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## INNOTRACK

Integrated Project (IP)

Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

### D 6.1.2 Models and Tools

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| PP  | Restricted to other programme participants (including the Commission Services)        |   |
| RE  | Restricted to a group specified by the consortium (including the Commission Services) |   |
| CO  | Confidential, only for members of the consortium (including the Commission Services)  |   |

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## Glossary

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|            |   |
|------------|---|
| CBS        | Cost Brake down Structure                             |
| D-LCC      | LCC tool used by DB                                   |
| IM         | Infrastructure manager                                |
| LCC        | Life Cycle Cost                                       |
| LCM        | Life Cycle Management (LCC tool used by ProRail)      |
| LRU        | Line Replaceable Unit                                 |
| LSC        | Life Support Cost                                     |
| OLAP       | On Line Analytical Processing                         |
| Optimizer+ | Simulation tool used by ProRail                       |
| PriFo      | LCC tool developed by JBV                             |
| RailSys    | Simulation tool used by DB                            |
| RAMS       | Reliability, Availability, Maintainability and Safety |
| RBD        | Reliability Block Diagram                             |
| Ril 413    | Track standard used by DB                             |
| SRM        | Safety Risk Model                                     |
| SRU        | Shop Replaceable Unit                                 |
| TRAIL      | Simulation tool used by NR                            |
| T-SPA      | Track Strategic Planning Application by NR            |
| UNILIFE    | LCC tool developed by UNIFE                           |
| UNIDATA    | LCC tool developed by UNIFE                           |

# 1. Executive Summary

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INNOTRACK addresses mainly the objective of reducing Life Cycle Costs (LCC), while improving the RAMS characteristics of a conventional line with a mixed traffic duty. In the field of railways, RAMS technology and LCC are widely implemented and will provide a definite advantage to the IM:s (Infrastructure Manager) in helping calculate costs for the implementation of innovative technologies. In the frame of INNOTRACK these methods will be defined at a European level and used to identify cost drivers and assess the track components. The sub-project SP6 deals with RAMS and LCC.

Banverket had the responsibility to conduct a survey on various models and tools used by different IMs and related industries as a part of the work of WP1 within SP6. The input from IMs and related industries is not sufficient to draw a fully comprehensive picture of RAMS and LCC to be reported. Based on the limited information following conclusions can be drawn.

## Conclusions:

- RAMS programmes and analysis are in a very initial stage within IMs and the manufacturers.
- Data quality and data availability are the major problems in meeting RAMS and LCC targets.
- TRAIL, RailSys, Optimizer+ are some of the tools used by IMs for availability simulation.
- Manufactures and contractors depend on the information provided by IMs to carry out their RAMS and LCC analysis.
- LCM, D-LCC, T-SPA are the LCC tools used by IMs as per the survey. These tools in general used for enhancement projects not explicitly for LCC calculation for the whole track system.
- Catloc, UNILIFE/UNIDATA, PriFo are some of the additional tools found out during the survey which can be used for benchmarking.
- Safety Risk Model (SRM) is a tool which models a wide range of safety hazards in railway systems.
- Major benefits of RAMS and LCC analysis are found out to be optimising maintenance strategy and taking decision on maintenance/renewal with the regulators.

## Areas of improvement:

- Environmental costs needs to be considered while modelling LCC.
- Risk analysis has to be considered in LCC calculation.
- Spare part planning needs to be done as per availability targets.
- IMs have to clearly define RAMS and LCC specifications in the contracts with manufacturers and contractors; this will be done in workpackage 6.4 (RAMS and LCC in contracts/wordings/policies).
- IMs should define achievable RAMS targets and lay out a procedure to attain those targets.
- Unforeseen costs like reduction of passengers, loss of good will due to train delays should be modelled.

## 2. Introduction

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The Project INNOTRACK aims to develop a cost-effective high performance track infrastructure for heavy rail systems. INNOTRACK addresses mainly the objective of reducing Life Cycle Costs (LCC) while improving the RAMS characteristics of a conventional line with a mixed traffic duty.

INNOTRACK project brings IM (infrastructure managers) and railway supply industry together, to investigate and evaluate leading edge track system technologies, adopting a controlled methodology to assess life cycle cost benefits of “track-technology solutions” and of a set of emerging railway hardware solutions. It will also support the overall sustainability of the railway sector, meeting needs such as the increase of track availability and network capacity. The results of this project will build on a standardised LCC formulation developed within the project, based on best LCC practices at EU level and independently assessed.

Optimisation of track constructions or track components regarding technical and economic requirements is essential for railway companies to fit the market and to compete against other means of transport. Due to the long lifetime of the track and track components – ranging between 20 to 60 years – pre installation technical and economic assessments are necessary to optimize the track construction and get the return on investment (ROI) in a manageable timeframe. LCC and RAMS technology are two acknowledged methods for assisting the optimisation process.

The RAMS characteristics determine essential parameters of the system such as the usability and acceptability of the system, the operation and maintenance costs, and the users’ safety and health risk when operating the system. The RAMS technology is a recognised management and engineering discipline to guarantee the specific functionality of a product over its complete life cycle. RAMS technology helps to keep the operation, maintenance and disposal costs on a predefined acceptable level by establishing the relevant performance characteristics at the beginning of the procurement cycle and by monitoring and controlling their implementation throughout all project phases.

LCC is an appropriate method to identify cost drivers and to gather the costs of a system, module or component over its whole lifetime including development, investment maintenance and recycling costs. Different views and evaluations allow the comparison of different systems and deliver necessary information for technical and economic decision.

In the field of railways, RAMS technology and LCC are widely implemented and will provide a definite advantage to the IMs in helping calculate costs for the implementation of innovative technologies.

In the frame of INNOTRACK these methods will be defined at a European level and used to identify cost drivers and assess the track components. The project is divided in 7 Sub-projects:

1. Duty
2. Track support structure
3. Switches and crossings
4. Rails
5. Logserv
6. LCC
7. Dissemination and Training

This report is included in Sub-project 6 LCC and covers an estimated state-of-the-art of LCC and RAMS knowledge and use among INNOTRACK partners as well as information about existing models and tools.

## 3. Main section

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### 3.1 Objective

The objectives are:

- To do market analysis of models and tools.
- To analyse of possibilities for adoption of methods and results from other systems.
- To do an inquiry of models and tools for RAMS and LCC.
- To check the portability of methods and results from other systems.

