INNOTRACK

Integrated Project (IP)

Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

D6.4.1
Key values for LCC and RAMS

Due date of deliverable: 2009-02-28

Actual submission date: 2009-02-28

Start date of project: 1 September 2006 Duration: 36+4 months

Organisation name of lead contractor for this deliverable: Banverket

Revision: Final

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	PU
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)	

Table of Contents

Glossary **2**

1. Executive Summary **3**

2. Introduction **4**

2.1 Information acquisition 4
2.2 Aim and objectives 4
2.3 Limitations and definitions 4
2.3.1 Limitations 4
2.3.2 Definition of system, subsystem and component for substructure, S&C and permanent way 5
2.3.3 Definition of inspection, maintenance and service 5
2.3.4 Definition of origin state and final state 6
2.3.5 Definition of boundary conditions for substructure, S&C and permanent way 6
2.4 Activities/method 6
2.5 Organisation and Resources 7

3. Results **8**

3.1 Conclusions from earlier WP and SP 8
3.1.1 SP 1 Duty and Requirement 8
3.1.2 SP 5 Logistic for track maintenance and renewal 8
3.1.3 WP6.1 State of the Art 8
3.1.4 WP 6.2 LCC Methodology 9
3.1.5 WP 6.3 RAMS Technology 9
3.1.6 WP 6.5 LCC and RAMS analysis 10
3.2 Result from Questionnaire 10
3.3 Result from literature review 12
3.4 Limitations because of public purchase regulations 14
3.5 Gap analysis 14

4. Discussion **16**

5. Conclusions **17**

6. Bibliography **18**

7. Annexes **20**

7.1 Questionnaire 20
7.2 Answers 24

Glossary

Abbreviation/acronym	Description
CBS	Cost Break down Structure
FIT	Failure Rate in Time
KPI	Key Performance Indicators
LCC-A	Life Cycle Cost –Analysis
MART	Mean Active Repair Time
MATBF	Mean Accumulated Tonnage Between Failure
MDBF	Mean Distance Between Failures
MDT	Mean Down Time
MMH	Mean Maintenance Hour
MTBCF	Mean Time Between Critical Failure
MTBF	Mean Time Between Failures
MTBM	Mean Time Between Maintenance
MTBSAF	Mean Time Between Service Affecting Failure
MTTF	Mean Time To Failures
MTTM	Mean Time To Maintain
MTTR	Mean Time To Restoration/Mean Time To Repair
MWT	Mean Waiting Time
NPV	Net Present Value
PBS	Product Break down Structure
PPM	Passenger Performance Metric
RCF	Rolling Contact Fatigue
ROI	Return on Investment
S&C	Switches and Crossing
TOC	Total Cost of Ownership

1. Executive Summary

Most commonly used key values to describe RAMS (Reliability, Availability, Maintainability and Safety) are: failure rate, MTBF (Mean Time Between Failure), MTTF (Mean Time To Failure), MTTR (Mean Time to Repair), train delay caused by infrastructure failures, hazard rate, number of derailment and number of accidents. Some other key values for RAMS are MART (Mean Active Repair Time), MMH (Mean Maintenance Hour), MTTM (Mean Time To Maintain), time for maintenance, MTBCF (Mean Time Between Critical Failures), MTBSAF (Mean Time Between Service Affecting Failure), MWT (Mean Waiting Time), and PPM (Passenger Performance Metric). IM use key values on system, subsystem and component level while manufacturers and contractors use them on component level.

LCC is used to find cost drivers in investment projects. Most commonly key values for LCC are cost for corrective and preventive maintenance mainly on subsystem level. The impact of using LCC is to get decision support for changing equipment and maintenance strategy.

The gap analysis confirms that the use of key values for LCC and RAMS is in a development phase and that there is a need to develop measurable key values for RAMS and LCC.

Results from the gap-analysis show that there are several development areas. Although it is necessary to keep in mind that most papers in the literature review do not consider the environment for the “outdoor” infrastructure systems. This means that the system is more affected by the operational conditions than in an in-house plant. Other parameters that make it difficult to define or put up key values for RAMS and LCC for infrastructure are that there is a third part operating the track (traffic companies) and also that maintenance often can be outsourced.

Key values to develop or set objective for are:

- Workshop resources – skilled personnel, availability of maintenance personnel, availability of maintenance equipment
- Unplanned workshop visits
- Preventive maintenance cost
- Corrective maintenance cost
- Hindrance due to maintenance actions
- Maximum number of stopping failures
- Speed reduction
- Availability parameters
- Cost for down time
- LCC value that must not be exceeded
- Risk assessment

Objectives for an LCC-contract can be formulated not exceeding the LCC – level by a certain percentage. Sub objectives can be formulated as decreasing the wear amount, decreasing the amount of corrective maintenance, decrease train delays or/and the MTTR.

Also key parameters for boundary conditions needs to be expressed e.g. traffic volume, traffic mix.

It is also difficult to collect data for maintenance cost and condition due to long technical life time, different accounting systems for maintenance, modification and renewal costs and different maintenances contracts e.g. lump sum performance contracts.

The fact that the railway system is operated and maintained by several different companies/organisations makes it difficult to share or get hold of decision support data in order to plan and maintain the system with an holistic approach in order to avoid sub optimisation. An important task is therefore to develop methods and information systems to improve the possibilities of delivering feedback concerning e.g. failure rates to the manufacturers or cost for maintenance activities to IM or manufacturers that has contracts with LCC-commitments.

2. Introduction

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 (Reliability, Availability, Maintainability and Safety) characteristics of a conventional line with a mixed traffic duty.

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.

RAMS technology is a recognised management and engineering discipline to guarantee the specified functionality of a product over its' complete live cycle. RAMS technology keeps the operation, maintenance and disposal costs at a predefined accepted 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.

This report is included in Sub-project 6 LCC and covers the subject of using RAMS and LCC in contracts.

2.1 Information acquisition

Information about how RAMS and LCC are used in contracts was obtained from following sources:

- Questionnaires sent to the participants in the working group and reference group, to get an overview of their use of RAMS and LCC in contracts.
- Discussion and telephone conversation with infrastructure managers and suppliers.
- Previous related reports from Innotrack.
- Literature review scientific publications
- Internet search

The primary source of data was from the questionnaire, shown in Annex1. Annex 2 shows the list of IMs/ Suppliers to which the questionnaires were sent.

2.2 Aim and objectives

The aim is to derive a definition of national and international key values for LCC and RAMS in contracts.

The objectives are:

- Definition of national and international key values for LCC and RAMS
- Definition and monitoring method to audit arrangements

The objective for this deliverable is the first one.

2.3 Limitations and definitions

2.3.1 Limitations

The limitations are in line with INNOTRACK, i.e. focusing on developing better tools, methods and innovations for operation and maintenance on substructure, switches and crossings, superstructure (permanent way) and logistics, meaning that this workpackage is mainly focused on contracts including mentioned asset.

2.3.2 Definition of system, subsystem and component for substructure, S&C and permanent way

The railway asset structure has in the questionnaire been defined according to below structure.

System	Subsystem	Component
Railway Infrastructure	Substructure	Culvert
		…..
	Permanent way Rail	Fastening
		Sleeper
		Insulated Joints
		Under sleeper pad
		Ballast (40 cm below sleeper)
	S&C	Frog,
		Switch blade,
		…..

2.3.3 Definition of inspection, maintenance and service

Focus of this workpackage is on introducing RAMS and LCC in operation and maintenance contracts. Concerning the issue of maintenance terminology it was decided that the definitions in EN 50126 should form the base for a common terminology with 2 exceptions:

- Inspection in order to investigate the need for maintenance is often included in the condition based maintenance. The participants in Innotrack have chosen to enhance the inspection as a separate post beside preventive and corrective maintenance.
- Service, there is a grey zoon between maintenance and service. Service could be included in both operation and preventive maintenance. When service is enhanced it must be clearly defined what it contains, e.g. snow removal, cleaning.

