any life-cycle assessment that was carried out within their organisations. The results varied across Europe, although some activity was carried out within all countries; and that environmental outputs were performed less frequently than life-cycle costing. The respondents recognised the growing importance of both environmental and life-cycle costing.

The LCAT models have been designed to bring together both the improved deterioration rates described in chapter 3 and the ability to use monitoring intervention and replacement techniques, described in chapters 4, 5 and 6 or from user experience.

LCAT models have been created for plain line track, metallic bridges and soil cuttings. These assets were selected due to interest from the infrastructure managers and availability of sufficient data to calculate deterioration rates. These three models have been written in Microsoft Excel to provide transparency and allow users to amend the models as they need in the future. A consistent layout and style has been used to give a common identity to the models.



Soil Cuttings



Track



Metal Bridges

Figure 3-12 Examples of areas where LCAT is developed today.

The outputs from the LCAT are intended to assist the justification of interventions, to optimise spending of maintenance budgets, to compare different interventions and to predict the timing of future works and expenditure.

Training workshops have been organised to discuss, explain and demonstrate the LCAT models to infrastructure managers and other users. This has also allowed the models to be refined, based on feedback from these sessions.

The examples below show the application of the LCAT for a metallic bridge and plain track.

The metallic bridge is a single span structure with half-through girders and is a typical railway asset. The inputs to the LCAT describe the properties of an individual element of the bridge, its dimensions and acceptable limits for both condition and loss of section which determines the strength in terms of shear and bending. The LCAT uses these limits, together with any defined maximum intervals for specific interventions. These limits are applied to the degradation rates within the LCAT and a life-cycle plan is generated, as shown in Figure 1-14. It shows the financial and environmental costs relating to the physical works, and coating and section loss over time.

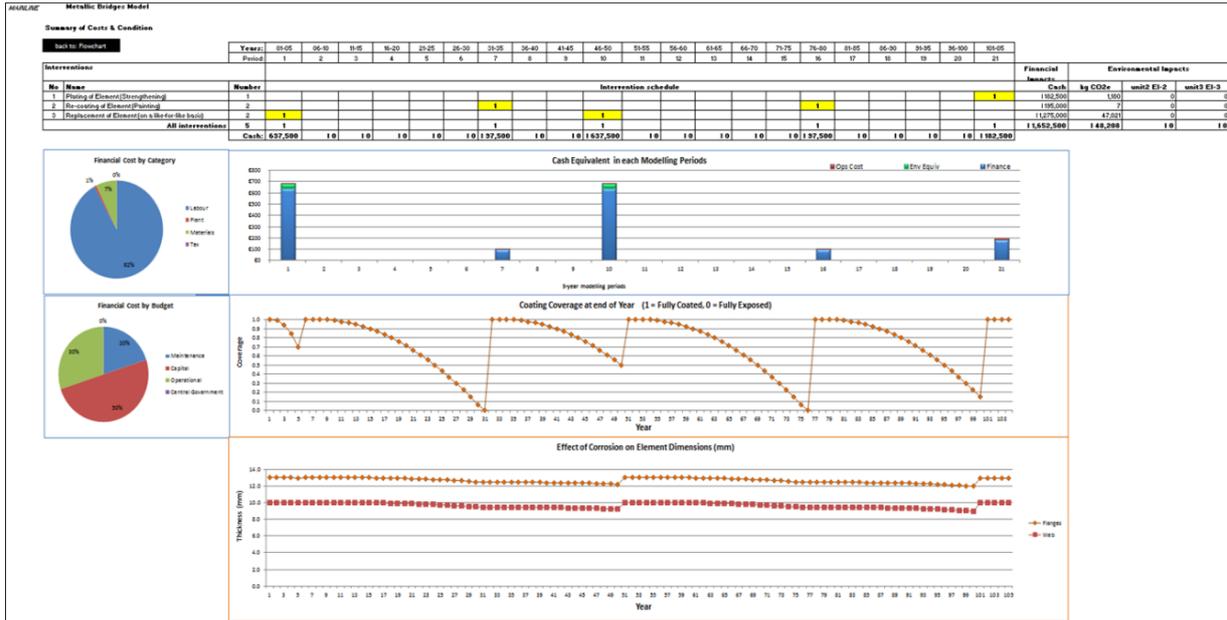


Figure 3-13 Example of LCAT output screen

The track example is for a length of route with good drainage and formation that is used by freight. Acceptable quality limits (Q) have been defined by the user to trigger interventions for tamping of the ballast and also relaying the track. Again, the degradation rates within the LCAT create the life-cycle plan shown in Figure 1-15.

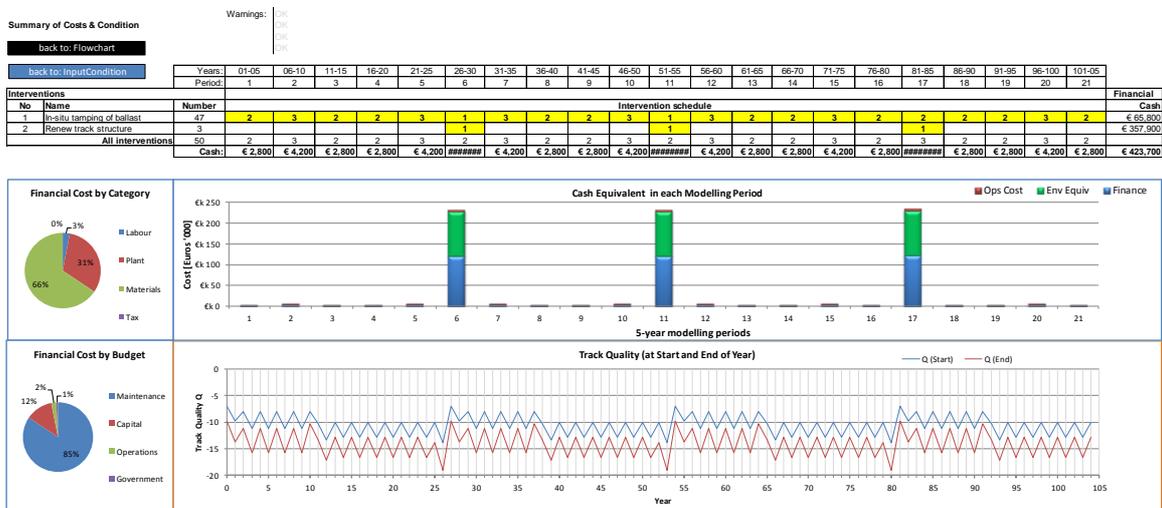


Figure 3-14: Life Cycle Plan generated based on the degradation rates within the LCAT

3.4 Potential impact

The MAINLINE project has targeted a reduced environmental footprint for selected items of rail infrastructure in terms of embodied carbon and other environmental benefits. The project has:

- Improved degradation and asset modelling to develop more realistic life cycle assessment to establish environmental impact of the proposed intervention works.
- Investigated monitoring techniques to compliment or replace existing examination techniques, reducing the need for construction works.
- Applied new technologies to extend the life of elderly infrastructure
- Investigated new construction methods for the replacement of obsolete infrastructure
- Developed decision support tools to assess whole life environmental and economic impact.