#### 3.1.1 Activities

- Questionnaire II was sent to Innotrack participants. It was based on the responses from questionnaire I.
- Each participant did their own survey in their country in order to find models and tools in use by other industries.
- Study of models found in similar projects.
- Personal interviews on existing models and tools.

#### 3.1.2 Time schedule

The time to furnish the report (D6.1.2) was 6 months from the start of the project. The status of the report will be “public”.

#### 3.1.3 Risk

The following risks concerning the objective to provide a clear picture of the current status of RAMS and LCC within railways and related industries were identified:

- Insufficiency of data collected.
- Inadequate involvements of Infrastructure managers and suppliers.
- Unawareness respectively inconsistency of different RAMS and LCC terms.
- No common understanding of LCC.
- No common and consistent definitions concerning investment, operation, maintenance and renewal.

## 3.2 Organisation and resources

Organisation and resources for this work package are given in Table 1. Banverket is responsible for delivery of WP 6.1 which includes D6.1.1 and D6.1.2.

Another partner in the working group is ProRail.

Table 1: Organisation and resources.

| Workpackage                   | 6.1 - State of the art |     |    |      | Start date or starting event: |     |     | T0 |
|-------------------------------|------------------------|-----|----|------|-------------------------------|-----|-----|----|
| Participant id                | UIC                    | VAS | BV | ADIF | Alstom                        | NR  | OBB |    |
| Person-months per participant | 2                      | 1   | 1  | 1    | 0.5                           | 0.5 | 1   |    |
| Participant id                | RFF                    | DB  |    |      |                               |     |     |    |
| Person-months per participant | 1                      | 1   |    |      |                               |     |     |    |

### 3.3 Information acquisition

Information on RAMS and LCC was obtained from the following sources:

- Questionnaires were sent to the participants in INNOTRACK to get more detailed information about RAMS and LCC standards, models and tools in use.
- Discussions and telephone conversations with IMs and suppliers.
- Discussions and telephone conversations with non-rail industries. A questionnaire was sent to different industries in Sweden.
- Published papers.
- Internet research.

The questionnaire-I was sent to 24 of the participants. Questionnaire –II was sent to those who answered the 1<sup>st</sup> questionnaire. Till now seven responses have been received. The primary source of data was from the questionnaire II, shown in Annex 1.

### 3.4 Collated information

#### 3.4.1 LCC and RAMS

Figure 1 shows the interaction between RAMS and LCC related to this project. Understanding the failure modes is the starting point of any RAMS calculation. These failure modes will be understood by obtaining the degradation models of substructure, rails and switches from SP2 –SP4. Boundary conditions such as vehicle conditions, track conditions, load, environment etc, play a major role in determining the degradation curves as shown in the figure 1. Once failure modes are understood, for each failure mode reliability and maintainability activities are carried out e.g, determining failure rates, maintenance actions and periodicity etc. Then these values are entered into the LCC model to obtain the costs. Subsequently costs are optimised by trading-off between costs, availability and safety for different alternatives. Availability and safety are calculated by integrating reliability and maintainability parameters. Once LCC are optimised, a maintenance strategy can be derived.

Availability target is an input but must also be an output value needed to be measured in order to validate the LCC Value and Exchange year.

## Understandings for LCC-model

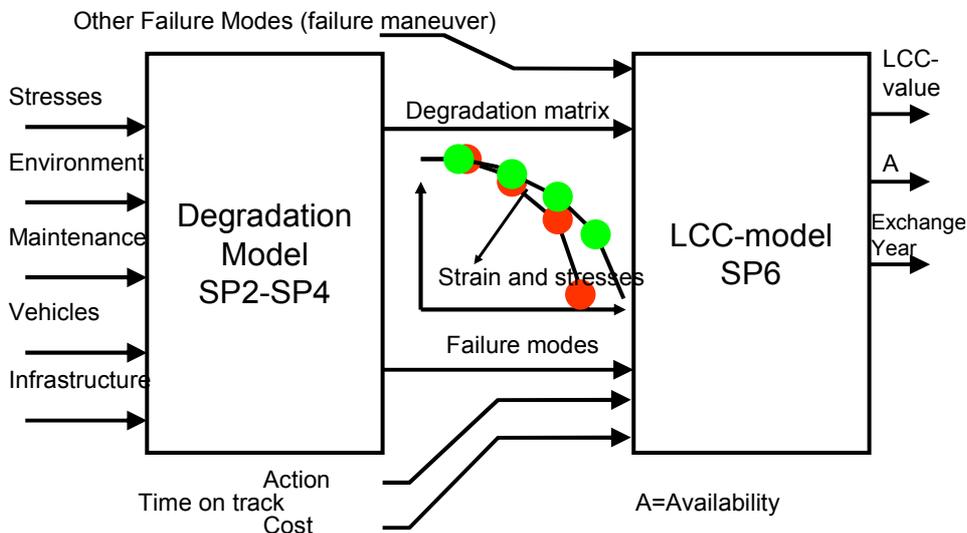


Figure 1: Understanding for LCC-Model

### 3.4.1.1 RAMS

RAMS is a characteristic of a system's long term operation and is achieved by the application of established engineering concepts, methods, tools and techniques throughout the lifecycle of the system.

EN 50126 defines basic RAMS elements as:

**Reliability:** defined as probability that an item can perform a required function under given conditions for a given time interval ( $t_1, t_2$ ).

**Availability:** defined as ability of a product to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval assuming that the required external resources are provided.

**Maintainability:** defined as probability that a given active maintenance action, for an item under given conditions of use can be carried out within a stated time interval when the maintenance is performed under stated conditions and using stated procedures and resources.

**Safety:** defined as the state of technical system freedom from unacceptable risk of harm

RAMS is the basis for building up a maintenance strategy to keep up the required function during an object's total life time. It also describes how dependable an object is, taking into consideration its operating environment and usage profile.