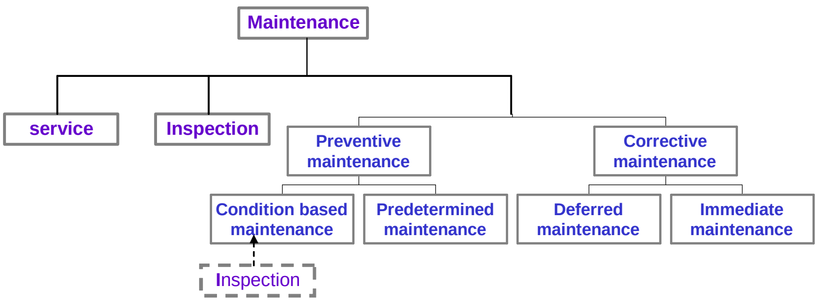

Figure 1. Service, inspection and maintenance

The definitions for maintenance and inspection are:

Maintenance:

The combination of all technical and administrative actions, including supervision actions, intended to retain a product in, or restore it to, a state in which it can perform a required function. (IEC 60050(191))/ EN 50126

Inspection:

Check for conformity by measuring, observing, testing or gauging the relevant characteristics of an item. NOTE: Generally inspection can be carried out on before, during or after other maintenance activity. EN 13306:2001.

The following definition is suggested for Service:

Actions that prevents an accelerated degradation by removing dirt, water, snow and other debris without restoring the actual function of the asset.

2.3.4 Definition of origin state and final state

The following definitions are introduced in order to define the system/component condition and cost before the contract starts respectively the final condition and cost after the contract ended.

- **Origin state** is the condition and cost for the railway system before the contract starts.
- **Final state** is the estimated state and cost for the railway system, after the contract has ended.

These two parameters will be more clearly defined in deliverable 6.4.2 and are necessary in order to form objectives and measure the outcome of the contract.

2.3.5 Definition of boundary conditions for substructure, S&C and permanent way

Boundary conditions in a contract are those factors that might change the commitments within the contract, beyond what the contractors are able to have any influence over, see figure 2. Such factors are:

- Traffic:
  - Type of train and their maintenance standard – Yaw stiffness/wheel profiles/
  - Axle weight
  - Speed
  - Traffic Volume
- Track related:
  - Track quality
  - Structure beneath Substructure
- How to establish on place for maintenance (Logistic time)
- Climate

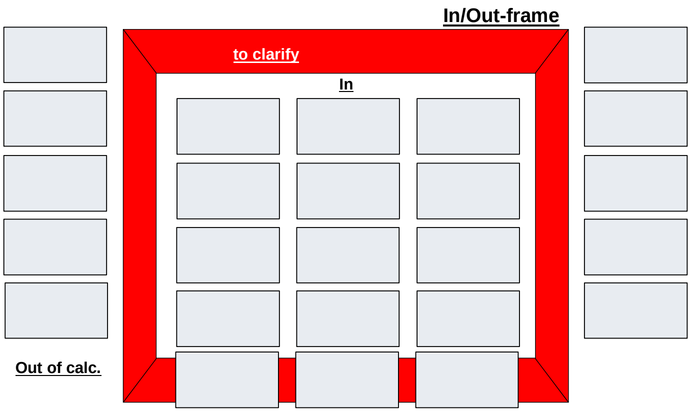

Figure 2. Boundary conditions

Note that if other assets or systems are considered, e.g. signalling system, there might be other boundary conditions to consider.

2.4 Activities/method

The deliverable WP 6.4.1 is based on the following activities:

– A small literary review - short description of why, how and when LCC and RAMS should be used in contracts with suppliers/contactors, what are the benefits, risks, etc. And what are the most commonly used key values?

- Results from earlier Subprojects (SP:s) and Work Packages (WP:s)
- A small state of the art based on a questionnaire, answering questions - how is LCC and RAMS used in contracts today amongst INNOTRACK participants
- Gap analysis, between results from the literature review and the state of the art and results from earlier work in INNOTRACK
- Discussion/conclusion
- Suggestions for development areas

2.5 Organisation and Resources

The organisation and resources for this work package is given in Table 1. Banverket is responsible for delivery of WP 6.4 which includes deliverables D6.4.1 and D6.4.2.

Workpackage	**6.4 – RAMS and LCC in contracts/ wordings/policies**		**Start date or starting event: October 2008**					**T0: Aug 2009**
Participant id	UIC	VAS	BV	ADIF	Alstom	OBB	DB	CORUS
Person-months per participant	1,96	0,30	2	0,5	0,50	1	1	0,4

Table 1. WP 6.4 Organisation and resources

A reference group was picked out, in order to conduct a broader survey. Participants in the reference group were:

- Balfour Beatty
- Carillion
- České dráhy, a.s.
- Network Rail
- Prorail
- Speno
- VAE

3. Results

Results from other SP:s and WP:s, the literature and internet search and the questionnaire is presented with focus on finding key values for RAMS and LCC.

3.1 Conclusions from earlier WP and SP

3.1.1 SP 1 Duty and Requirement

SP 1 has identified track maintenance problems that generate the highest costs for the railway and gathered vehicle and track information associated with these problems, which can be used to model the problems. These models could then be used to test new and innovative methods of track maintenance, and establish the potential impact of these methods on track LCC.

Two "low resolution models" have been identified: VTISM and DeCoTrack. These two models could be used to describe the origin condition (costs and degradation speed) and also estimate/simulate what will happen with the maintenance cost and the degradation speed if new innovations are to be introduced in the railway system.

3.1.2 SP 5 Logistic for track maintenance and renewal

In SP 5 the interface between contractors and infrastructure managers has been reviewed based on extensive and structured interviews targeting the project objectives relevant for improvement of cost efficiency and performance of track maintenance and renewal works.

The following priority areas from the report findings were put forward for the future work:

- Market, long term funding, strategic planning
- Contracting strategy including harmonisation of procurement
- Review of current rules and regulations for cross acceptance of machinery, staff and works, proposal for harmonisation including qualification of contractors
- Review of existing safety rules and regulation, current practices, proposal for harmonisation in particular with focus on protecting staff working on the track.

3.1.3 WP6.1 State of the Art

The general understanding about RAMS and LCC is in its infancy stage among most of the participants. This means that INNOTRACK can support the use of LCC thinking and RAMS technology within the railway sector. Tools and models are mostly self-developed. Some tools in use fore RAMS analysis are TRAIL, RailSys, Optimizer+ and for LCC; LCM, D-LCC, T-SPA. Not many RAMS standards are being used. It can be concluded that participants do not consider RAMS issues in all phases of system life cycle. Only IMs define reliability target for their systems. One reason may be that there is not sufficient feedback from the IMs to the manufacturers. Manufacturers and contractors depend on the information provided by IMs to carry out their RAMS and LCC analysis

Reliability analysis is mostly done by expert estimation, not by the tools. Most of the participants have failure databases. All IMs define availability targets. Very few do spare parts planning in accordance with target availability. Availability analysis is also done mostly by expert estimation. Maintainability targets are considered by only very few participants. Analysis is mostly done by experts. 50 % of IMs have safety targets for their systems and 35 % of the participants do prepare hazard logs for their system.

Less than 50% of the participants do have an LCC standard/ guideline. In general LCC is used to evaluate investment alternatives and very few participants consider penalty cost, traffic disruption cost, cost due to un-availability/ downtime in their LCC calculations.

3.1.4 WP 6.2 LCC Methodology

Because of Due to the the long lifetime of the track and track components, pre installation technical and economic assessments are necessary to optimise the track construction and get the return on investment (ROI) in a manageable timeframe.

The original purpose of deliverables D6.2.2 and D6.2.3 was to assess and improve the existing models and tools within each Infrastructure Manager. However, according to WP6.1 results, few IM's have established standards and models for LCC analysis. Therefore, the WP6.2 workgroup decided to focus on available commercial tools to use in future steps of the project, which resulted in choosing D-LCC as LCC application for Innotrack.