3.4.1 Major impacts

Economic Impact

Many Infrastructure Managers do not yet use Life Cycle Costing (i.e. financial) and/or Life Cycle Assessment (i.e. environmental) in the planning of maintenance and renewal of their rail infrastructure. There is a lack of data and methods and here the MAINLINE project gives guidance. There is also often a lack of economic resources for maintenance which may lead to a shorter service life and less sustainability than would otherwise be the case; results from the MAINLINE Project give advice that may help to improve this situation. The Life Cycle Assessment Tools (LCAT) have been developed which allow users to demonstrate optimum interventions and reduced capital expenditure.

Europe has a railway network of some 230,000 km with an asset value of more than 1500 billion € and is spending – with large variations – less than 1% of it for yearly maintenance, UIC (2006, 2010)². A large proportion of the civil engineering structures and tracks are old; of the 500,000 bridges, 35 % are over 100 years old and earthworks and tunnels are often older. Nonetheless they can, with the help of the outcomes from the MAINLINE project, safely remain in service for longer periods than currently anticipated, improving the ability of the railways to deliver increased mobility across Europe and play an increasingly important role in the development of integrated, safer, “greener” and “smarter” pan-European transport systems.

The results from the MAINLINE project will facilitate longer service lives for existing railway infrastructure, which will bring about great savings for rail administrations in Europe. This will be done by providing improved life extension methods (WP1), understanding of infrastructure degradation (WP2) and enhanced monitoring and examination techniques (WP4). MAINLINE has also provided methods to optimize replacement of obsolete structures (WP3), and developed a tool for evaluating all these options (WP5), in a transparent economic cost and environmental impact framework. A modest 10 year increase in the service life of 2% of the bridges due to the outputs from the MAINLINE project implies that the replacement of 10,000 bridges could be postponed for 10 years with notional cost savings calculated below.

² UIC (2007): Lasting Infrastructure Cost Benchmarking (LICB). 10-years of Benchmarking 1996-2005, Paris, September 2007.

- The average construction cost (K) of a new railway bridges is about 1M €.
- With a low interest rate (p) of 2% the present value of the cost for a rebuilding a bridge in 10 years will be $K/(1+p)^{10} = 0.820 K$.
- The saving compared to rebuilding the bridge now will then be $K - 0.820 K = 0.180 K$.
- Not replacing 1,000 bridges per year gives a saving of $1,000 \times 0.180 \times 1 \text{ M€} = 180 \text{ M€}$.

Similar savings will be available for other kinds of infrastructure; for instance in INNOTRACK significant performance enhancements for Switches and Crossings (S&C) were developed and demonstrated. Follow up in 2013, 4 years after INNOTRACK, proved LCC savings in order of 20% for the four demonstrated S&C. MAINLINE also showed that there is potential to enhance replacement methods of S&C by reducing replacement time, ensuring good track alignment and reducing varying track stiffness.

Additional savings have arisen from the MAINLINE results for plain line track and soil cuttings.

The combined impact will thus be an effective and efficient improvement of infrastructure based on whole life considerations. The impact will be especially important in considering the improvement of combined rail freight and passenger networks that require substantial infrastructure upgrading, as is the case within Eastern Europe and developing economies.

Environmental Impact

Traditionally the main environmental consideration associated with railway operation has been related to reducing noise and vibration, but with the main environmental focus now turning to climate change and the associated carbon agenda new considerations are becoming important. In common with many other parts of the built environment the carbon impact of railway infrastructure is dominated by usage rather than initial construction or ongoing maintenance. In this respect, the railway is already very favourable with emissions of the order of 50 g CO₂/passenger km compared to road and air transportation with double or triple values, Network Rail (2010)³ However if the railway industry is to play its part in meeting the carbon reduction targets set within Europe then the carbon impact of infrastructure maintenance and renewal activities will have to decrease.

Within the MAINLINE project a tool has been developed that enables railway administrations to assess the environmental (carbon) impact of various maintenance or renewal interventions under consideration and hence have the opportunity to select the one with the least impact. Unfortunately, the current state of knowledge about the carbon impact of typical interventions is limited, which means that it is difficult to quantify the benefits from the project. However the example below gives an indication of the kind of benefits that could be realised:

- The emission of carbon dioxide from the building of a concrete bridge containing 160 m³ of concrete can be calculated in the following way.
- 1 m³ of concrete weighs approximately 2.3 tonnes.
 - Concrete contains about 400 kg of cement per tonne
 - Cement production creates approximately 700 kg CO₂/tonne

³ Network Rail (2010): Managing rail's environmental impacts in CP5 and beyond. Sustainable Rail Programme. <http://www.networkrail.co.uk/browse%20documents/planning%20for%20cp5/long%20term%20planning%20framework%20supporting%20documents/managing%20rail's%20environmental%20impact%20in%20cp5%20and%20beyond.pdf> [accessed 2 Dec 2010]

- This gives $160 \times 2.3 \times 0.4 \times 0.7 \text{ ton} = 103 \text{ tonnes CO}_2$.
- Add to this we add 150 kg reinforcement steel per m^3 of concrete.
 - Steel production is responsible for some 1.2 kg CO_2/kg steel
 - This gives $160 \times 0.15 \times 1.2 \text{ tonne} = 29 \text{ tonnes CO}_2$.
- In total, estimated emissions are $103 + 29 \approx 130 \text{ tonnes CO}_2$ per new bridge.

Research projects developing a new generation of lightweight, low energy, self-compacting concretes for structural applications has shown that it is possible to replace substantial quantities of cement with PFA (pulverised fuel ash) or GGBS (ground granulated blast furnace slag) without affecting structural performance. This can save around 40% of the embedded energy in concrete (Owens 2010), which would mean a reduction of 40 tonnes CO_2 from the concrete – equivalent to a 30% reduction in overall carbon footprint for such a bridge.

The potential for savings in a new build scenario can be demonstrated by reference to the Environment Product Declaration prepared for 190 km of a new single track railway with 90 bridges of a total length of 11 km and with 25 km of tunnels, Bothniabanan (2010). In a per km analysis, the bridges were calculated to emit 8 050 ton CO_2 equivalents and use 22 GWh (80 TJ) during construction and 60 years of maintenance. The energy use per km of tunnel was of the same magnitude but the emission was about half of that of the bridges. On a per bridge basis, this gives, on average, an emission of 1020 ton CO_2 equivalents and a use of energy of 2,65 GWh (9,5 TJ). So the savings in extending the life of existing structures instead of replacing them are large.

Impact on excellence of European research

Railway lines cross National borders in Europe so the infrastructure ought to be analysed in the same way on the different sides of these borders, particularly as the basic infrastructure types are similar. Hence it is advantageous to study them together as today most countries are too small to support this kind of endeavour in isolation.