### 3.4.1.2 LCC

The concept of LCC is a decision support tool which calculates the costs during the entire life cycle of a product or system. It is usually divided into 4 phases, as shown in Figure 2:

1. Research and Development,
2. Investment,
3. Operation and Maintenance and
4. System Phase-Out.

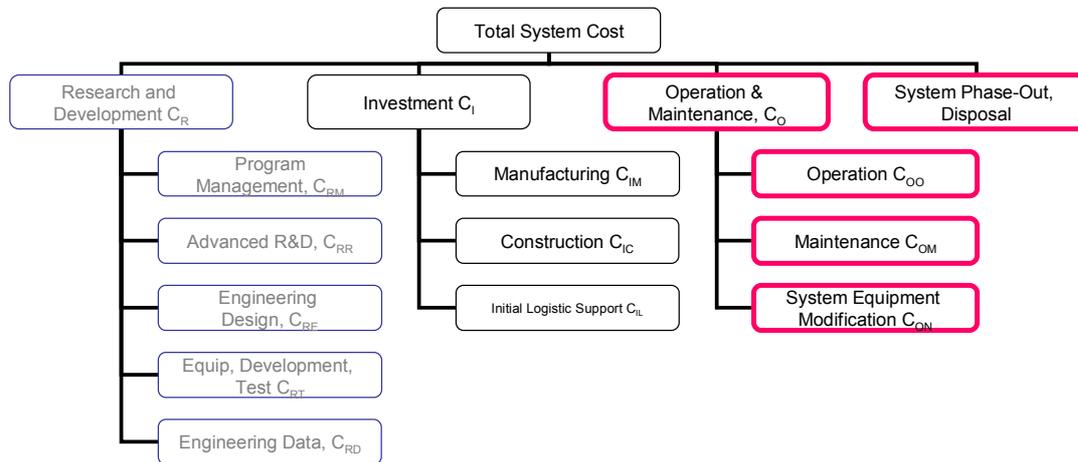


Figure 2: The different Phases for a system.

The use of the Life Cycle Cost model is to optimise the costs during an asset lifetime. The process includes 6 steps [1]:

1. Definition of System Requirements
  - LCC analysis needs to be based on:
    - a definition of system operational requirements, maintenance concept, and
    - a program plan and profile illustration major life-cycle activities and the projected operational horizon for the system.
  - Requirements should be addressed in terms of function to be performed, quantities required and geographical distribution, reliability factors, maintenance and support concept.
2. Cost Breakdown Structure (Cost Categories):
  - Product break down structure.
  - A cost break down structure , showing all the phases during the assets lifetime:
    - Research and development.
    - Investment (manufacturing, construction and initial logistic support)
    - Operation and maintenance.
    - Disposal, system phase – out.
  - Cost categories must be well defined, all must have the same understanding of what is included, cost doubling must be eliminated.
  - The cost structure and categories should be coded in such manner as to allow analysis of certain specific areas of interest (e.g. system operation, energy consumption, equipment design, spares, and maintenance personnel and support).
  - The cost structure should be compatible with the program work break down and with the management accounting records.
  - Where subcontracting is prevalent, it is often desirable and necessary to separate supplier cost (bid-cost etc) from the product cost.
3. Cost Estimating:
  - Known factors or rates, estimating relationships, expert opinion.

- Discounting, relates to the time value of money, and all the future cost must be adjusted to the net present value (NPV).
  - Inflation.
4. Build a cost model that is adapted to the situation.
  5. Cost profile, presenting the results in a graphical manner.
  6. Evaluation of alternatives.

The main cost elements in a LCC-model are presented in table 2. They can be detailed further.

Table 2: Main cost elements in LCC calculations

| Research & Development phase (R&D)  | Investment phase  | Operation and Maintenance Phase (O&M)   | System phase out and disposal cost  |
|---|---|---|---|
| Program management cost<br><br>Advanced R&D cost<br>Engineering design cost<br>Equipment development and test cost<br><br>Engineering data cost | System/equipment manufacturing cost<br>- inspection and test cost<br>System construction cost:<br>- construction material cost<br>Initial logistic support cost:<br><br>- training and equipment cost | Cost of system/equipment life-cycle operations<br>- operation personnel cost<br>- operators training cost<br>- operation facility cost<br>- support and handling equipment cost<br>Cost of system/equipment life-cycle maintenance<br>Maintenance personnel and support cost:<br>- corrective maintenance cost<br>- preventive maintenance cost<br>Cost of spare/repair parts<br>Test and support equipment maintenance cost<br>Transportation and handling cost<br>Maintenance facilities cost<br>Technical data cost<br>Cost of system/equipment modification | Cost of system/equipment phase-out and disposal<br>Disposal cost<br>Cleaning cost<br>System residual value<br>Regeneration/recycling cost |

### 3.4.2 Results from Questionnaire II

The questionnaire II was sent to those participants who had answered the questionnaire I (see Table 3).

Table 3: Participants and answering rate

|                        | IM   | Manufacturer | Contractor | Total |
|------------------------|------|--------------|------------|-------|
| Questionnaire sent     | 6    | 4            | 1          | 11    |
| Questionnaire received | 4    | 2            | 1          | 7     |
| Answering rate         | 66 % | 50 %         | 100 %      | 63 %  |

It is pointed out that the manufacturers and the contractors only answered the questions that were specific to their products not to the whole track system. It is not possible for them to have operation data or a full database of the infrastructure.

The summary of the answers is given below (for question numbers see Annex 1):

Part I: General understanding about RAMS and LCC

- 1-2. There is no clear RAMS program plan existing. RAMS is still in a very early stage of implementation. The guidelines for RAMS are based on CENELEC standard EN 50126 and other standards like CP-DDE-134, DIN 40041. Participants use different developed or standard templates.
3. Availability in percentage, repair time, numbers of failures, delay on track works on suppliers etc are some of the few parameters that are introduced in the contracts by IMs. Manufacturers use the information specified to them by the customers.
4. Traffic volume, axle load, type of rail etc are some of the factors that have major affect on RAMS and LCC values. Track condition and maintenance history are not considered.
5. RAMS analysis is not carried out in all the life cycle phases. It is mostly done in the investment phase and operation and maintenance phase.
6. There are very few specific databases existing for RAMS. Participants use SAP (Systemanalyse und Programmentwicklung), SQL, Oracle or self developed dataset in MS Excel and Access to store RAMS data.
7. There is no clear validation method existing for validating RAMS and LCC calculations, It is still very novice in nature. However, it is being done by taking small samples, simulation, experience etc.
8. Participants named a few benefits that they have experienced from RAMS and LCC analysis but the major ones are optimising maintenance strategy and taking decision on maintenance/renewal with the regulators and funding bodies. It also helps in pointing out the consequences of none funding for maintenance and renewal.
9. Service life time is calculated from a technical perspective and it is mostly done on historical analysis by experts' estimation.
- 10-11 IMs use a constant discounting rate for their life cycle period. However manufacturers and contractors use the discounting rate mentioned by IMs. This applies similarly for inflation rate
- 12-13. Costs due to downtime, unavailability, traffic disruption, penalties etc in some cases are calculated by simulation tools such as TRAIL and RailSys. These tools take care of different probabilistic methods. Manufacturers are not able to calculate this because of lack of information and contractors depend on data from IMs.
14. Environmental costs are not explicitly considered in the LCC calculation except cost for noise barrier or pads. ÖBB considers these costs only in the big investment projects.
15. Tamping, rail grinding, ballast cleaning, renewal etc are some of the maintenance actions that are cost drivers in the LCC calculation but the most common cost driver according to the participants is tamping. IM, manufacturers and contractors all identify tamping and grinding as cost drivers.