3.1.5 WP 6.3 RAMS Technology

The use of RAMS analysis in the railway infrastructure is limited and where it occurs it is in an early stage, especially in the track and civil engineering sector. This is in contrast e.g. to the signalling sector where the use of RAMS is more used. The reason is the complexity of the railway system and the tradition of the track and civil engineering system. The complexity stems from several sources. One is the interaction of several railway areas (track, S&C, catenary and signalling, etc.). A second complication is the vast need of data for RAMS analysis. This data is often hard to define and scattered between different databases and organisations. In other words, there exists a lot of measured data in the track sector, but this data is seldom easy to obtain and often difficult to compare between railways since they are defined/measured in different manners. Furthermore it is not obvious which data is relevant for RAMS analysis. Additionally, geographical distribution of assets and various influences of the environment increase the complexity.

More basic development is necessary before RAMS analysis can become fully functional in the railway community.

Consequently, it was decided to focus on the identification of necessary developments in the current deliverable.

Some conclusions are:

- It is necessary to find common definitions of RAMS-related terms in the railway sector. As an example we can pose some questions regarding the term "availability", e.g.:
    - is it an unction of the capacity of utilisation of the line?
    - which data can we collect in order to describe this?
    - do we need a common definition for train delays?

  Definitions currently employed differ between the infrastructure managers.
- The problem of different definitions is further enhanced by the different maintenance strategies of the European railway organisations.
- New products pose a problem in that key data for RAMS analysis are normally not available.
- Areas identified as priorities for future developments are:
  1. Extended data collection and analysis
  2. Extended databases
  3. Better definitions of failures and general RAMS terminology
  4. Improvements in verification of data employed for reliability analyses
  5. More data collection through wheel impact load (weighing) detectors and intelligent infrastructure
  6. Use of reliability data in planning of predictive maintenance

Due to the above stated reasons the work in INNOTRACK with RAMS is not fully what was planned in the DoW. The work is more an important step forward in using RAMS for track and civil engineering purposes. The work in WP6.3 is therefore probably more important than expected.

There is also a need for agreement on unique economical boundary conditions, specifically the capital budgeting techniques, the choice of proper discount rate and the choice of time horizon for LCC analysis.

A detailed theoretical analysis performed towards the definition of an unique criterion for discounting and the time horizon of LCCA has driven to the following first suggestions:

- To consider a variation of 3% to 5% for the discount rate, with a reference value of 4%
- To consider a range of 30 to 40 years as time horizon, with 40 years as a recommended upper bound for large investments on ballasted tracks assessed through LCCA (closely linked with an accurate estimation of the alternatives residual value as discussed)

3.1.6 WP 6.5 LCC and RAMS analysis

In WP 6.5 the D-LCC software has been used to build LCC – calculation models for substructure, S&C and rails. The following key value has been identified:

Reliability:

- Mean Time Between Failure (MTBF) for corrective maintenance
- Mean Time Between Maintenance (MTBM) for preventive maintenance
- Train delaying failures

Availability:

- Train delay hours

Maintainability:

- Mean Time to Repair (MTTR)
- Mean Down Time (MDT)
- Mean Maintenance Hour (MMH)

Safety:

- Hazard Rate
- Number of derailment due to asset
- Number of accidents

3.2 Result from Questionnaire

The aim with the questionnaire was to do a small state of the art over how and if RAMS and LCC were used in contracts. Based on earlier work in Innotrack there was a pre understanding that the use of RAMS and LCC was in its infancy phase amongst the participants. Only a few IM and Manufacturers has been using LCC and RAMS in contracts, mostly in renewal or new investment contracts. The aim with the questionnaire was to find objectives, key values, methods for using RAMS to calculate LCC commitments, but also included questions for the second deliverable in WP6.4 definition and monitoring methods to audit the agreement, see Annex 7.1.

The questionnaire was sent out to 15 participants within INNOTRACK and 11 responses were received.

These 15 participants were divided into 3 categories i.e. Infrastructure Manager, Contractors and Manufacturers. The answering rate was 73 % and can be seen below in Figure 3.

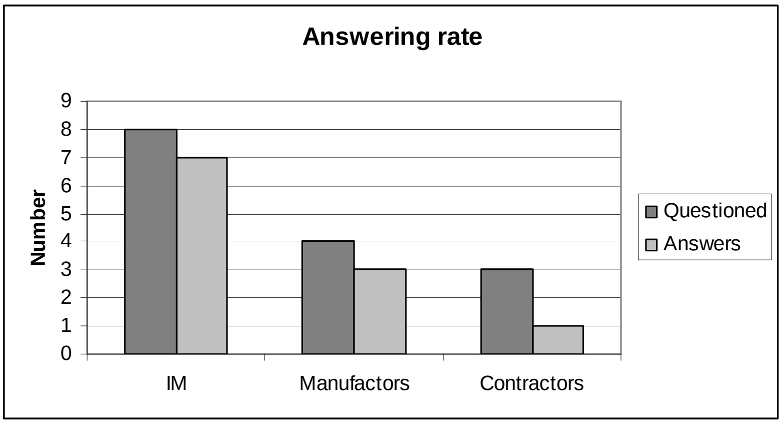

Figure 3. Answering rate

The summary of the answers is given below:

- Most commonly used key values to describe RAMS are: failure rate, MTBF, MTTF, MTTR, train delay caused by infrastructure failures, hazard rate, number of derailment and number of accidents. Some other key values for RAMS are MART, MMH, MTTM, time for maintenance, MTBCF, MTBSAF, MWT and PPM. IM use key values on system, subsystem and component level while manufacturers and contractors use them on component level.
- LCC is used to find cost drivers in investment projects. Most commonly key values for LCC are cost for corrective and preventive maintenance mainly on subsystem level. The impact of using LCC is to get decision support for changing equipment and maintenance strategy.
- RAMS is calculated for systems or/and subsystem by using:
  - specific scheme (procedures)
  - special expert teams
  - expert estimation,
  - failure and inspection databases
  - reliability handbooks containing reliability data of key systems and components
  - project management tools, that guides through the RAMS methodology
  - analyses by external party
  - rail defect list in the catalogue of rail defects
  - data from track tests
  - field data
- It is possible to follow up key values for RAMS from test sites, laboratory, failure recording system, way side monitoring. Development areas are collection of maintenance historical data and feedback of e.g. failure data to suppliers.
- Targets for key values are e.g. decrease of train delay, MTTR, maintenance cost, wear, amount of corrective maintenance.
- Key values for railway availability, other than train delays can be e.g. obtained capacity/planned capacity, up and down time, availability for service, passenger performance metric.
- RAMS key values can be used to calculate LCC commitments, e.g. corrective maintenance cost, number of error, hours needed to do corrective and preventive maintenance, amount of trains that can not drive, MTBF and MTTR.
- Prediction of future levels of RAMS and LCC are difficult but have been done by special simulation tools or based on historical data.
- RAMS and LCC parameters are used in contracts, but only in few cases, in general for new investment contracts.

- There are special maintenance programs to consider during duration time, which is supervised by the IM. When the maintenance is outsourced it can be difficult for the IM to get feedback, especially when it is outsourced as a performance contact. One development area is to give feedback to the supplier.
- Templates for procurement are used. But only in few cases, templates are included that describe demands on key values for LCC and RAMS.
- Cost for down time or cost due to un-availability are measured in cost/min, determined by charges, models that calculate the cost of downtime which includes unexpected errors, expected downtime caused by mainentenace, cost for using busses, etc.
- Critical Boundary conditions are:
    - Traffic: type of train and their maintenance standard, yaw stiffness, wheel profiles, axle weight, speed, traffic volume
    - Track related: track quality
    - Structure beneath substructure
    - How to establish on place for maintenance (Logistic time)
    - Climate
    - Some other added, e.g. product quality
- It is possible to monitor boundary conditions by recording and monitoring systems

3.3 Result from literature review

The literature review aims to find papers that describe research and scientific knowledge or experience in the subject field. A search in different data bases such as Compendex, Emerald, Raildok but also internet resulted in 21 papers, see reference list. The review focus has been to find key values for LCC and RAMS, meaning that references to some of the papers on the reference list might be excluded.