By carrying out a project such as MAINLINE together it will be easier to implement its results in the different states of Europe. By co-operating on a European level it is also possible to share resources and reach a result in a shorter time, which is necessary in order to meet the demands on the railways, and at a significantly lower overall cost. Additionally, good practice can be promulgated more easily and effectively to achieve the best benefits from project outputs.

Research partners from all over Europe get increasingly more connected through different projects. Their special fields of expertise are well known and collaboration between Scandinavian and Iberian partners and/or UK institutes has been going on for some years. Working together, exchanging ideas and solutions to solve actual problems for end users is an effective way to exchange knowledge. As research has become an internationally competitive field, this joint project has helped European research in an international context. The universities and research institutes have benefited from direct contact with end users. Problems have been discussed and the importance attached by end users to economic issues has been better appreciated. Additionally, the growing importance of environmental impact has been considered jointly, thus promoting consensus and common understanding of future constraints.

The collaboration in this project has helped promote market ready solutions - this is a very effective way to sell European expertise, and researchers/practitioners have been able to establish contacts with European industries and end users outside their normal working locations. Language problems still exist for railway maintenance personnel, however, by increased collaboration this may be reduced and finally overcome with better educated younger personnel. Future contacts with experts from other countries will be facilitated and

collaboration will be enhanced, especially the contact between Eastern and Western European Universities will be facilitated.

Steps needed to bring about these impacts

Project results need to be implemented by the railway owners in their infrastructure management systems. Recently technical developments in earlier projects, such as Sustainable Bridges, INNOTRACK and Urban Track have been introduced successfully in many railways and the new ideas of life time extension and LCC developed by the MAINLINE project have been disseminated. However, more examples and tests are needed to show how life cycle methods and effective maintenance planning can work together. This will, in time, increase the understanding and popularity of these methods. As this is a novel way of planning and managing the maintenance of railway infrastructure no guidelines, rules or standards exist, hence railway administrations themselves might have difficulties in testing and adopting the methodology. However, MAINLINE has undertaken the basic research and development activities and produced guidelines for everyday use. In this way the end users can rely on the results and the acceptability of the methods will be higher. Acceptability will be enhanced if it can be shown that the savings that can be made by extending the lifetime of infrastructure components have no negative influence on the safety. The real life use of the MAINLINE LCAT by project partners, which is expected to take place in the near future, coupled with further research into degradation models and the subsequent development of LCATs for other asset types can effectively strengthen this position and the acceptability of the methods will be enhanced considerably.

A second step is the dissemination throughout the rail organizations of the methods developed in both this and earlier projects, and a third step is the full scale use of them. Examples need again to be presented in UIC workshops and at railway conferences. More data will then be available and the methods can be further refined. Looking at the spending on infrastructure in general, the LCC method will become more and more important for all parts of the society. The political discussion will help to involve infrastructure managers and economists to consider life time extensions.

European dimension

When MAINLINE started, FP7 was the most suitable programme to support an international research collaboration of public and private partners at the European level. It defined a framework for collaboration (contractual framework, role and responsibility of the partners, IPR rules, centrally defined financial regime, project review and reporting methodology, etc.) that facilitated the organisation of international RTD collaborations which would be difficult to set up outside of the European RTD Programmes. Moreover MAINLINE also benefited from the connections between researchers and industries that were made in earlier joint European research activities. Of particular importance to the MAINLINE project was co-operation with its sister FP7 project SMARTRAIL, where data and expertise was shared in a very constructive way.

The consortium consisted of railways partners from all over Europe. All of them have collaborations with neighbouring countries and a direct interest in good co-operation with them. In this way MAINLINE could benefit from many other European and nationally funded projects that all of them were involved in. Indeed, the MAINLINE consortium was carefully selected to include MAV (the Hungarian railway) and TCCD (the Turkish railway) as active members in this project. They have brought not only their own expertise but also a view from the eastern part of Europe and have been well placed to promote dissemination and exploitation of the MAINLINE results. For example, MAV have very good operational and research activities connected to the former Russian Federation and Eastern European areas. Their solutions and strategies are very interesting and valuable for new research activities in

the field of maintenance. On the one hand the project will benefit from this knowledge and on the other hand dissemination of project results will be very much easier having partners of known expertise to spread this information in existing working groups.

The MAINLINE partners has benefited from, and built upon, existing knowledge acquired in previous and on-going European, international and national projects. The liaison was ensured by the MAINLINE partners involved in these projects or having ongoing collaborations with the coordinators of these projects. This liaison avoided unnecessary duplication and ensured that MAINLINE was well placed to make use of any emerging results, so allowing MAINLINE to meet its objectives in the most efficient and effective way.

3.4.2 Dissemination activities and exploitation of results

Dissemination

The dissemination and communication about the project and its findings to the relevant target audiences is crucial for the success of the project. An information dissemination plan was set up at the start of the project, which detailed the project dissemination and communication activities, their objectives, targets, tools and associated budget. The objectives of the MAINLINE dissemination and communication activities have been to:

- implement the dissemination plan by ensuring effective communication at all levels and by providing appropriately targeted information to all identified audiences;
- ensure liaison with stakeholders;
- ensure visibility of the results obtained and make available information relevant for further application;
- exchange the knowledge with the scientific community in order to obtain new insights to be integrated into the project research;
- foster synergies and complementarities with other relevant EU, and national and international programmes and projects;
- ensure that rail sector stakeholders and the general public appreciate the added value of EU support and how it contributes to a cost effective, well maintained rail infrastructure.

More precisely, MAINLINE has held three workshops:

- Midterm workshop at UIC in Paris, 14-15 May 2013, to identify common fields of interest with the SMARTRAIL project, funded by FP7 under the same theme
- Workshop targeted to Central and Eastern Europe, Budapest, 15 May 2014, to disseminate knowledge and results to Central and Eastern Europe
- Final workshop at UIC in Paris, 30 September 2014, to present and distribute final project results: LCAT tools, guidelines and other reports

The project also undertook a two-step training programme on the use of the Life Cycle Assessment Tool (LCAT) to present and distribute the LCAT tools developed in MAINLINE, together with the user manual.

In addition, MAINLINE partners have made presentations in many national and international events. The most comprehensive presentation was a Mini Symposium held as part of the IABMAS (International Association for Bridge Management and Safety) 2014 Conference, held in Shanghai on 7-10 July 2014, where 8 papers were presented.

Finally, MAINLINE has produced many deliverables, most of which are public and available on the project website: <http://www.mainline-project.eu>. The consortium also published several press releases through UIC, all available on the public website as well. Some

partners have also published articles in national journals, notably in Sweden, Denmark and Hungary.

The results have been presented to established international working groups throughout the project. Future exploitation of the results is expected to continue after the project ends through the creation of new working groups supported by the relevant project partners, probably under the overall umbrella of UIC. By working with established UIC groups like TEG (Track Expert Group) and PoSE (Panel of Structural Experts), MAINLINE has also reached standardisation bodies.

In addition MAINLINE has worked together with the European sister project SMARTRAIL including arrangement of a common workshop, technical meetings and exchange of documents.