16. RAMS analysis conducted by experts' estimation is by:
  - Historical analysis of past faults.
  - Meetings, questionnaires etc.
  - Track tests.
17. Risk analysis is not considered widely in modelling LCC. However, it is captured through the predictions of future track conditions particularly broken rails that lead to derailments.
18. There is no clear procedure to get RAMS and LCC data in case of maintenance being outsourced. Some railways are using a shared information system with the contractors, some collect data by expert estimation.
19. LCC is used as management scenario for alternative investment scenarios/maintenance strategies and new contracts.
20. Data quality and data availability are the major problems faced in order to meet RAMS and LCC targets. Some other problems are linking between inputs and outputs to RAMS and LCC, long life span of the system, lack of financial means for renewal/maintenance etc. Manufactures and contractors should need feedback from IMs.
21. Description of self-developed RAMS/LCC software is given in chapter 3.4.3 and 3.4.4.
22. Improvement of the system or development of system (for example higher steel grades, systems with longer inspection and maintenance intervals), regular observations of track (seeing the trends in the condition) as well as diminishing the number of switches installed etc are the major actions taken by the participants to improve RAMS characteristics and reduce LCC of their systems.

## Part II: RAMS

- 1-2. No clear indication of methods to calculate reliability parameters. Mostly it is estimated and derived from historical data. In some cases reliability function is developed but the failure distribution is still unknown for the track components.
- 3-4. There is no reliability block diagram existing for the track. Though IMs fix reliability target for the track, there is no clear and common method of how this is executed. OBB i.e. fix reliability targets on number of speed restrictions.
5. Broken rails, track buckles, track twist, broken fishplates, switches especially frogs and tongues etc are the most failed components of the track. (Sleepers not mentioned, pads in rail fastenings are mention by ÖBB)
6. IMs categorise failures due to their effect on the systems. NR has developed a risk scoring matrix for this purpose. The categories are aligned to company objectives such as safety, train performance, cost, asset stewardship, business performance, customers and stakeholders.
7. Failure effects on environment are not modelled.
8. Quality of initial installation, maintenance actions and strategy, loads, wheel-rail-interaction, sub grade, radius etc are few boundary conditions that affect reliability the most.

- 9-10. There is no clear method of fixing availability targets. In one case availability targets are based on train delay minutes, in another case on the number of planned and unplanned activities. Some participants consider the number of speed restrictions as availability target.
11. No spare part planning is done based on availability targets.
12. Estimation of train delays is simulated based on number of speed restrictions, allowed time for repair and individual component reliability data.
13. Sub grade, radius and traffic volume are mentioned as boundary condition that affect availability most.
- 14-16. Maintainability distribution is still unknown to the participants. There is no clear method of fixing maintainability targets. But there are general targets for the whole track system i.e. quality index.
17. Periodicity of preventive maintenance actions are calculated due to engineering judgement, experience, RCM analysis, deterioration rates derived from regular track recordings and inspection etc
18. Sub grade, radius, traffic volume and deterioration rates derived from regular track recording and inspection are mentioned as boundary condition that affect maintainability the most.
- 19-20. NR uses a Safety Risk Model (SRM) based on fault trees and event trees to model a wide range of safety hazards in railway. In addition a Precursor Indicator Model (PIM) which is linked to the SRM has been established to monitor the trend in precursor events e.g. broken rails and how this trend translates into the risk profile of serious train accidents. It also uses a Hazard Reporting Index to log hazards.

### Part III: LCC

1. Parameters used for LCC calculation are lifetime, cumulative and annual tonnage, track/technology description type, costs for renewal, maintenance and operational difficulties/ hindrance.
- 2-3. Track renewal cost is the major cost driver as per the participants. Track possession time optimisation, six sigma on maintenance activities, contracting strategy (reducing number of renewal contractors) are some of the actions taken to reduce track renewal cost. There are also some actions like high initial quality of track, rehabilitation of sub-standard formation, extension of life span also considered to be major cost drivers.
4. Most costs are on an aggregated level, i.e. not broken down to labour cost or maintenance vehicle costs.

### Part IV: Specific questions

- 1-6. For answers, see chapter 3.4.3-3.4.4
7. Manufacturers and contractors need information from IMs on how the track is used i.e. traffic volume and traffic type, data on the substructure and the curvature and maintenance actions and failure statistics.

8. IMs need information about new systems costs, reliability, and maintainability.

### 3.4.3 LCC models/tools used by Infra Managers

#### **T-SPA (Network Rail).** [2], [3] [4], [7] [8] [23]

T-SPA is Network Rail's Track Strategic Planning Application. It is a decision support tool designed to provide an analysis of a broad range of renewal and maintenance options, linking in particular the volumes and cost of the work to the condition and ultimately the performance of the railway infrastructure. The primary objective of T-SPA is to support the development of robust long term plans, the quality of which is critical to the future funding of the infrastructure maintenance and renewal. The requirements on a decision support tool to support robust long-term plans for the rail network are demanding, including a need to:

- Enable the user to specify a comprehensive range of scenarios constructed around future train service patterns, varying maintenance regimes and renewal options.
- Incorporate relationships that provide quantification of for example: when assets have reached the end of their service life; how the condition of the assets changes during their time in service; and how the degradation impacts on the performance of the network.
- Draw from detailed and, in some cases, disparate data sources - including asset age and type, historical and forecast traffic, and current asset condition - to enable the model relationships to predict with an appropriate degree of accuracy.
- Allow analyses to be performed at different levels of detail ranging from single routes or sections of routes through to the whole railway infrastructure comprising almost 20,000 track miles.
- Perform calculations sufficiently quickly to provide a practical what-if capability, implying computational times in the order of a few minutes for a route to a few hours maximum for the whole network.