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 delivers necessary information for technical and economic decision. (Emblemsvåg, 2001)

Other similar method is TCO total cost of ownership and functional products. TCO may include such elements as order replacement, research and qualification of suppliers, transportation, receiving inspection, rejection, replacement, downtime caused by failure and disposal cost. TCO may be applied to any type of purchase, (Ellram, 1993, Ellram, 1994). Also functional products is an adjoining or new way of describing commitments that include the deliverable of a product/system with a performance commitment including product support, design for maintenance, service delivery performance, designed for low life-cycle cost, customers focus reliability and cost (Markeset and Kumar, 2005).

According to Akselsson and Burström (1994) the acquisition process with the lift cycle cost method can be summoned up as in table 2. Results from other papers have been added in the note column followed by a reference notification.

According to Nissen (2008) the acquisition process and the LCC methodology should also include disposal and risk assessment. Economic risk assessment, using either a probabilistic approach or a sensitivity approach, can be used to reduce uncertainties (Cole and Sterner, 2000).

Needed key data are (Akselsson and Burström, 1996):

- Investment cost
- Material structure (Product tree) and spare part list
- Preventive maintenance programme and workshop resources needed
- Preventive and corrective maintenance costs
- Cost drivers in maintenance such as inspection cost and periodical maintenance cost on S&C as well as the frequency of periodical maintenance (Nissen, 2008). Cost drivers are also unplanned maintenance, process bottlenecks, equipment with high energy requirements,

potential liability issues, training costs, facility costs, disposal cost (Markeset and Kumar, 2005).

- Hindrances due to maintenance actions (Veit, 2005)
- Component maintenance and resources needed
- Degradation speed, according to the operational conditions and the maintenance programme e.g. interval for rail replacement (Girsch and Frank, 2008)
- For calculation of corrective maintenance following data are needed:
  - Failure rate
  - Repair time
  - Classification of failures
  - Workshop resources needed
  - Speed reduction (Veit and Wogowitsch, 2002)
  - Downtime caused by failure (Ellram, 1995)
- Availability parameters; annual running hours (Emblemsvåg, 2001)
- Safety values can be translated to monetary values by classifications in Safety consequences. Key values for safety could be expressed as e.g. “Derailment frequency due to rail breakages” (Vatn, 2002).

Steps	Activities	Note
1	Establishment of LCC model	When establishing the LCC model it is recommended to carry out a pre study on an existing system similar to the one to be purchased in order to validate the model, establishing a reference system
2	Determination of the operational profile	in order to create the basis for the systems reliability performance and need for maintenance. According to Veit (2005) reliability performance for track components are affected by transport volumes, different alignment, rail profiles and steel grades. Sabotage?
3	Request for proposals	Following factors must be considered: • Principals of the LCC evaluation • Suppliers responsibility for performance • Expected guarantees from the supplier • Operational profile of the system/component • The present maintenance organisation • The LCC calculation model must be provided with the request for proposal • Computer software for the calculation should normally be provided by the customer • Data necessary for the evaluation
4	Evaluation and amplification of the proposal	
5	Negotiations with tenders	including a guaranteed LCC value and reliability performance
6	Modification of contract	necessary according to an agreed change procedure
7	Delivery	
8	Verification of guarantee	By using an agreed change procedure

Table 2. **Acquisition process**

The customer also performs calculations according to the LCC model and also uses previous experience to estimate corrective maintenance, preventive maintenance, component maintenance and workshop resource (Akselsson and Burström, 1996).

The availability performance analysis produces input to the LCC calculation, such as failure rates and repair time but also identifies components most likely to fail or taking most time to repair and components causing unavailability (Akselsson and Burström, 1996).

The contract will contain rules for project realization, e.g. change procedure and guarantees specified in such a way that can be verified. Guarantees should cover an LCC value that must not be exceeded (i.e. not to be exceeded by more than X per cent). Reliability and maintainability performance are also desirable e.g. maximum number of stopping failures and unplanned workshop visits and average or maximum repair time (Akselsson and Burström, 1996).

3.4 Limitations because of public purchase regulations

Public procurement is regulated in The Public Procurement Act. The Act comprises the procedures laid out in Europe Directives. The Public Procurement Act includes no limitations regarding which contract form that may be used by the Owner (Förordning (2007:1099)).

3.5 Gap analysis

In the gap analysis the result from the literature study is compared with the result from other SP:s /WP:s and the result form the questionnaire in order to find development areas. The result is summoned up in table 3. The development areas are to develop or formulate parameter or key values for:

- Spare part lists, also spare part cost and logistics
- Workshop resources – skilled personnel, availability of maintenances personnel, availability of maintenance equipment
- Unplanned workshop visits
- Preventive maintenance cost
- Corrective maintenance cost
- Hindrance due to maintenance actions
- Maximum number of stopping failures
- Speed reduction
- Availability parameters
- Cost for down time
- LCC value that must not be exceeded
- Risk assessment

Also key parameters for boundary conditions needs to be expressed e.g. traffic volume, traffic mix.

KEY PARAMETERS from		
Literature study	Other SP:s and WP	Small state of the art
Investment cost	Considered	Considered
Material structure (Product tree)	Considered	Considered
spare part list	Need to be developed	Not considered
Preventive maintenance programme	Considered	Considered
Workshop resources needed	Not considered	Not considered

KEY PARAMETERS from		
Literature study	Other SP:s and WP	Small state of the art
Preventive maintenance costs	Considered, but could be difficult to get e.g. for outsourcing reasons	Considered
Corrective maintenance costs	Considered, but could be difficult to get e.g. for outsourcing reasons	Considered
Cost drivers	Introduced in SP1, but needs to be more specified and discussed, e.g. how to reduce inspection costs or periodical maintenance costs?	Not considered
Hindrance due to maintenance actions	Not considered	Not considered
Component maintenance and resources needed	Considered	Considered
Degradation speed	Considered	Not asked
Failure rate	Considered	Considered
Repair time	Considered	Considered
Classification of failures	Considered	Considered
Workshop resources needed	Not considered	Not asked
Maximum number of stopping failures	Not formulated	Not formulated
Unplanned workshop visits	Not formulated	Not formulated
Average or maximum repair time	Considered	Considered
Speed reduction	Not formulated	Not formulated
Downtime caused by failure	Need to be developed	Need to be developed
Availability parameters; annual running hours	Expressed as train delay, development area	Need to be developed
Safety values	Considered	Considered
LCC value that must not be exceeded	Not formulated	Not formulated
Risk assessment	Need to be developed	Need to be developed

Table 3. **Gap analyse**

4. Discussion

The gap-analysis shows that there are already RAMS parameters in use, even if the basic data for calculating them are in some cases uncertain.

The result from the gap-analysis shows that there are several development areas. Although it is necessary to keep in mind that most of the papers in the literature review do not consider the environment for the “outdoor” infrastructure systems, which means that the system is more affected by the operational conditions than in an in-house plant. Other parameters that make it difficult to define or put up key values for RAMS and LCC for infrastructure are that there is a third part operating the track (traffic companies) and also that the maintenance often can be outsourced.

Objectives for an LCC-contract can be formulated not exceeding the LCC – level by a certain percentage. Sub objectives can be formulated as decreasing the wear amount, decreasing the amount of corrective maintenance, decrease train delays or/and the MTTR.