Exploitation

Project partners will ensure that MAINLINE continues to develop after project finalisation. Universities and research institutes will continue their research into key issues which have been identified as important for further investigation and have the potential for providing tools or methods to improve sustainability and cost effective solutions for railway infrastructure. Examples of issues relevant for further research are:

- Identification of track condition taking into account other maintenance activities
- Strengthening and assessment of bridges
- Deterioration of tunnels
- Strengthening of earthworks

UIC has and will spread the results among its members mainly through two expert groups namely Track Expert Group (TEG) and Panel of Structural Experts (PoSE). On several occasions, this has been carried out during the MAINLINE project. Also a working group has been proposed to continue the development of the LCAT under the UIC umbrella.

Railway infrastructure managers which have been part of the project will continue to exploit the outcome within their own organisation. MAV has translated selected deliverables into Hungarian in order to maximise the exploitation of the MAINLINE results. It is expected that the railway infrastructure managers will be able to include relevant parts of the guidelines into national good practise and that the Life Cycle Assessment Tool (LCAT) can be further developed and customised to fulfil the requirements of different infrastructure managers. It has been a key issue for the project that the tool has been developed in Excel and the programming is open for further customisation.

The industrial partners will continue to exploit the guidelines and the tools within their organisation and by including the results into their services. Thereby consultants and contractors can provide assistance to disseminate and exploit the results to railway infrastructure managers who have not participated in the project.

The life-cycle approach developed within the project and the principles of the LCAT will be used by Cerema (formerly SETRA) to the development of a new bridge management system (for road bridges) in France. Consequently the work performed within the railway infrastructure field will be extended to cover road infrastructure as well.

TWI is a research and technology organisation that has a membership base of more than 700 members across the globe and in a variety of industry sectors. Thus, it is in a position to disseminate and adapt the results from MAINLINE to a number of industrial situations. TWI identifies the combination of Life Cycle Costs (LCC) and Life Cycle Assessments (LCA) as a key area to develop expertise in. TWI has sponsored a research project in this area and is looking for other opportunities to build on the achievements of MAINLINE.

3.5 MAINLINE Partners and Contact

MAINLINE Coordinator

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MAINLINE Partners

1. Network Rail Infrastructure Limited (NR)
United Kingdom
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Contact: David Castlo
2. COWI A/S (COWI)
Denmark
www.cowi.dk
Contact: Jens Sandager Jensen
3. University of Surrey (Surrey)
United Kingdom
www.surrey.ac.uk
Contact: Marios Chryssanthopoulos
4. TWI Limited (WI)
United Kingdom
www.twi.co.uk
Contact: Ujjwal Bharadwaj
5. Universidade do Minho (UMinho)
Portugal
www.uminho.pt
Contact: Paulo Cruz
6. Luleå Tekniska Universitet (LTU)

Sweden

www.ltu.se

Contact: Lennart Elfgren

7. Deutsche Bahn AG (DB)

Germany

www.deutschebahn.com

Contact: Britta Schewe

8. MÁV Magyar Államvasutak Zrt. (MAV)

Hungary

www.mav.hu

Contact: László Daczi

9. Universitat Politècnica de Catalunya (UPC)

Spain

www.upc.edu

Contact: Joan Ramon Casas

10. Technische Universitaet Graz (TUGRAZ)

Austria

www.tugraz.at

Contact: Peter Veit

11. Türkiye Cumhuriyeti Devlet Demiryolları (TCDD)

Turkey

www.tcdd.gov.tr

Contact: Salih Akbaykal

12. Damill AB (DAMILL)

Sweden

www.damill.com

Contact: Dan Larsson

13. COMSA SAU (COMSA)

Spain

www.comsaemte.com

Contact: Carlos Saborido

14. TRAFIKVERKET (TrV)

Sweden

www.trafikverket.se

Contact: Anders Carolin

15. Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement (Cerema)
France
www.cerema.fr/
Contact: Christian Cremona

16. ARTTIC (ARTTIC)
France
www.arttic.eu/
Contact: Carlos Triay

17. SKANSKA AS (SKANSKA)
Czech Republic
www.skanska.cz/
Contact: Tomáš Krejčí

18. Sinclair Knight Merz Limited – Jacobs (SKM)
United Kingdom
<http://www.jacobs.com/>
Contact: Samuel Luke

4. Final report – Use and dissemination of foreground

4.1 Section A

4.1.1 List of Scientific Publications

Peer-reviewed publications

No	DOI - Permanent identifier (if available)	Title	Author(s)	Title of the periodical or the series	Volume/ Issue	Publisher	Place of publication	Date of publication	URL	Relevant pages	Open access is/will be provided to this publication
1	10.1016/j.compstruct.2013.10.004	Composite patch repair of steel plates with fatigue cracks growing in the thickness direction	E.S. Aggelopoulos , T.D. Righiniotis , M.K. Chryssanthopoulos	Composite Structures	Vol. 108	Elsevier BV	Netherlands	01/02/2014		729-735	No
2	http://dx.doi.org/10.1061/(ASCE)BE.1943-5592.0000527	Unbonded Transverse Posttensioning of a Railway Bridge in Haparanda, Sweden	Nilimaa, J., Blanksvärd, T., Täljsten, B. & Elfgren, L	Journal of Bridge Engineering	Vol. 19/Issue 3	American Society of Civil Engineers (ASCE)	USA	01/03/2014		4013001	No
3	10.1061/(ASCE)ST.1943-541X.0001116	Assessment of the Strengthening of an RC Railway Bridge with CFRP utilizing a Full-Scale Failure Test and Finite-Element Analysis	A Puurula, O Enoksson, G Sas, Th Blanksvärd, U Ohlsson, L Bernspang, B Taljsten, A Carolin, B Paulsson, L elfgren	Journal of Structural Engineering	N/A	American Society of Civil Engineers (ASCE)	USA	09/10/2014		D4014008	Yes
4	http://dx.doi.org/10.1080/157	Loading to failure and 3D nonlinear FE modelling of	Puurula, A., Enochsson, O., Sas, G., Blanksvärd,	Structure and	Vol. 10/Issue	Taylor and Francis	UK	02/12/2014		1606-1619	No

No	DOI - Permanent identifier (if available)	Title	Author(s)	Title of the periodical or the series	Volume/ Issue	Publisher	Place of publication	Date of publication	URL	Relevant pages	Open access is/will be provided to this publication
	32479.2013.836546	a strengthened RC bridge.	T., Ohlsson, U., Bernspång, L., Täljsten, B. & Elfgren, L	Infrastructure Engineering	12	Ltd.					
5	10.1080/15732479.2013.879319	Bridge condition modelling and prediction using dynamic Bayesian belief networks	M. Imran Rafiq , Marios K. Chryssanthopoulos , Saenthan Sathananthan	Structure and Infrastructure Engineering	Vol. 11/Issue 1	Taylor and Francis Ltd.	UK	02/01/2015		38-50	No