#### **D-LCC (Deutsche Bahn)** [6], [5]

D-LCC provides bottom-up cost estimating, supports the detailed examination of costs and parameters affecting LCC and performs Net Present Cost analysis incorporating the time scale (life cycle phases).

D-LCC analyse the following:

- Evaluation and comparison of alternative design approaches
- Comparison of alternative strategies
- Identification of cost effective improvements
- Project's budget and economic viability assessment
- Long term financial planning

D-LCC allows the user to apply pre-defined LCC models as well as to create new cost breakdown structure (CBS) and models. An existing CBS can be easily tailored to meet all needs of any particular project. Product tree cost calculation option allows for incorporating the product. D- LCC supports detailed examination of dynamics of future cash flows over multiple time periods.

The main analyses available in D-LCC are:

- Total and detailed costs.
- Cost profile.

- Cost profile by elements.
- Cost effectiveness.
- Basic CBS tree.
- Optimal repair level analysis (calculate the cost and effectiveness of various level of repair alternatives per product tree item, thus supporting optimal decision making).
- Versatile user definable graphs and tables.

More information can be obtained from [www.ald.co.il/download/dload.html](http://www.ald.co.il/download/dload.html)

### **LCM (ProRail) [10], [11], [12] [13], [13], [24]**

Life Cycle management (LCM) is ProRail's LCC calculation tool. The tool helps in finding out the cost effectiveness maintenance action out of different alternatives. LCM calculations include the following steps:

- Define the project, time frame, boundaries, delimitations etc
- Define different alternatives. Information on different alternatives are gathered by experts groups doing the brain storming
- Description of the project
- Different maintenance activities, costs, failure rates etc are entered into the tool. The tool does not provide a scope of calculating failure rate from the failure data. It is calculated manually and entered into the tool
- The tool provides total costs for different alternatives broken down to different cost categories and finds out the most cost effective alternative
- The tool also represents the costs graphically. A sensitivity analysis can be carried out
- Lastly, description of why the alternative is chosen is entered into the tool

### **LCC methodologies (OBB) [20], [21], [22]**

Principles:

- Comparison of incremental change to previous state
- LCC Calculation is based on various standard infrastructure and operational conditions existing on ÖBB "Standard" kilometre with various parameters such as
  - track design (rail type, welded/joints, sleepers: concrete or wood, type of fastening)
  - alignment (curve, radii, grade)
  - load of track (cross tons per day, one way or both way of operation)
- Basic data are derived as a combination of working cycle cost (from renewal, tamping, rail grinding, rail replacement until next complete track renewal)
- The working cycles are specified by experts working groups and verified with data from entire network.
- Calculation of work performed in each working cycle gives the cost stream for each action.
- Different cost streams of alternative courses of action are the input of cost optimization studies.

- If the lifespan of the different solutions varies, the residual value of the solution with the longer lifetime is considered in the evaluation
- Using methods with internal rate of return with various solutions makes the methods independent of rate of inflation and interests.
- The methods are extending to switches and crossings and bridges.

Results:

- Depreciation is the most important cost factor of the annual costs (~50%-67%). Depreciation can be reduced by extension of life cycles. An optimal maintenance strategy is achieved, if the lifespan is maximised.
- On heavily used lines, the costs of operational difficulties are very high (up to 33% of annual costs). Thus a good initial quality which allows less maintenance work (i.e., longer intervals between tamping, etc.) is essential.

### 3.4.4 RAMS and Maintenance models/tools used by Infra Managers

#### **TRAIL (Network Rail) [9]**

TRAIL is a discrete event simulation model to estimate availability based on individual component reliability data. Some of the important features of TRAIL are given below

- TRAIL's level of granularity is user definable and can be down to the level of individual track circuits or other assets. This allows the reliability of each track circuit to be incorporated into the overall model by incorporating the MTBF, MTTR and performance degradation effects, thereby modelling the entire failure profile.
- When a failure is generated, train services that enter the faulty section between the failure time and the end of the repair are subjected to the effects characterised by the failure modes. The delays are applied to each train delayed and the sum of the delay is attributed to the faulty section for the final statistics.
- TRAIL has the ability to model a number of failure rate distributions using standard functions such as Weibull. This allows failure rates to be entered as a function of time or usage.
- The final aspect of availability is analysis of down time or performance loss. TRAIL analyses the performance loss in two elements. The first element is the performance loss that occurs between the start of the failure and the commencement of the repair. The second element is total performance loss of an asset that occurs during the repair.
- The ideal way in which TRAIL could move to an optimal solution would be to stipulate a target performance, e.g. to achieve less than 100,000 minutes, and list either asset categories or individual assets that make the largest contribution to delay and what changes in reliability would be required. The result would likely be some form of Pareto relationship ordered by assets requiring the most amount of upgrade.

### **RailSys (Deutsche Bahn)**

RailSys is a simulation tool used to calculate delay time of the traffic for both planned and unplanned situations. The traffic is described based on DB standard (upper limit, average and lower limit). The simulation with RailSys results in calculating delay time per train, which is multiplied by delay cost per minute. Finally, the costs for non-availability are calculated on the possession time according to the track standard (Ril 413).

Some features of RailSys are given below:

- Integrated concept
- Microscopic mapping of the infrastructure
- Modular design of the simulation area
- Simulation of new technologies of train protection on systems
- Conflict recognition by means of occupation time steps
- Timetable construction and planning for new or existing lines, nodes and networks
- Elaboration of complete operation programs in consideration of marginal conditions
- Dimensioning and assessment of the infrastructure
- Simulation of non-disrupted and disrupted operation to judge the timetable stability/quality

More information can be obtained from [www.ive.uni-hannover.de/software/index\\_de.shtml](http://www.ive.uni-hannover.de/software/index_de.shtml)

### **Optimizer+ (ProRail)**

Optimizer+ is a simulation tool which determines the relationship between maintenance costs and performance - in terms of availability, reliability and safety. Following steps are taken to achieve the objectives:

- Collecting information on objects and building library database – Information like failure mode, failure cause, failure condition, MTTF, MTTR etc are gathered for each component and introduced to the library database
- Building systems - Systems can be modelled in Optimizer+ using the building blocks. For each system, a risk analysis is carried out, in which the specific failure behaviour is described at the component level. Within the model, all possible risks with regard to the company goals are mapped out. The goal of the model is to make the risks posed to the company goals by component failure more transparent, so that maintenance can be modified accordingly.
- Formulating risk analysis – For several building blocks, carrying out a thorough risk analysis make it possible to formulate a concrete relationship between failure behaviour, its effect on company goals and the frequency with which this effect repeats itself. This determines the risk (probability multiplied by effect). The company goals with regard to costs, availability and safety form the point of departure for the risk analysis.
- Anchoring maintenance plans – On the basis of the results of the risk analysis, the existing maintenance plan is modified for several building blocks. With the help of Optimizer+, preventive maintenance actions are determined for the critical components as well as the frequency with which they are to be carried out.
- Simulation and optimization – With the help of the simulation module within Optimizer+, the quantitative relationship is determined between failure behaviour on the one hand and availability, reliability and maintenance costs on the other. Based on the risk analysis, several simulation models are created and calculated.