The environmental conditions in which the equipment is to be operated, such as temperature, humidity, dust, maintenance facilities, maintenance and operation personnel training etc. often have considerable influence on the product reliability characteristics and thereby on the maintenance and product support requirement. During the operation phase, manufacturers can benefit from obtaining information about the product’s technical health as well as conformance and deviations from the expected performance targets (Markeset and Kumar, 2003).

Today sharing of maintenance data is not so common, which can make it risky for the contractors to commit themselves in long duration contracts, guaranteeing a performance deliverable. This might raise the question if it is necessary to create a web-based platform for exchanging maintenance data such as failure rate, failure type, maintenance action, maintenance

5. Conclusions

Most commonly used key values to describe RAMS are: failure rate, MTBF, MTTF, MTTR, train delay caused by infrastructure failures, hazard rate, number of derailment and number of accidents. Some other key values for RAMS are MART, MMH, MTTM, time for maintenance, MTBCF, MTBSAF, MWT, NFAC and PPM. IM use key values on system, subsystem and component level while manufactures and contractors use them on component level.

LCC is used to find cost drivers in investment projects. Most common key values for LCC are cost for corrective and preventive maintenance mainly on subsystem level. The impact of using LCC is to obtain decision support for changing equipment and maintenance strategy.

The gap analysis confirms that the use of key values for LCC and RAMS is in a development phase and that there is a need to develop measurable key values for RAMS and LCC.

Key values to develop ore set objective for are:

- Workshop resources – skilled personnel, availability of maintenances personnel, availability of maintenance equipment
- Unplanned workshop visits
- Preventive maintenance cost
- Corrective maintenance cost
- Hindrance due to maintenance actions
- Maximum number of stopping failures
- Speed reduction
- Availability parameters
- Cost for down time
- LCC value that must not be exceeded
- Risk assessment

Also key parameters for boundary conditions need to be expressed e.g. traffic volume, traffic mix.

It is also difficult to collect data for maintenance cost and condition due to long technical life time, different accounting systems for maintenance, modification and renewal costs and different maintenance contracts e.g. lump sum performance contracts.

The fact that the railway system is operated and maintained by several different companies/organisations makes it difficult to share or get hold of decision support data in order to plan and maintain the system with an holistic approach in order to avoid sub optimisation. An important task is therefore to develop methods and information systems to improve possibilities of delivering feedback concerning e.g. failure rates to the manufactures or cost for maintenance activities to IM or manufactures that has contracts with LCC-commitments.

6. Bibliography

References

Akselsson, H. and Burström, B. (1994). Life cycle cost procurement of Swedish State Railways' high-speed train X2000. *Proceeding Instn Mechanical Engineering Vol 28,* pp 51-59.

Cole, R. J. and Sterner, E. (2000). Reconciling theory and practice of life-cycle costing. *Building Research & Information*, 28:5, pp 368-375

Emblemsvåg, J. (2001). Activity-based life-cycle-costing. *Managerial Auditing Journal*, 16/1, pp 17-27.

Elram, L. M. (1995). Total cost of ownership. An analysis approach for purchasing. *International Journal of Physical Distribution and Logistics Management*, Vol. 25. No 8, pp 4-23

Elram, L. M. (1993). A Framework for Total Cost of ownership. *International Journal of Physical Distribution and Logistics Management*, Vol. 4 No. 2, pp 49-60

Ferreria, L. (2005). Rail Track Infrastructure Ownership; Investment and Operational issues. *Transportation*, 24 (2), pp 183-200.

Förordning (2007:1099) om offentlig upphandling och upphandling inom områdena vatten, energi, transporter och posttjänster

Girsh, G. , Heyder, R., Kumpfmüller, N. and Belz, R. (2005). Comparing the life-cycle cost of standard and head-hardened rail. *Railway Gazett, September 2005*, pp 549-551.

Girsh, G. and Frank, N. (2008). LCC Rail: a software tool for life-cycle-cost –calculation. *Rail Engineering international Edition 2008,* No 2, pp 8-11.

Lindholm, A. and Suomala P. (2007). Learning by Costing , Sharpening cost image through life cycle costing. *International Journal of Productivity and Performance Management*, Vol . 56, No. 8, pp651-672.

Lindholm, A. and Suomala P. (2004). The Possibility of Life Cycle Costing in Outsourcing Decision Making. Frontiers of E-Business Research 2004. pp226-241.

Nissen, A. (2008). Classification and Cost Analysis of Switches and Crossings for Swedish Railway – a case study.

Nissen, A. (2008). LCC-analysis for Switches and Crossings – A case study from the Swedish Railway network.

Markeset, T. and Kumar, U. (2003). Product support strategy: conventional versus functional products. *Journal of Quality and Maintenance Engineering*, Vol . 11 No. 1, pp 53-67.

Markeset, T. and Kumar, U. (2003). Design and development of product support and maintenance concepts for industrial systems. *Journal of Quality and Maintenance Engineering*, Vol . 9 No. 4, pp. 376-392.

Saraswat, S. and Yadava G. S. (2008). An Overview on reliability, availability, maintainability and supportability (RAMS) engineering. *International Journal of Quality & Reliability Management.* Vol. 25 No 3, pp330-344.

Swaffield, L. M. and McDonald, A. M. (2008). The contractor's use of life cycle costing on PFI projects. *Engineering Construction and Architectural Management,* Vol. 15, No. 2, pp132-148.

Vatn, J. (2002). A Life Cycle Cost Model for prioritisation of track maintenance and renewal. *ProM@in – Progress in Maintenance and Management of Railway Infrastructure*, pp 21-25.

Veit, P. (2005). The ÖBB life cycle cost. *European Railway review.* Pp 69-72.

Veit, P. and Wogowitsch, M.(2002). Track Maintenance based on life-cycle cost calculations. *ProM@in – Progress in Maintenance and Management of Railway Infrastructure*, pp 6-13

Vipulanandan, C. (2008). Life Cycle Cost Model For Water, Wastewater Systems. Underground Construction Systems, October 2008, pp 80 – 84

Zoeteman, A. (2001). Life cost analysis for managing rail infrastructure, Concept of a decision support system for railway design and maintenance. *European Journal of Transport and Infrastructure Research.* Vol 1., No 4. pp 391-413.

7. Annexes

The questionnaire was sent out to ADIF, BV, DB, NR, OBB, Prorail CD, RFF, Balfour Beatty, Carillion, Speno, Alstom, VAE, VAS and Corus Rail

7.1 Questionnaire

Small State of the Art/ Questionnaire – the use of RAMS & LCC in contracts

Questionnaire

Small State of the Art

INNOTRACK SP6 WP4

RAMS & LCC in Contracts

The scope of this questionnaire is to find best practice in use and development areas.

This questionnaire is answered by:

- □ Infrastructure Manager
- □ Supplier
- □ Contractor

Definition:

System	Subsystem	Component
Railway Infrastructure	Substructure	Culvert
		…..
	Permanent way	Rail
		Fastening
		Sleeper
		Insulated Joints
		Under sleeper pad
		Ballast (40 cm below sleeper)
	S&C	Frog,
		switch blade,
		…..

Abbreviations:

MTBF Mean Time Between Failures
MTTF Mean Time To Failures
MDBF Mean Distance Between Failures
MTBM Mean Time Between Maintenance
MTTR Mean Time To Restoration/Mean Time To Repair
MTTM Mean Time To Maintain
MDT Mean Down Time

See also http://www.electropedia.org/iev/iev.nsf/index?openform&part=191

RAMS and LCC, see also Table 1 for an example

1. Which key values do you use for describing RAMS (reliability/availability/maintainability/safety) for the system/subsystem/component?

2. If you calculate RAMS for system or/and components, describe how?

3. Is it possible to measure and follow up key values for RAMS? Describe how and if there are improvement areas?

4. Do you target your key values? If yes, describe how.

5. Train delays are often used as an availability parameter. Are there other ways of measuring availability for the railway system? Describe how.

Do you use RAMS key values to calculate LCC commitments? Describe how.