Paper in proceedings of a conference/workshop

No	Title	Author(s)	Proceedings	Date of publication	Start Date of Conference/ Workshop	End Date of Conference/ Workshop	Publisher	Publisher location	ISBN	URL	Relevant pages	Open access is/will be provided to this publication
1	Evaluating Environmental Impacts of an Old Metallic Railway Bridge using LCA	H.Y. Lee, B. Imam, J. Sadhukhan and M.K. Chryssanthopoulos	2nd Int. Conf. on Railway Technology: Research, Development and Maintenance	11/04/2014	08/04/2014	11/04/2014	Civil-Comp Press	Stirlingshire, Scotland.	978-1-905088-59-1	http://www.civil-comp.com/pubs/catalog.htm?t=description&f=rw2014	Paper 286	No

No	Title	Author(s)	Proceedings	Date of publication	Start Date of Conference/ Workshop	End Date of Conference/ Workshop	Publisher	Publisher location	ISBN	URL	Relevant pages	Open access is/will be provided to this publication
2	MAINLINE - MAINTenance, renewal and Improvement of rail transport iNfrastructure to reduce Economic and environmental impacts	J.S. Jensen, M. Sloth, P. Linneberg, B. Paulsson, L. Elfgren	Seventh International Conference of Bridge Maintenance, Safety and Management	09/07/2014	07/07/2014	11/07/2014	CRC Press / Balkema	London	978-1-138-00103-9		8	No
3	Extending the life of elderly rail bridges by strengthening	J. Nilimaa, T. Blanksvärd, B. Täljsten, L. Elfgren, A. Carolin, B. Paulsson	Seventh International Conference of Bridge Maintenance, Safety and Management	09/07/2014	07/07/2014	11/07/2014	CRC Press / Balkema	London	978-1-138-00103-9		7	No
4	Influence of advanced assessment methods on the LCA of elderly bridges	M. Soriano, J.R. Casas	Seventh International Conference of Bridge Maintenance, Safety and Management	09/07/2014	07/07/2014	11/07/2014	CRC Press / Balkema	London	978-1-138-00103-9		8	No

No	Title	Author(s)	Proceedings	Date of publication	Start Date of Conference/ Workshop	End Date of Conference/ Workshop	Publisher	Publisher location	ISBN	URL	Relevant pages	Open access is/will be provided to this publication
5	Performance profiles of ageing steel railway bridges affected by atmospheric corrosion	A.N. Kallias, M.K. Chryssanthopoulos	Seventh International Conference of Bridge Maintenance, Safety and Management	09/07/2014	07/07/2014	11/07/2014	CRC Press / Balkema	London	978-1-138-00103-9		8	No
6	Life-Cycle Assessment Tool for railway infrastructure	D. Castlo, P. Linneberg, R. Puddicombe	Seventh International Conference of Bridge Maintenance, Safety and Management	09/07/2014	07/07/2014	11/07/2014	CRC Press / Balkema	London	978-1-138-00103-9		5	No
7	Lifetime analysis of infrastructures	P. Cruz, H. Gervásio, L. Simões da Silva	Seventh International Conference of Bridge Maintenance, Safety and Management	09/07/2014	07/07/2014	11/07/2014	CRC Press / Balkema	London	978-1-138-00103-9		7	No
8	Challenges within Life Cycle Cost (LCC) studies and Life Cycle Assessment (LCA)	P. Linneberg, A.O.S. Solgaard, K. Eriksen, J.S. Jensen	Seventh International Conference of Bridge Maintenance, Safety and Management	09/07/2014	07/07/2014	11/07/2014	CRC Press / Balkema	London	978-1-138-00103-9		8	No

No	Title	Author(s)	Proceedings	Date of publication	Start Date of Conference/ Workshop	End Date of Conference/ Workshop	Publisher	Publisher location	ISBN	URL	Relevant pages	Open access is/will be provided to this publication
9	Test to failure of a steel truss bridge – Calibration of assessment methods	T. Blanksvard, J. Häggström, J. Nilimaa, N. Sabourova, N. Grip, B. Täljsten, L. Elfgren, A. Carolin, B. Paulsson, Y. Tu	Seventh International Conference of Bridge Maintenance, Safety and Management	09/07/2014	07/07/2014	11/07/2014	CRC Press / Balkema	London	978-1-138-00103-9		6	No
10	The future of ageing metallic bridges	Chryssanthopoulos MK, Imam B.	Seventh International Conference of Bridge Maintenance, Safety and Management	09/07/2014	07/07/2014	11/07/2014	CRC Press / Balkema	London	978-1-138-00103-9			No
11	Assessment and full scale failure test of a steel truss bridge	Häggström, J., Blanksvärd, T., Collin, P.&Täljsten, B	IABSE 37th symposium Madrid 2014 : Engineering for progress, nature and people	30/07/2014	02/09/2014	05/09/2014	IABSE, Proc Vol 102	Zürich				No
12	Maintenance and Renewal of Concrete Railway Bridges. Results from EC Project Mainline	J Nilimaa, J Häggström, N Bagge, Th Blanksvärd, G Sas, U Ohlsson, L Bernspång, B Täljsten, L	Nordic Concrete Research Meeting	10/08/2014	13/08/2014	15/08/2014	Nordic Concrete Federation	Oslo, Norway	978-82-8208-043-9		25-28	No

No	Title	Author(s)	Proceedings	Date of publication	Start Date of Conference/ Workshop	End Date of Conference/ Workshop	Publisher	Publisher location	ISBN	URL	Relevant pages	Open access is/will be provided to this publication
		Elfgren, A Carolin, B Paulsson										
13	Life-cycle management of bridges based on robustness to deterioration	Joan R. Casas	AUSTROADS Bridge Conference	24/10/2014	22/10/2014	24/10/2014	AARB	Sydney, Australia				
14	A Combined Economic and Environmental Performance Framework for Railway Infrastructure Maintenance	H Y Lee, B Imam, M K Chryssanthopoulos, R J Murphy	2014 IET Asset Management Conference	27/11/2014	27/11/2014	28/11/2014	not known					
15	MAINLINE - MAINTenance, renewaL and Improvement of rail transport iNfrastructure to reduce Economic and environmental impacts	Linneberg et al.	FIB 2015	18/05/2015	18/05/2015	20/05/2015	not known					

Article/section in an edited book or book series

Title	Author(s)	Title of the book (series)	Volume	Date of publication	Publisher	Publisher location	URL	Relevant pages	Open access is/will be provided to this publication
Presentation of MAINLINE project in Hungarian	László Daczi, MAV	World of Rails	3/2014	18/06/2014	Preflex 2008 Ltd.	Budapest	http://www.sinkevilaga.hu/	25-35	yes