### **MathOffice (Deutsche Bahn)**

MathOffice is versatile and not industry-specific software for the solution of mathematical/statistical tasks with the emphasis on reliability and maintenance. It supports analyses in the field of RAMS and LCC Engineering (Reliability, Availability, Maintainability, Safety and Life Cycle Costs).

MathOffice provides a complete array of data analysis, plotting and reporting tools for standard life data analysis. The software performs life data analyses utilizing multiple lifetime distributions. Additionally, it supports forecasting and optimising of reliability, availability and maintenance actions.

MathOffice allows

- Life span analyses
- Spare parts and capacity planning
- Cost forecasting and improvement

MathOffice includes advanced features, like data filtering for ultimate user control of data views. OLAP (On Line Analytical Processing) allows users to quickly navigate and explore their information, analysing data across multiple dimensions like products, time periods, failure causes and other classifications.

MathOffice has

- Flexible interfaces
- Data base management system with open format
- Report and diagram system with open configuration
- Data Warehouse technologies and parameter directory

Import and Export features enable to transfer Project input data to and results from MathOffice in a variety of popular formats, including Microsoft Excel and Microsoft Access. Reporting capabilities include easy-to-use Graph and Report Wizards for complete user customisation of output graphs and reports.

MathOffice supports

- Assessment of technology
- Implementation of individual process analyses and concepts
- Independent comparison of options
- Flexible simulation and optimizing tools
- Advisory service

Benefits of MathOffice use cover

- Increased process transparency
- Reduction of decision uncertainties and risks
- Foreseeable cost trends
- Reduction of complaints and reworking measures
- Improved quality

### 3.4.5 Some additional LCC models/tools

#### **CATLOC (Systecon AB, Sweden) [13]**

CATLOC is a general use LCC tool, not specific to railway application. It has been developed by Systecon AB, Sweden. Some features of the tool are described as:

- User defined LCC models
- Ease and flexibility to produce different cost breakdown structures. The cost breakdown need not follow a predefined tree structure
- Flexible graphical result views to improve analysis and interpretation of results
- Powerful support of data defaults to gradually improve model accuracy rather than enforcing detailed parameter values up-front
- Management and comparison of several datasets in parallel
- Efficient and flexible import and export of data
- Sensitivity analysis

**PriFo (JBV, Norway) [18], [19]**

The Norwegian Railway Administration (JBV) has developed a LCC model for prioritisation of maintenance and renewal projects. The following dimensions are included in the LCC model:

- Safety costs
- Punctuality costs
- Maintenance and operational costs
- Cost due to increased residual life length
- Project costs

Inputs to the model are:

- Qualitative information – information from measurements and analysis of track quality, trends etc
- Safety related information – information on states and values related to various RIF (Risk Influencing Factors)
- Punctuality information – information on the ordinary speed of the line and any speed reductions due to the degradations the project is intended to fight against
- Maintenance and operating costs – costs of extra runs of the measurement car, extra line inspections etc
- Residual life length
- Project costs
- Cost parameters

More on this tool can be found out from [www.promain.org/images/publications/Innovations-LCC.pdf](http://www.promain.org/images/publications/Innovations-LCC.pdf)

**UNILIFE & UNIDATA (UNIFE, Belgium) [14], [15], [16], [17]**

UNILIFE and UNIDATA are the LCC tools used for rolling stock application. UNILIFE is used for sub-system LCC data transfer where as UNIDATA is used for component LCC data transfer. UNIDATA is a subset of UNILIFE.

UNILIFE/UNIDATA handles LRUs and SRUs taking into account their corrective and preventive maintenance. Failures are split into train failure categories. The impact on LCC or LSC can be evaluated by the introduction or removal of redundancy, improvements to equipment reliability or changes to the maintenance requirements. These are simple calculation tools and can be downloaded from [www.unife.org/docs/lcc/Unidata.xls](http://www.unife.org/docs/lcc/Unidata.xls) and [www.unife.org/docs/lcc/Unilife.xls](http://www.unife.org/docs/lcc/Unilife.xls)

## 4. Conclusions

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Seven questionnaires have been received, out of 11 sent out. These 11 participants are those who answered the questionnaire I. The input from the IMs and related industries are not sufficient to enable a fully comprehensive picture of RAMS and LCC to be reported.

Based on this limited information, the following conclusions can be drawn. The survey does not claim to be exhaustive because of not many responses from the IMs and suppliers contacted.

The conclusion can be drawn as given below

- RAMS programme and analysis are in a very initial stage within IMs and the manufacturers.
- Data quality and data availability are the major problems in meeting RAMS and LCC targets.
- TRAIL, RailSys, Optimizer+ are some of the tools used by IMs for availability simulation.
- Manufactures and contractors depend on the information from IMs to carry out their RAMS and LCC analysis.
- LCM, D-LCC, T-SPA are the LCC tools used by IMs as per the survey. These tools are in general used for enhancement projects not explicitly for LCC calculation for the whole track system.
- Catloc, UNILIFE/UNIDATA, PriFo are some of the additional tools found out during the survey which can be used for benchmarking.
- Safety Risk Model (SRM) is a tool to model a wide range of safety hazards in railway.
- Environmental cost are not considered while modelling LCC
- Risk analysis is not considered widely in LCC calculation.
- Spare part planning is not being done as per availability targets.
- Major benefits of RAMS and LCC analysis are found out to be optimising maintenance strategy and taking decision on maintenance/renewal with the regulators.

### Areas of improvement:

- Environmental costs needs to be considered while modelling LCC.
- Risk analysis has to be considered in LCC calculation.
- Spare part planning needs to be done as per availability targets.
- IMs have to clearly define RAMS and LCC specifications in the contracts with manufacturers and contractors; this will be done in workpackage 6.4 (RAMS and LCC in contracts/wordings/policies).
- IMs should define achievable RAMS targets and lay out a procedure to attain those targets.
- Unforeseen costs like reduction of passengers, loss of good will due to train delays should be modelled.