6. Is it possible to predict future levels for RAMS and LCC? Describe how.

7. Do you have RAMS and LCC parameters in your contract? Describe them and how they are used.

8. A target for LCC might be to keep the maintenances cost on a certain level during the contract period of e.g. 10 years and in the same time keep the degradation speed on a committed level. Is there a maintenance programme? And how is it supervised?

9. Do you use special templates for procurement including demands on key values for LCC and RAMS?

10. How do you consider cost of downtime/cost due to un-availability of track in the LCC model?

Boundary condition

11. Do you agree that critical boundary condition that will affect RAMS and LCC-commitments are?:

    Traffic:

    - Type of train and their maintenance standard – Yaw stiffness/wheel profiles/
    - Axle weight
    - Speed
    - Traffic Volume

    Track related:

    - Track quality
    - Structure beneath Substructure
    - How to establish on place for maintenance (Logistic time)

    Climate

    If not, please give a comment………….

12. Are these boundary conditions possible to monitor, concerning changes that might affect the degradation speed during the contract period. Describe how:

Your other comments:

Table 1; Use of RAMS/LCC – example – from BV, X=in use

	Example	**Railway system**	**Sub system**	**Component level**
Reliability	Failure rate, MTBF, MTTF, MDBF, MTBM Other:	Line, section X X X - -	X X X - - Critical item list Critical function list	X X X Number of remarks leading to short - range planned action Number of train delaying failures MWT Mean Waiting Time
Availability	Total train delay Train delay caused by infrastructure Other	X X Deliverance of train time slots according to plan	- X No	- X No
Maintainability	MTTR, MTTM, MDT Other	Qualification/competence requirements for maintenance personnel	X-for corrective maintenance Mean logistic time Mean time to restore Special tools and test equipment	Possible – but not always done Spare part supply
Safety	Number of derailments, number of external accidents, number of internal accidents Others	X X X Safety planning done according to regulations	Accident and incidents due to maintenance activities	
LCC in use			LSC Life Support Cost Program ERTMS-022	
key values			Cost of corrective maintenance Cost of preventive maintenance Analysis of cost drivers	

Potential impact on LSC commitments			Changing: Equipment Maintenance practice operating process	

Your table to fill in (?)

	Example	Railway system	Sub system	Component level
Reliability	Failure rate, MTBF, MTTF, MDBF, MTBM Other:			
Availability	Total train delay Train delay caused by infrastructure Other			
Maintainability	MTTR, MTTM, MDT Other			
Safety	Number of derailments, number of external accidents, number of internal accidents Others			
LCC				
key values				
potential impact on LSC commitments				

7.2 Answers

1. Which key values do you use for describing RAMS

From	Answer
A	Reliability: Failure rate, MTBF, MTTF → as function or regular intervals in most cases for subsystem, component Availability: train delay caused by infrastructure → cost calc. simulation RailSys maintainability
B	MTBF, Failure rate Train delay (hours and Numbers). Can be broken down to subsystem and component MTTR
C	At the moment we are using LCC and RAMS parameters only for internal evaluations. Therefore we only answer a few of the following questions.
D	See table1
E	See table1
F	
G	We use all of them, but for the component rail only.
H	MTBF, Failure rate (FIT/Failure in Time), MTTR, Technical Availability A, Preventive Maintenance (Intervals, Time for Maintenance), Hazard rate (safety related)
I	

2. If you calculate RAMS for system or/and components, describe how?

From	Answer
A	The exact values are not often well known in a useful accuracy. Therefore A implemented a specific scheme: a. Describe the aim/ task of your LCC b. Set up LCC team for the specific question (technical experts, one expert for the LCC more or less as moderator) c. Describe the system for calculation – full LCC or reduced (depends of comparison and decision making support or full economical calculation) d. Describtion of necessary parameters – In/ Out frame. Important for the following up data mining and documentation if the are not all the point implemented (e.g. social, noise, customer effects, etc.). and explanation why in or out of the calc. → team work e. Built up LCC model (CBS and PBS) f. Data mining for necessary data – both costs and intervals if data **available**; **otherwise** experts estimation g. Adaption of the LCC model as result of the foregoing work (e.g. no difference between the systems as assumed before) h. LCC-A (NPV, annuity) incl. the sensitivity (rates, intervals, costs) Recommendation for the decision based on LCC
B	Data from inspection database BESSY and Failure report system Ofelia – failure rate, MTBF can be calculated, from Ofelia – MTTR. This can be done both for subsystem and components. For new assets expert estimations based on historical data from earlier asset behaviour.

	Calculations of values based on reliability modelling is done in some cases e.g. signalling systems?
C	
D	From failure data (FMS – Failure Management System), calculate MTBF and MTBCF, and crucially look at the distribution too, this is then included in a reliability handbook containing reliability data of key systems and components. For new projects we use AvSim software to calculate RAMS data and use our TRAIL model to overlay timetable data to predict, delays etc.
E	We have a structured way of making RAMS analysis. Depending on type of project the projectmanager PRM decides what aspects of RAMS are relevant for his projects. In a hand-out the PRM is guided through the RAMS methodology. We describe the following items: - Question to be answered - input - method - output The output and method is decided by de PRM based on the guidelines in the hand-out.. The analyses is done by external party. At start of project the PRNM, external party and most of time RAMS expert (me) have discussion how to run the RAMS analyses. After that the extern party starts evaluate and calculate, using the described inputs etc.. The report is evaluated and put in RAMS dossier.
F	
G	See our example in deliverable 6.3.2 chapter 2.3. The starting point are the most relevant rail defects as listed in the Catalogue of Rail Defects UIC 712. For each relevant defect, the MTBF and the MTTM are considered. The data are from a number of track tests, many of them were considered in SP4.
H	First step: Calculation of failure rates for components based on field data (if available), expert estimations or other data bases (Military handbook, NPRD etc.) Second step: Calculation of the values of subsystems/systems based on the reliability modelling (parallel and serial structure**).**
I	

3. **Is it possible to measure and follow up key values for RAMS? Describe how and if there are improvement areas**?

From	**Answer**
A	EDV system for MTBF, MTTR - test sites, laboratory specific RAMS software for calc A Comment: There are improvement areas: problem is that the RAMS software is specified to other systems than treck, e.g.electricity. The main idea is up or down. Track has the UP, but at defined lim. Values we improve, e.g. rail grinding, have up with the improved system, but not the “new” function (but a remaining life time).
B	Yes. Ofelia, BESSY and some other systems make it possible to evaluate RAMS values. One enhancement areas are to get better control of the maintenance history i.e. to know what maintenance activities that has been conducted during the contract time. This can be difficult when having lump sum performance contracts.

C	
D	Yes – we use FRACAS (Failure Reporting and Corrective Action System) and DRACAS (Data Recording and Corrective Action System) to follow up on failures and update our RAM data, this feeds back into the reliability handbook**.**
E	We have several intranet applications which monitor the performance of the rail infra. The output of the different application is not yet consistent. It is possible to make a relation between activities, cost and performance.
F	
G	The most important values for rail are related to wear and rolling contact fatigue. Other data like for internal defects are not accessible to us as a rail supplier. They should be evaluated from rail failure statistics of the individual railways. Some of them have such a statistics based on the UIC 712, and the quality of the data should be sufficient. Without such a field study, we think that it will not be possible to set any limiting values.
H	Yes. Implementation of data (failure) recording systems is in the responsibility of the infrastructure managers. RAMS values should be evaluated from failure statistics and from recorded maintenance programmes of the individual railways.
I	

4. **Do you target your key values? If yes, describe how**.