Thesis/Dissertation

No	Title	Author(s)	Date of approval	Institution name	Institution location	ISBN	URL	Open access is/will be provided to this publication
1	Advanced assessment methods for elderly bridges. State-of-the-art and justification based on LCA	Miriam Soriano	03/04/2013	Polytechnic University of Catalonia	Barcelona, Spain			yes
2	Design of One Span Concrete Railway Bridges: Design According to the Eurocodes and the Spanish National Annex, M.Sc. Thesis, Civil Engineering	Aida Garcia Rodriguez	28/02/2014	Luleå University of Technology	Luleå, Sweden		http://pure.ltu.se/portal/files/100183314/LTU-EX-2014-97091701.pdf	yes
3	Design of Reinforced Concrete Railway Bridges with Spans from 3 to 9 meters: Design According to the Eurocodes and the Swedish National Annex, M.Sc. Thesis, Civil Engineering	Adolfo Martinez Diaz	31/03/2014	Luleå University of Technology	Luleå, Sweden		http://pure.ltu.se/portal/files/98351504/LTU-EX-2014-97016471.pdf	yes

4	Life Cycle Cost Analysis for Railway Bridges: A Case Study of the Rautasjokk Bridge, M.Sc. Thesis, Civil Engineering	Javier Maroto Carreño	13/04/2014	Luleå University of Technology	Luleå, Sweden		http://pure.ltu.se/portal/files/100191772/LTU-EX-2014-100131258.pdf	yes
5	Transition Zones for Railway Bridges: A Study of the Sikån Bridge, M.Sc. Thesis, Civil Engineering	Andrea Fara	15/09/2014	Luleå University of Technology	Luleå, Sweden		http://pure.ltu.se/portal/files/98663247/LTU-EX-2014-98579460.pdf	yes

4.1.2 List of Dissemination activities

Period 1

Activity no.	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
1	oral presentation to a scientific event	NR	Presentation about MAINLINE to SMARTRAIL inaugural meeting	14/10/2011	Dublin, Ireland	Industry/research	39	Europe
2	oral presentation to a scientific event	UIC	MAINLINE presentation for UIC Rail System Forum Plenary Session	27/10/2011	Paris, France	Industry	60	International
3	oral presentation to a scientific event	UIC	MAINLINE presentation at the UIC Expertise Development Platform	17/11/2011	PKP HQ Warsaw, Poland	Industry	25	European and Asian countries
4	oral presentation to a scientific event	UIC	MAINLINE presentation at the Transport Research Arena (TRA) 2012, joint session with SMART Rail	24/04/2012	Athens, Greece	Scientific community - Industry	35	10-12 European countries
5	oral presentation to a scientific event	LTU	fib 2012 Symposium, Stockholm: Concrete Structures for a Sustainable Community – presentation about Strengthening, Prestressed bridges, Arch bridges, and Fastening technology introducing MAINLINE	11/06/2012	Stockholm, SE	Scientific community - Industry	200	EU and North America
6	articles published in the popular press	LTU	“Transversal post tensioning of RC trough bridges: laboratory tests”, article published by Jonny Nilimaa, Thomas Blanksvård, Lennart Elfgren, Björn Täljsten in Nordic Concrete Research	01/11/2012	Oslo, Norway	Industry/Research		EU Nordic countries

Activity no.	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
7	oral presentation to a scientific event	TWI	Participation in Railway Research UK Association Conference, representing MAINLINE	07/11/2012	London, UK	Scientific community	150	UK based
8	oral presentation to a scientific event	SKM	CIRIA Conference – Developments in modelling deterioration and degradation of civil assets - Joint presentation on the MAINLINE Project by SKM, NR and Surrey	13/12/2012	London, UK	Scientific community - Industry	30	UK
9	press releases	UIC	First MAINLINE press release sent to UIC members and published on UIC website in English, French and German	03/01/2013	email/UIC website	Scientific community – Industry – Policy makers		International
10	oral presentation to a scientific event	LTU	MAINLINE presentation on a meeting with CIR (CIB-IABSE-RILEM Swedish Group)	29/01/2013	Göteborg, Sweden	Scientific community - Industry	40	Sweden
11	oral presentation to a scientific event	UIC	Reporting to the two UIC-groups PoSE (Panel of Structural Experts) and TEG (Track Expert Group)	30/01/2013	Paris, FR	Industry	60	International
12	flyers	UIC	MAINLINE brochure available	04/02/2013	Paris, FR	Scientific community – Industry – Policy makers		International
13	oral presentation to a scientific event	SKM	Bridges Asia 2013 Conference – Presentation on Cost Effective Asset Management and Life Extension of Bridges – Introducing MAINLINE Project by Sam Luke	25/02/2013	Hong Kong	Industry	50	International
14	articles published in the popular	COWI	In Danish "EU støtter optimal drift og vedligehold af infrastruktur", In English "EU supports optimal operation and	01/03/2013	Denmark	Industry – Policy makers		Denmark

Activity no.	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
	press		maintenance of infrastructure"					
15	exhibitions	TCDD	Euroasia Fair - On TCDD stand there was a representative part for UIC and the project was presented	09/03/2013	Istanbul, Turkey	Scientific community – Industry – Civil society – Medias		International
16	oral presentation to a scientific event	DB	Workshop Civil Engineering I.NVT 42 Presentation of the project MAINLINE to DB railway engineers	14/03/2013	Fulda, Germany	Scientific community	25	Germany
17	articles published in the popular press	TRV	Test to failure of railway bridge (In Swedish), Ny Teknik, Norrländska socialdemokraten, Norrbottens-Kuriren, Piteå-Tidningen	14/03/2013	Luleå, Sweden	Industry – Policy makers	232000	Sweden
18	oral presentation to a scientific event	LTU	MAINLINE Presentation at 5th Future Infrastructure Forum	27/03/2013	Cambridge, UK	Scientific community – Industry	40	UK

Period 2

Activity no.	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
19	web sites/applications	MÁV	Intranet for MAINLINE at MÁV Headquarters	04/04/2013	Budapest, HU	Scientific community		Hungary
20	oral presentation to a scientific event	SKM	Railway Solutions Asia 2013 Conference – Presentation on LCC/LCA models related to MAINLINE; Presentation on Development of Cost and	18/04/2013	Kuala Lumpur	Industry	50	International

Activity no.	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
			Environmental Life Cycle Models for Rail Assets					
21	oral presentation to a scientific event	LTU	Extended Life of Railway Bridges. Results from EC-FP7-project MAINLINE. IABSE Conference	07/05/2013	Rotterdam, Netherlands	Scientific community – Industry	50	International
22	posters	UIC	First roll-up banner produced to be used in MAINLINE events	13/05/2013	Paris, FR	Scientific community – Industry		International
23	organisation of workshops	UIC	Common workshop with sister project SMARTRAIL	14/05/2013	Paris, France	Scientific community – Industry	60	Europe
24	oral presentation to a scientific event	SKM	Roads Australia Summit 2013 - Key note speaker on innovation in asset management, life extension and MAINLINE LCC/LCA	29/05/2013	Sydney, Australia	Industry	300	International
25	oral presentation to a scientific event	UIC	FEHRL Infrastructure Research Meeting - two presentations of MAINLINE	06/06/2013	Brussels, Belgium	Scientific community – Industry	50	International
26	oral presentation to a scientific event	SKM	Railway Engineering 2013 Conference - 3 papers presented	10/07/2013	London, UK	Scientific community – Industry	100	International
27	media briefings	TRV	Test to failure of railway bridge (In Swedish)	12/09/2013	Luleå, Sweden	Medias	50	Sweden
28	oral presentation to a scientific event	LTU	Finding the Hidden Capacity of Railway Bridges. Technical Seminar	13/09/2013	Cambridge, UK	Scientific community – Industry	40	International
29	web sites/applications	LTU	Test to failure of a Railway Bridge. http://www.ltu.se/org/sbn/Nyheter-och-aktuellt/Alla-nyheter-2013/Brottbelastning-av-	13/09/2013	Luleå, Sweden	Scientific community – Industry – Civil society – Policy makers – Medias		Sweden + International