The following information will be useful for WP 6.2 and WP 6.3 which was covered in WP 6.1:

- RAMS parameters that are used for LCC analysis.
- Different maintenance activities that are considered in LCC.
- Functionality of different existing LCC and RAMS models and their usefulness.
- Existing methods for RAMS calculations.
- Different costs that are considered in LCC analysis and the costs that are not considered.
- Existing RAMS database and how data is collected and managed.
- There is need to develop common understanding for maintenance, renewal, modification, upgrading etc prior to LCC calculation.

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[19] Vatn, Jørn (2007), PriFo (Confidential)

[20] Veit Peter (2002), Track Maintenance based on life –cycle cost calculations, *Journal of Innovations for a cost effective Railway Track*, November 2002, pp 6-13. <http://promain.sever.de>

[21] ÖBB (2007), Methodologies of ÖBB (Draft)

[22] **Interviews** 2007-02-07, Vienna, with Nicole Kumpfmüller, DB, Wilhelm Saliger, ÖBB, Florian Auer, ÖBB, Thomas Philipp ÖBB, Michael Wogowitsch ÖBB

[23] 2007-02-14 Video Meeting, Andy Kirwan, Network Rail

[24] 2007-02-27 Telecom meeting Ted Luiten ProRail

#### Links

[www.ald.co.il/download/dload.html](http://www.ald.co.il/download/dload.html)

[www.ive.uni-hannover.de/software/index\\_de.shtml](http://www.ive.uni-hannover.de/software/index_de.shtml)

[www.promain.org/images/publications/Innovations-LCC.pdf](http://www.promain.org/images/publications/Innovations-LCC.pdf)

[www.unife.org/docs/lcc/Unidata.xls](http://www.unife.org/docs/lcc/Unidata.xls)

[www.unife.org/docs/lcc/Unilife.xls](http://www.unife.org/docs/lcc/Unilife.xls)

## 6. Annexes

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1. Questionnaire-II
2. Participants to whom questionnaire was sent

## Annex 1

# Questionnaire – II

## INNOTRACK SP6 WP1 State of the art (RAMS & LCC)

Questionnaire-II has been prepared as a follow up to survey conducted by questionnaire I. The scope of this questionnaire is to find out what are the models and tools followed by different IMs and Manufacturers for their RAMS and LCC analysis.

This Questionnaire is divided into 4 parts. 1<sup>st</sup> part deals with the general understanding on RAMS and LCC in your organisation. 2<sup>nd</sup> and 3<sup>rd</sup> parts deal with more specific to RAMS and LCC respectively while the 4<sup>th</sup> part deals with specific questions to different participants.

### ***Index***

|                   |  |
|-------------------|--|
| <i>PART – I</i>   | <i>General understanding on RAMS and LCC</i> |
| <i>PART – II</i>  | <i>RAMS</i>                                  |
| <i>PART – III</i> | <i>LCC</i>                                   |
| <i>PART - IV</i>  | <i>Specific Questions to Participants</i>    |

### Participants in this questionnaire:

| <b>Group</b> | <b>Participant</b> | <b>Contact Person</b>   |
|--------------|--------------------|-------------------------|
| IM           | ADIF               | Antonio Nunez del Moral |
| IM           | BV                 | Lars Schyllander        |
| Man          | Corus              | Simon Thomas            |
| IM           | DB                 | Mirjana Jovanovic       |
| IM           | OBB                | Wilhelm Saliger         |
| IM           | Prorail            | Ted Luiten              |
| IM           | NR                 | Andy Kirwan             |
| Man          | VAE                | Peter Eichberger        |
| Man          | VAS                | Norbert Frank           |
| Man          | UNIFE (Bombardier) | Ulf Kjellsson           |
| Con          | Speno              | Wolfgang Schoech        |

IM – Infrastructure Manager

Man – Manufacturer

Con – Contractor

## Part I - General Understandings on RAMS and LCC

- 1) Do you have RAMS program plan? How different RAMS activities are managed?
- 2) How do the guidelines for RAMS and LCC look like? Please provide an example.
- 3) What RAMS and LCC parameters do you introduce in the contract?
- 4) Which factors (mentioned in Part I, Questionnaire I) have major effects on RAMS and LCC values from your experience? How these factors are measured (i.e., in what units)?
- 5) What are the system life cycle phases where you carry out RAMS tasks as per EN 50126?
- 6) Please provide an example of your RAMS database. (i.e., how is data stored? What data do you consider? etc)
- 7) How do you validate your RAMS and LCC calculations?
- 8) What are the major benefits that you have experienced from your RAMS and LCC analysis in the past?
- 9) How do you calculate service life time of your system? How do you calculate from technical or economical point of view? Please explain.
- 10) How do you calculate discounting rate?
- 11) How do you calculate inflation rate?
- 12) How do you calculate cost due to down time, unavailability, traffic disruption, penalty etc in the LCC model?
- 13) What probabilistic methods do you consider for the above?
- 14) How do you consider environmental cost (noise, etc) in the LCC model?

- 15) Which maintenance actions (mentioned in part C, Questionnaire I) are the major cost drivers in the LCC calculation?
- 16) How is RAMS analysis done by expert estimation? Please explain.
- 17) How is risk analysis considered while modelling LCC?
- 18) When you outsource maintenance, how do you get the data for RAMS and LCC analysis?
- 19) How do you use LCC to obtain management indicators/ to have feedback for technical improvement/ to evaluate maintenance strategies or to evaluate investment alternatives?
- 20) What are the major problems do you face in meeting RAMS and LCC targets?
- 21) Please provide a description of your self-developed RAMS/ LCC software (what are the functions in the software, what are the inputs/ outputs of the software etc).
- 22) What actions are you taking to improve RAMS characteristics and reduce LCC for your system?

## Part II – RAMS

### Reliability

- 1) How do you calculate reliability parameters (for example MTBF)? Please explain the method. (*MTBF is the most used reliability parameter as per survey by Questionnaire I*)
- 2) What kind of distribution (exponential, weibull etc) does it follow mostly as the system level as well as at the component level?
- 3) How do you fix reliability target for the track?
- 4) Please give an example of reliability block diagram of track system.
- 5) Which are the most failed components in the track? Please provide their failure rates from your experience.