From	Answer
A	At the moment we target key values for new technique/ components at specific test sites: measurements
B	Yes, objectives for availability are put up in values “Decrease train delay hours”, also MTTR for some critical asset like catenary and in general for the whole system in values like – time to establish on failure place. For maintainability there are also targets to decrease the amount of corrective maintenance and transform it to preventive maintenance. For some specific contracts. e.g. grinding; the objective is to extend the life length., but this is not always expressed in the contract.
C	
D	Yes – Particularly in new projects, where failure rates may lead to design changes after trials or extended trials.
E	Our KPI performance indicators are targeted for whole of Es country. It needs to be defined in more detail e.g. for every line. We also have key values for maintenance costs and during the negotiations of the contract this is used.
F	
G	We focus on rail wear replacement and grinding cycles, demonstrating the improvement factors of new high strength rail steels.
H	We focus not on determined values, but on extending the life time of our systems and on reducing the maintenance/inspection effort.
I	

5. **Train delays are often used as an availability parameter. Are there other ways of measuring availability for the railway system? Describe how.**

From	Answer
A	Part of the national transportation contracts which costs money
B	Availability for railway can be a function of the capacity of utilisation of the line; Obtained capacity / Planned capacity, calculated for a point in time or over a time interval. This definition treats availability as a function of the obtained capacity and a constant planned capacity. The planned capacity might be set to the theoretical capacity, the practical capacity, or lower. One advantage of defining planned capacity as the theoretical capacity is that availability then takes on values between 0 and 1, not higher.
C	
D	Yes – our TRAIL model for new projects will either calculate availability for service (time out of use ie in possessions) or train delay. The other measure PPM (Passenger Performance Metric)
E	We use the following 4 algorithms : KPI-Beschikbaarheid = { (MB – onderhoudstijd – storingstijd) / MB } x 100%; MB = Σ (maximale beschikbare uren x baanvakwaarde x aantal spoorzones) TAO=number of errors effecting trains FHT=MTTR Duur= MTTM Baanvakwaarde=parameter to indicate the amount of trains on the infra Spoorzone= indicats the area that is affected by the error Maximale beschikbare uren: number of hours each “spoorzone” of the track is open for trains.
F	
G	One other point is to determine the down time required for maintenance. The total infrastructure availability also depends whether scheduled maintenance down time or idle time of operations can be foreseen for maintenance and repair.
H	Recording of Up- and Downtime of systems/components and hence calculation of the availability**.**
I	

6. Do you use RAMS key values to calculate LCC commitments? Describe how.

From	Answer
A	Described above
B	Not in general, corrective maintenance cost can be calculated based on data from the failure system Ofelia, preventive maintenance is more difficult.
C	
D	Yes – RAMS is considered in the LCC of new projects and this then feeds in the Infrastructure Cost Model, which is the model of overall business costs.
E	We calculate the number of errors in the area or line. We also how many hours are needed for maintenance (corrective and preventive). We also estimate how much money is needed for maintenance.

	The time that trains cannot use the infra is translated to the amount of trains that can not drive. Then this is calculated as costs for the passengers using 7 euro per passenger per hour. We also use keyfigures for every cargotrain that is delayed. And many more items
F	
G	We do not commit us either to RAMS values nor LCC. For RAMS see 3 and 4 above. Our RAMS analyses presented so far are informative only.
H	MTBF, MTTR values are the base for calculation of costs for corrective maintenance. But up to now our LCC calculations are only informative.
I	

7. Is it possible to predict future levels for RAMS and LCC? Describe how.

From	Answer
A	
B	With more knowledge and by using degradation models and or simulation tools it would be possible. It will also be necessary to control the boundary conditions and what maintenance actions that has been conducted
C	No
D	Yes – We use our TRAIL/AvSim models to predict reliability in new projects. We also use the Duane model to plan and then monitor Reliability growth.
E	Yes, based on history we predict the reliability, availability and calculate the LCM
F	
G	With knowledge on actual field data it should be possible.
H	?? RAMS/LCC prognosis could be based on predicted and if possible tested system/component performance behaviour compared to systems/components in operation (knowledge of field data)
I	

8. Do you have RAMS and LCC parameters in your contract? Describe them and how they are used.

From	Answer
A	We do not have RAMS/ LCC parameters in our contracts, but: we started with specific LCC contracts at the planning part (A standards: take into account all follow up costs at the planning phase) and ask our planning office for the calc. we use LCC also for “risk” calculation before implementing a new (track) product problem of contract: to define boundary conditions, e.g. loading collective, for 10 years (its not a boxed system)
B	Only in a few cases. Parameters are failures per year per system, MTTR and MTBF per system.
C	Currently the LCC parameters become implemented in the new frame contract for electronic control centres. Parameters see table 1 C

D	Yes – we specify reliability parameters in our procurement contracts based on parameters such as MTBSAF, MTTR and Mean Active Repair Time, as well as distributions on such parameters, so we can look at worse case repair times.
E	Depends on the project. Problem with this is that E does not provide the cost keyfigures to the external parties. And most of the consultancy / engineering companies have keyfigures on new infrastructure, but not for maintenance. This knowledge is only available at E and its main contractors for (small) maintenance.
F	
G	Just informative. There were customers outside Europe that required RAMS values. Discussion showed that they did not know what to ask for.
H	Only in a few cases. Parameters are failures per year per system, MTBF per system. RAMS and LCC values are in most cases only for informational but not for contractual reasons.
I	

9. A target for LCC might be to keep the maintenances cost on a certain level during the contract period of e.g. 10 years and in the same time keep the degradation speed on a committed level. Is there a maintenance programme? And how is it supervised?

From	Answer
A	maintenance program: preventive knowledge based and condition based mtn. as result of measurements supervised: central division and regional responsibility (both with a budget)
B	The maintenance program is a combination of condition based and predetermined maintenance. It is supervised by internal regulations. The maintenance program is based on B:s maintenance strategy that's in line with the overall objectives for the railway system and the Parliament transport policy.
C	We are using a maintenance plan for the internal services without any special supervision.
D	Yes – we have maintenance schedules and this is tailored to the route and projects, the maintenance plan is an integral part of any new capital or upgrade projects
E	Right now 4 of the 39 contracts are transformed to so called "prestatie gericht onderhoud-". This means performance based maintenance. The basis for these contracts are specs for sustainability, availability / reliability and safety. The contract period is 5 - 6 year (not sure). The contractor has to give FMECA's for all systems, based on these he has to make a maintenance concept and inspection plan. He also has to predict the number of "train free periods" needed to do maintenance. And he offers a price for the contract period. This are really output contract. The remaining contract are a mix of input and output contracts. For these contracts the amount of work to be done, for each system and activity, is agreed and contracted.
F	
G	We can do such maintenance predictions only for wear and RCF. This requires a detailed study and understanding of the railway system. Up to now, this knowledge is with the railway infrastructure managers. We have some customers where we follow up with these

	topics on a project level. We have no influence on the contractual prices between the IMs and the contractors and so we cannot commit to any cost limits.
H	An appropriate maintenance programme goes hand in hand with the system life time. To reduce maintenance costs in the first period of the life cycle also shortens the system life time and hence increase the total LCC. An appropriate optimised maintenance programme is beside other things the base of reducing LCC. In our case maintenance manuals (with recommended average maintenance intervals) are handed over to the IM´s but the programme is not supervised.
I	

10. Do you use special templates for procurement including demands on key values for LCC and RAMS?

From	Answer
A	LCC contract for the calculation (assignment to planning office), but not implemented key values (question is: which solution is the best LCC based)
B	Only in few cases, e.g. purchasing of signalling boxes.
C	
D	Yes – specify key parameters such as MTBSAF, MTTR and MART and set distributions of these parameters
E	Do not understand the question
F	
G	This corresponds to the input data required for our LCC rail software, i.e. life cycle prognosis including maintenance activities and all related costs.
H	No.
I	

11. How do you consider cost of downtime/cost due to un-availability of track in the LCC model?

From	Answer
A	Costs per minute are known; simulation with splitting models used software RailSys. If costs per Min. change, the simulation has to be redone
B	Not used in contracts
C	
D	Cost of un-availability is determined in the D country by our charges from the Railway Regulator
E	We have a model that calculates the cost of the downtime for society (passengers and cargo). This includes unexpected errors (15 euro per hour per passenger, 1000 euro per cargo train), expected downtime caused by maintenance (15 euro per hour per passenger, 1000 euro per cargo train), costs for using busses, reduction of benefits for traincompany because passengers choose other form of transportation, moment in the week of the downtime.