Activity no.	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
			jarnvagsbro-1.109046?l=en					
30	organisation of workshops	TWI	Railway Asset Management Seminar hosted by TWI - Presentation of the MAINLINE Project (Bjorn Paulsson)	20/09/2013	Abington, UK	Scientific community – Industry – Policy makers	45	EU Countries
31	Presentations	TWI	European Transport Conference - presentation linked to WP4 in MAINLINE	30/09/2013	Frankfurt, Germany	Scientific community – Industry	400	European level
32	articles published in the popular press	LTU	Bron som inte ville ge upp (The bridge which did not want to give up. In Swedish) Tåg, No 10, p 20-23	01/10/2013	Editors in Stockholm Sweden	Scientific community – Industry – Civil society – Policy makers – Medias	7000 (circulation)	Sweden
33	web sites/applications	UIC	Newsletter about current project progress on MAINLINE website	01/10/2013	http://www.mainline-project.eu/	Scientific community – Industry – Civil society – Policy makers – Medias		International
34	oral presentation to a scientific event	TrV	Days of structures conference - focus on WP1 and WP3 of MAINLINE	22/10/2013	Sigtuna, Sweden	Policy malers	70	Sweden
35	oral presentation to a scientific event	TWI	R4i Research for Impact (Making Public Funding Work) - presentation of MAINLINE via poster (Polyvios Polyviou)	31/10/2013	Abington, UK	Scientific community – Industry – Policy makers – Medias	150	UK
36	articles published in the popular press	LTU	Tested to destruction. Railway Gazette International, p 47, Nov 2013	01/11/2013	Editors in Sutton, UK	Scientific community – Industry – Civil society – Policy makers – Medias	10200 (circulation)	International
37	oral presentation to a scientific	TUGR AZ	LCAT, A standardised, Europe-wide available Life Cycle Assessment	12/11/2013	Frankfurt, Germany	Scientific community – Industry	70	International

Activity no.	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
	event		Tool at LCM 2013					
38	oral presentation to a scientific event	COWI	Presentation of MAINLINE for the Trafikverket, Malmö Municipality og Copenhagen Malmö Port (CMP)	19/11/2013	Malmö, Sweden	Industry – Policy makers	30	Sweden
39	oral presentation to a scientific event	SKM	AusRail Conference 2013 - Presentation on asset management, life extension and MAINLINE LCC/LCA models	27/11/2013	Sydney, Australia	Industry	200	International
40	oral presentation to a scientific event	COWI	Presentation of MAINLINE for the Danish Road Directorate	29/11/2013	Copenhagen, Denmark	Industry – Policy makers	11	Denmark
41	interviews	UIC	Björn Paulsson was interviewed about MAINLINE by Angel Aparicio, a Professor from UPM (Madrid University)	10/12/2013	telephone	Scientific community	1	Spain
42	oral presentation to a scientific event	LTU	Finding the Hidden Capacity of Railway Bridges. Technical Seminar for Railway Infrastructure Managers	14/12/2013	Luleå, Sweden	Scientific community – Industry	15	Sweden
43	flyers	UIC	Production of MAINLINE flyer to promote 2014 events - first version	13/01/2014	Paris, France	Scientific community – Industry – Policy makers		International
44	press releases	TWI	TWI's corporate website - link to MAINLINE's website and forthcoming events	21/01/2014	http://www.twi-global.com/	Scientific community – Industry – Civil society – Policy makers – Medias	111000	International
45	oral presentation to a scientific event	UIC	Presentation of MAINLINE during the PoSE/TEG meeting at UIC with NR and DB	29/01/2014	Paris, France	Scientific community	40	Europe

Activity no.	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
46	oral presentation to a scientific event	SKAN SKA	Oral promoting of MAINLINE grant on grant called "Centre for effective and sustainable transport infrastructure"	13/02/2014	Brno, Czech Republic	Scientific community – Industry – Policy makers	25	Czech Republic
47	oral presentation to a scientific event	COWI	Presentation of MAINLINE for Rail Net Denmark	11/03/2014	Copenhagen, Denmark	Industry – Policy makers	1	Denmark
48	flyers	UIC	Production of MAINLINE flyer to promote 2014 events - second version	20/03/2014	Paris, France	Scientific community – Industry – Policy makers		International
49	press releases	UIC	Second MAINLINE press release sent to UIC members and published on UIC website in English, French and German	24/03/2014	Paris, France	Scientific community – Industry – Policy makers		International
50	oral presentation to a scientific event	Surrey	Presentation at the 2nd International Conference on Railway Technology	11/04/2014	Ajaccio, France	Scientific community – Industry	50	International
51	oral presentation to a scientific event	NR	TRA 2014 - Life Cycle Assessment Tool (LCAT) for railway infrastructure	17/04/2014	Paris, France	Scientific community – Industry	15	International
52	posters	UIC	Second roll-up banner produced to be used in MAINLINE events	28/04/2014	Paris, France	Scientific community – Industry – Policy makers		International
53	organisation of workshops	UIC	Workshop targeted to Central and Eastern Europe	15/05/2014	Budapest, Hungary	Scientific community – Industry – Medias	50	Europe
54	posters	UIC	Third roll-up banner produced to be used in MAINLINE training sessions	27/05/2014	Paris, France	Scientific community – Industry		International
55	organisation of	SKM	Training session on the use of the	11/06/2014	London, UK	Scientific community	25	International

Activity no.	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
	workshops		Life Cycle Assessment Tools - step 1			– Industry		
56	oral presentation to a scientific event	UIC	Presentation of MAINLINE at yearly meeting of Track experts inside TrV	23/06/2014	Borlänge, Sweden	Scientific community	30	Sweden
57	oral presentation to a scientific event	COWI	MAINLINE Mini Symposium at IABMAS 2014 conference with 8 presentations	09/07/2014	Shanghai, China	Scientific community – Industry – Policy makers	40+	International
58	press releases	UIC	Article in UIC news about MAINLINE Mini Symposium at IABMAS 2014 Conference	15/07/2014	Paris, France	Scientific community – Policy makers		International
59	press releases	UIC	Third MAINLINE press release sent to UIC members and published on UIC website in English, French and German	25/07/2014	Paris, France	Scientific community – Industry – Policy makers		International
60	oral presentation to a scientific event	LTU	Maintenance and Renewal of Concrete Railway Bridges – Results from EC Project MAINLINE.Nordic Concrete Meeting	13/08/2014	Reykjavik, Iceland	Scientific community – Industry – Civil society – Policy makers – Medias	70	International
61	oral presentation to a scientific event	COWI	Presentation of MAINLINE for the Great Belt Bridge Management	28/08/2014	Korsør, Denmark	Industry – Policy makers	6	Denmark
62	press releases	TWI	Information about MAINLINE Final Workshop	29/08/2014	http://www.iow.org/	Industry – Policy makers – Medias	500+	International
63	articles published in the popular press	LTU	Paper submitted in Structural Health Monitoring: Investigation of changes in modal characteristics before and after damage of a	31/08/2014	SAGE Publications Ltd	Scientific community		International