- 6) Provide an example of failure categorisation (significant, major, minor and negligible) of the system in terms of their effect on the system.
- 7) What are the failure effects on environment (noise, vibration etc) that you consider?
- 8) What are the boundary conditions that affect the reliability of components/ system most from your experience? and how?

## Availability

- 9) How do you calculate availability parameters? Please explain the method. (*Inherent Availability is the most used availability parameter as per survey by Questionnaire I*)
- 10) How do you fix availability target for the track?
- 11) How do you do spare parts planning according to the availability target?
- 12) How do you estimate train delay caused by infrastructure? How do you estimate reliability and maintainability targets from this availability parameter (I.e., train delay)?
- 13) What are the boundary conditions that affect the availability of components/ system most from your experience? and how?

## Maintainability

- 14) How do you calculate maintainability parameters? Please explain the method. (*MTTR is the most used maintainability parameter as per survey by Questionnaire I*)
- 15) What kind of distribution (exponential, weibull etc) does it follow mostly as the system level as well as at the component level?
- 16) How do you fix maintainability target for the track?
- 17) How do you calculate periodicity of each kind of preventive maintenance action?

- 18) What are the boundary conditions that affect the maintainability of components/ system most from your experience? and how?

## Safety

- 19) How do you calculate safety parameters? Please explain the method. *(Number of accidents is the most used safety parameter as per survey by Questionnaire I)*
- 20) How do you prepare hazard log? Please describe.

## Part III – LCC

- 1) Please describe the model that you use for LCC calculation and list all the parameters that you consider in that.
- 2) What are the major cost drivers that you have encountered in your past LCC calculations? What percentage do they have in total LCC?
- 3) What actions do you take on these major cost drivers?
- 4) What is the percentage of labour cost in total LCC? What actions do you take to reduce it?

## Part IV – Specific Questions to Participants

- 1) How do you consider benefit in LCC? **(DB)**
- 2) How do you evaluate non-constant discounting rate and inflation rate in your LCC calculation? **(OBB)**
- 3) What are the functions in Optimizer+? How it helps in maintenance modelling? **(Prorail)**
- 4) How do you carry out reliability growth analysis? **(BV)**
- 5) How do you manage RAMS database in SAP R/3? **(DB)**

- 6) What data/ information do you require from IMs for your RAMS and LCC analysis? **(All Manufacturers)**
  
- 7) What data/ information do you require from manufacturers for your RAMS and LCC analysis? **(All IMs)**

**Please mention any other issues on RAMS and LCC that you want to address that have not been covered above**

## Annex 2

### PARTICIPANTS TO WHOM QUESTIONNAIRES WERE SENT

#### Infrastructure Managers

| Organisation             | Activity   |
|--------------------------|--|
| ADIF                     | Constructing and Managing Infrastructure   |
| BV                       | Infrastructure manager in Sweden   |
| České dráhy, a.s.        | Transport service – freight and passenger , railway infrastructure operation and maintenance for SZDC (Railway Infrastructure Administration)  |
| DB Netz AG               | The Track Infrastructure Business Unit (DB Netz AG) is responsible for operating and marketing the track infrastructure. Acting under its own responsibility, the Business Unit provides non-discriminatory access to the rail infrastructure. It also prepares and coordinates the timetables in consultation with its customers.   |
| Network Rail             | Operator of Britain's rail infrastructure with a mission to maintain, improve and upgrade the railway infrastructure   |
| ÖBB Infrastruktur Bau AG | Constructing and Managing Infrastructure in Austria  |
| PRORAIL                  | Prorail has been licensed by the Dutch government to:<br>provide sufficient, reliable and safe railway infrastructure in the Netherlands, including the building, renewal and maintenance of railway track and stations;<br>Supply the train operating companies with train paths, transfer capacity and (travel) information services;<br>Ensure a fair and optimum distribution of available track capacity. |
| RFF                      | Operator and manager of the French rail infrastructure   |
| SNCF                     | Transport service – freight and passenger, railway. Delegate infrastructure operation and maintenance for RFF (Réseau Ferré de France)   |

#### Contractors

| Organisation           | Activity  |
|------------------------|---|
| BBRP                   | Design, project management and construction of complex railway projects                             |
| Carillion              | European contractor for railway projects and maintenance, with a broad range of capabilities.       |
| EFRTC                  | Group of Interest of the Track Work Contractors   |
| Speno International SA | Development, construction and exploitation of rail grinding equipment (including measuring systems) |

Manufacturers

| Organisation                    | Activity   |
|---------------------------------|--|
| <b>ALSTOM Transport SA</b>      | <b>Train manufacturer; Design, manufacturing, testing and commissioning, and maintenance of transport systems</b>  |
| <b>Corus</b>                    | <b>A major international steel company and a leading supplier of rails, steel sleepers, design and technical consultancy, and innovative solutions</b>   |
| <b>Goldschmidt Thermit GmbH</b> | <b>Development, Production and Sales of Consumables for the Aluminothermic Welding Technology as well as the execution of Aluminothermit Welds, enclosed arc welds, flash butt welds and grinding operations in all kinds of rail tracks worldwide</b> |
| <b>UNIFE</b>                    | <b>Group of Interest of the Railway Industry, where track infrastructure supply and track works</b>  |
| <b>VAE</b>                      | <b>Railway industry (supplier of switch systems and devices)</b>   |
| <b>VAS</b>                      | <b>A global leader in the development, production and supply of rails, including advanced technologies, logistics, system solutions and innovative track related services</b>  |
| <b>VCSA</b>                     | <b>World leaders in the switch gear field for all types of networks, railways, metros, tramways, both in Europe and throughout the world</b>   |

SAO (SME, Academia and Organisations)

| Organisation                                      | Activity  |
|---|---|
| Laboratoire Central des Ponts et Chaussées (LCPC) | Research and development in the field of geotechnics, environment, civil and urban engineering, road safety   |
| ConTraffic  | Technology benchmarking for switch point systems. Benchmarking for rail signalling components of European manufactures  |
| Damill  | Damill perform field measurements of track forces with our prototype to a wayside monitoring system. The measurements are performed mainly in the Swedish rail network and the purpose is to identify and group different vehicles according to their track behaviour. Gathered data is then to be analysed where we want to develop some automated techniques to separate the different force directions. We also want to identify and define the key parameters for a reliable and objective vehicle classification including effects related to the vehicles maintenance condition |
| G - Impuls  | It is a private company established in 1994. It provides all geophysical services in the fields of magnetic survey, geo-electric methods.   |

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