	We are now upgrading our LCM tool to incorporate all the items above. It will be used both for projects for 1:1 renewal and for new functionality.
F	
G	If given by the IM or the railway, this can be considered in an LCC analysis
H	Not applicable. These values must come from the IM´s. If we get this information we consider this in our calculations.
I	

Boundary condition

12. Do you agree that critical boundary condition that will affect RAMS and LCC-commitments are?:

From	Answer
A	Sensitivity analysis with combination of different functions related to BC (Monte Carlo), so the final result is also a function or a range. As specific mean value the risks in inaccuracy should be documented, explained
B	Yes. But also the maintenance programme (when outsourcing the maintenance contract it can be difficult to control how the maintenance program is conducted).
C	Type of train: yes but without its maintenance standard if it is within the limits (conicity).
D	Yes - These are all measurable through infrastructure recording and monitoring systems Eg Measurement train, substructure surveys, wheel profile measurement systems (WheelChex/Gotcha), maintenance checks. These then feedback into the maintenance schedules.
E	I agree but because of the large amount of different trains on our highly loaded track I don't think that we are able to put all of this knowledge is our calculations. But on system level (e.g. switches or track) LCC calculation are made using some of the mentioned parameters but that I am not the right person to answer this. If needed I can bring you in contact with the right person to give more detail. But on the other hand we measure the axle weight, number of trains, etc. of each switch. Based on this the switches are put in categories using parameters for track and signalling. The yearly costs for a switch depends on the category.
F	
G	Yes we agree. Additional properties affecting RAMS and consequently LCC are: a. general product quality – freedom from any manufacturing defects (internal and surface) b. rail steel grade – the wear and RCF performance relates to hardness c. rail length (avoid joints, they usually have higher failure probability than plain rail)
H	YES. But there are a few more (product quality (free of defects), maintenance programme, initial quality after installation ..) Yaw stiffness/wheel profiles/
I	

13. Are these boundary conditions possible to monitor, concerning changes that might affect the degradation speed during the contract period. Describe how:

From	Answer
A	definition typical routes/ track segments: logic sample overall. The results could be transferred to the network (spli model). The uncertainty has to be quantified (it is not a 100% solution)
B	Most of them could be monitored respectively recorded (e.g. traffic conditions, track quality, maintenance programme), but there are improvement areas such as knowing how the line is operated (type of traffic, loads, speeds, vehicles condition)
C	Traffic: All criteria can be monitored by axle load checkpoints (eg. ARGOS®) Track: Track quality can be monitored by measuring cars Soil can be checked only a few meters (2 m) beneath the substructure and then it will be a problem
D	**Yes -** These are all measurable through infrastructure recording and monitoring systems Eg Measurement train, substructure surveys, wheel profile measurement systems (WheelChex/Gotcha), maintenance checks. These then feedback into the maintenance schedules.
E	We measure a lot of parameters of the track: number of trains, tonnage, number of wheels, how do train go through switches, quality of the track, RCF, etc.. Some of them are monitored daily and some only twice a year with a special train.
F	
G	Wear and RCF should be monitored anyways. Internal defects are rechecked for safety by ultrasonic inspection.
H	Most of them could be monitored respectively recorded (e.g. traffic conditions, track quality, maintenance programme)
I	

Your other comments:

I. As a contractor we execute primarily work ordered by the infrastructure managers and do not have any influence in how to use our services in a strategy perspective. Thus, the questionnaire does not quite apply to us.

However, I would like to comment, that rail maintenance affects and is of course affected by RAMS and LCC:

- If you do not maintain rails, their service life is shorter in general and local spots need to be repaired or replaced with all the implied negative consequences.

- If you do maintain rails, that costs money and requires time in track, but is later on compensated by the positive consequences (just the opposite of the above case). However, life is very complex and thus each railway section may have a different situation. We as a contractor see a big potential for improving the situation with regards to RAMS and LCC, but the actual data needs to be provided by the IM's.

Within WP 4.5 we are about to elaborate a deliverable putting together respective information, serving as a basis for SP 6.

Table 1; Use of RAMS/LCC

Notes:

1. Mean time between service affecting failure
2. We don't tend to use MDBF, but rolling stock owners in UK do use miles per casualty
3. Only used in assessment of new designs. Thee is provision to record, but we do not use it as key metric

	Example	Railway system	Sub system	Component level
Reliability	Failure rate,	B, E	A, B, E	A, B,G
	MTBF,	B, D, E	A, B, D, E,	A, B, D, G
	MTTF,	B, D, E	A, B, D, E	A, B, D, E
	MDBF[2],			
	MTBM	D: Recording in Eclipse database		
	MTBSAF[1']	D	D	D
	Other:		B:Critical item list B:Critical function list	B:Number of remarks leading to short -range planned action B:Number of train delaying failures B: MWT Mean Waiting Time
Availability	Total train delay	A, B, D, E	A, D,	A, D
	Train delay caused by infrastructure	B, D, E	B, D, E	B, D
	Other	B: Deliverance of train time slots according to plan E: Number of errors affecting train schedule Number of errors not affecting train schedule Number of trains with less then 3 minutes of delay KPI availability; number of errors * recovery time * area * weighting factor Deliverance of train time slots according to plan		

	Example	Railway system	Sub system	Component level
	Down time required for maintenance (both preventive and corrective)			G
Maintainability	MTTR, MTTM, MDT Other	D[3] E D[3] B: Qualification, /competence requirements for maintenance personnel	B-for corrective maintenance , D[3]., E E D[3] B: Mean logistic time Mean time to restore Special tools and test equipment Prorail: Mean time to restore	B:Possible – but not always done D[3],, G D[3] B:Spare part supply
Safety	Number of derailments, number of external accidents, number of internal accidents Others Safety Planning Hazard analysis acc. to type of defect	B, D, E B, D, E B, D, E B: Safety planning done according to regulations A	D, E D, E D, E B: Accident and incidents due to maintenance activities Prorail: Accident and incident due to maintenance activities	D, E D, E D, E G

	Example	Railway system	Sub system	Component level
LCC		C: Electronic control centre (in preparation) D: All investment projects go through LCC calculation, tends to be a spreadsheet model – Most new projects look at reliability centered maintenance and look at most effective maintenance strategy for lowest LCC and optimised capacity E: More and more LCC calculations are done both on system level but also for project for new functionality	B: LSC Life Support Cost Program ERTMS-022 E: More and more LCC calculations are done both on system level but also for project for new functionality	A: Track standard planning phase G: Software LCC Rail
key values		D: Cost of maintenance, Cost of preventive maintenance. Cost of corrective maintenance cost, Capital Costs, Cost Drivers	B: Cost of corrective maintenance B: Cost of preventive maintenance B: Analysis of cost drivers C: Asset cost of control centre technology and their additional expenses (eg. Changes ot the building, energy supply, wiring etc.). Technical lifetime of the complete system. Definition of parts which will not reach lifetime of the system and their changing time. Energy demand, Cost of corrective maintenance. Cost of the	A: Dependes on system

	Example	Railway system	Sub system	Component level
		E: Cost of corrective maintenance. Cost of preventive maintenance. Analysis of cost drivers, both on system level but also on line level and contract level	preventive maintenance. E : Cost of corrective maintenance. Cost of preventive maintenance. Analysis of cost drivers	
Potential impact on LSC commitments		D: Changing equipment maintenance process and determining maintenance strategy for new investments	B: Changing: Equipment Maintenance practice operating process C: Changing Equipment. Maintenance practice operating process.	A: Recommendation form mtn, standard for track system/components G: Replacement due to wear. Maintenance against RCF defects