Activ ity no.	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
			railway bridge: A case study					
64	press releases	UIC	Fourth MAINLINE press release sent to UIC members and published on UIC website in English, French and German	11/09/2014	Paris, France	Scientific community – Industry – Policy makers		International
65	organisation of workshops	UIC	Training session on the use of the Life Cycle Assessment Tools - step 2	11/09/2014	Paris, France	Scientific community – Industry	25	International
66	flyers	UIC	MAINLINE Final book: Projects results - a summary	29/09/2014	Paris, France	Scientific community – Industry – Policy makers – Medias	500	International
67	press releases	UIC	Fifth MAINLINE press release sent to UIC members and published on UIC website in English, French and German	30/09/2014	Paris, France	Scientific community – Industry – Policy makers		International
68	organisation of workshops	UIC	MAINLINE Final Workshop with presentation and distribution of project results	30/09/2014	Paris, France	Scientific community – Industry – Policy makers – Medias	50	International
69	web sites/applications	UIC	Newsletter about final results on MAINLINE website	01/10/2014	http://www.mainline-project.eu/	Scientific community – Industry – Civil society – Policy makers – Medias		International
70	oral presentation to a scientific event	UIC	TEG meeting in Delft to ensure takeover of the work on LCA tools after the end of MAINLINE	06/10/2014	Delft, The Netherlands	Scientific community	25	European level
71	oral presentation to a scientific event	UPC	Life-cycle management of bridges based on robustness to deterioration	23/10/2014	Sydney, Australia	Scientific community – Industry	100	International

Activity no.	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
72	oral presentation to a scientific event	Surrey	Presentation at the IET Asset Management Conference	27/11/2014	London, UK	Scientific community – Industry – Policy makers	80	International

4.2 Section B

4.2.1 List of applications for patents, trademarks, registered designs, etc.

There have been no applications for patents, trademarks or registered designs.

4.2.2 List of exploitable foreground

Type of Exploitation Foreground	Description of exploitation foreground	Confidential	Exploitation products or measures	Sector of application	Timetable for commercial use or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary (s) involved
General advancement of knowledge	MAINLINE public reports, including guidelines and tools	No	Dissemination meetings with key Infrastructure Managers, at conferences and during everyday consultancy services. Results available on the public website.	F42.1 - Construction of roads and railways	2014 and beyond	None	All MAINLINE partners
Commercial exploitation of R&D results	MAINLINE Life Cycle Assessment Tools (LCATs)	No	Dissemination meetings with key Infrastructure Managers	F42.1 - Construction of roads and railways	2014 and beyond	None	All MAINLINE partners, especially consultancy companies such as COWI and Jacobs/SKM

Type of Exploitation Foreground	Description of exploitation foreground	Confidential	Exploitation products or measures	Sector of application	Timetable for commercial use or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary (s) involved
Exploitation of R&D results via standards	MAINLINE guidelines	No	Introduce conclusions and results when contributing to national codes and standards.	F42.1 - Construction of roads and railways	2014 and beyond	None	All MAINLINE partners, especially consultancy companies and Infrastructure Managers
General advancement of knowledge	LCAT methodology/tools	No	Introduce LCAT in education material at universities	P85.4 - Higher education	from 2014/15 academic year	None	All MAINLINE partners, especially universities
General advancement of knowledge	Benchmarking of degradation profiles	No	Degradation profiles	F42.1.2 - Construction of railways and underground railways	2015-2019	None	Network Rail and other Infrastructure Managers

MAINLINE public reports, including guidelines and tools

The intention of the MAINLINE project was that the core part of the results is public, this is why the most important deliverables, as well as the tools developed as main result, are freely accessible on MAINLINE public website. MAINLINE reports will be useful especially for Infrastructure Managers (IMs), but also to researchers, professors and students in universities in the years to come as they provide thorough analyses of methods and tools of infrastructure management and life cycle assessment (LCA). The guidelines provide a reference framework for decisions of IMs and the tools a basis for calculations and LCA, which can be used by IMs directly or further developed by consulting companies. The expected impact would be that IMs tend to use this kind of tools and approach more and more often.

MAINLINE Life Cycle Assessment Tools (LCATs)

It is expected that the presentation of the LCAT to Infrastructure Managers will make way for the use of the tool in the industry. COWI and Jacobs/SKM will be able to help IMs to tailor the tool to the actual business especially considering bridges, tunnels and cuttings. In this way the IMs can benefit from more cost-optimal management of railway or road infrastructure – including considerations of environmental impact.

Concerning COWI, the presentations can e.g. take place at annual meetings with COWI's customers and other infrastructure meetings like Danish Bridge Day or Danish Repair Day. The presenters will be key staff from COWI who have participated in MAINLINE.

Jacobs/SKM will use the outputs from MAINLINE to assist asset owners to further develop and update their current models.

MAINLINE guidelines

UIC will contribute to make sure that project results become part of best practise within European and international codes, standards and guidelines in the next years. In Denmark, COWI is active in the preparation of national codes and standards. In this context they will benefit from new best practice presented in the MAINLINE guidelines. COWI will when relevant include the MAINLINE work in e.g. national annexes to Eurocodes or other infrastructure standards. The contributors from COWI will be key staff who have participated in MAINLINE. In this way all the progress within maintenance, renewal and improvement provided by the guidelines will be implemented in Danish codes and best practice.

LCAT methodology/tools

The results will be used in the education and training of students in basic and advanced courses, as well as in workshops and seminars, starting from the current academic year. For Surrey for example, relevant project outcomes will be fed into teaching programmes, in particular its Master's courses. The LCAT tools developed for Bridges and Cuttings will be used by post-graduate students attending the MSc programmes in Bridge or Civil Engineering, and in the newly launched programmes on Infrastructure Engineering and Management.

Benchmarking of degradation profiles

Infrastructure Managers use modelling to show the future condition/risk profile of their assets which typically forms part of the funding requests from central government. The degradation profiles generated by MAINLINE will provide a benchmark against rates already used by the Infrastructure Managers, helping to validate assumptions made in their funding requests in the years to come. The degradation profiles could also be used by other parties who are creating their own life-cycle models.

The MAINLINE degradation profiles provide a good base, but further research/updates will allow them to be continuously refined and possibly to include further material types.