Project no. TIP5-CT-2006-031415

INNOTRACK

Integrated Project (IP)

Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

D6.5.1 Modular LCC/RAMS models for SP2 to SP5

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Dissemination Level		
PU	Public	X
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

Abbreviation/acronym	**Description**
IM	Infrastructure Manager
SP	Sub Project
WP	Work Package
LCC	Life Cycle Costing
CBS	Cost-Breakdown-Structure
PBS	Product-Breakdown-Structure
WBS	Work-Breakdown-Structure
LCCA	Life Cycle Cost Assessment
RAMS	Reliability, Availability, Maintainability, Saftey
CG	Coordination Group
EC	European Commission
KMS	Knowledge Management System
R&D	Research & Development
D-LCC	Decision by Life Cycle Cost
ALD	Advanced Logistics Development Ltd. (provider of D-LCC)
TLT	Technical Life Time
S&C's	Switches and Crossings

1. Executive Summary

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 and software 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 be assessed based on a standardised LCC formulation developed within the project, based on best LCC practices at EU level.

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 technologies are two acknowledged methods for assisting the optimisation process.

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 starting to be 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 sub-project SP6 deals with Life Cycle Cost assessment. Work Package 6.2 deals with Life Cycle Cost Methodology, Work Package 6.3 covers RAMS Methodology and this deliverable deals with LCC and RAMS analysis within Work Package 6.5.

Within Work Package (WP 6.5) LCC models will be generated and relevant data for LCC and RAMS analysis will be collected. The results compared for railway companies. As an input for the analysis the Sub Projects need to deliver the necessary data. The structure and quality of this data are defined in WP 6.2. A very important precondition for the data is the technical assessment done in the Sub Projects SP2 to SP5 as a result of measurements or simulations. The validation and harmonization between the Sub Projects are also important tasks. The validation of the technical data (life time, installation, maintenance interval, maintenance activities etc.) will be done in SP1 in order to confirm the system performance. A table sent to work SP leaders to determine the level of validation required, either full validation (e. g. in depth technical validation such as that being carried out for BBEST) or review validation (i. e. confirming the validation already carried out within the work package).

Another important task is the influence of maintenance on systems, modules or components derived from this kind of analysis. The work content of WP6.5 *LCC and RAMS analysis* includes:

- Generation of LCC and RAMS model
- Definition of parameter sets to analyze
- Identification of cost drivers
- Comparison of systems regarding LCC
- LCC and RAMS analysis for the innovation
- Guidance for LCC and RAMS

This deliverable reports the current work progress concerning the development of modular LCC and RAMS models for SP2 to SP5. It is important to note, that the required modular LCC and RAMS models and the overall performance of the models depend on the provided LCC/RAMS inputs by the SP’s as well as on the implemented improvements in the LCC tool. For time being the necessary cost data for the analysis are not available and need to be collected from the SP’s. Also the required improvements are not completed and implemented in the tool by ALD as the provider of D-LCC. These are important requirements to carry out the LCC calculations for the assessment of technical and economical effects of innovations. Therefore this report is focusing on current status of LCC evaluation, gives an overview about the LCC models based on response of the LCC template and the structure for building modular LCC models including the parameter sets to analyze.

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 characteristics of a conventional line with a mixed traffic duty.

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 decisions. In the field of railways, LCC methods are starting to be implemented and will provide a definite advantage to the IM's 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, modules or methods developed in SP2 to SP5 to fit the European problems defined in SP1.

The method is one of the most recommended for investment projects and assesses different solutions over the whole life cycle. Furthermore it is commonly used also for comparing different alternatives, assessment of disposal concepts, appraisement of profitability, identification of cost drivers and cost effective improvements, and in assessment and comparison of various strategy options, quality assessments, and for long term financial budgeting.

As there is a three stage LCC process to be taken into account within this project:

- LCC for new construction using track system of interest
- LCC for renewal under defined conditions
- Revise LCC to examine effect of increasing traffic and tonnage

Additionally to the costs, future requirements (increased tonnage, increased speed and increased axle loads) are also crucial issues for railway operations and are considered by the LCC and RAMS analysis.

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 specified functionality of a product over its complete life cycle, and to keep 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.

RAMS analysis is a useful method and IM's should make RAMS management. RAM(S) is a very important method for comparing systems performance (especially reliability) and set up safety requirements. Based on a contract between IM's and manufacturers, the values and assessment methods have to be defined. A clear definition of RAMS and LCC specifications in the contracts with manufacturers and contractors will help to achieve the RAMS targets, namely optimized products and reduced costs.

3. Basis for LCC and RAMS analysis

SP6 will determine cost drivers of existing track constructions and operational conditions, which have a major relevance for Innotrack. These cost drivers will give the focus on the relevant problems and guide the innovation regarding the higher levelled results of SP1. This sub project elaborates the national differences in a first step and points out the boundary conditions for the different sub projects SP2 to SP5. The European solution will be derived from the balance of maximum consistent conditions. This approach will then be used for the calculations in SP6. In SP6 the innovation, developed in SP2 to SP5 should be assessed in economic terms, whereas the technical assessment is carried out in the individual SP2 to SP5. This is the most important task to verify the economic impact of the innovations and to prove the main target of the project – reduction of 30% of LCC.

Work Package 6.2 defined the LCC and RAMS methods for this project and proposed a harmonized LCC calculation method to allow cross-country comparison, to identify cost drivers and assess the track components. Besides these methods the definition of common boundary conditions and requirements are fixed, the decision regarding an applicable LCC tool (D-LCC) is made and the development of a relational database proposed.

Reduced life cycle cost by 30% and the improved quality (RAMS) of the infrastructure are two of the main targets of Innotrack. To reduce the overall LCC we need a low install cost as well as reduced maintenance costs. In addition to costs, environmental requirements like noise pollution, particle emissions and vibrations also have become crucial issues for railway operations. Above all this project will also consider future requirements regarding increased tonnage, increased speed and increased axle loads. This will be taken into account by LCC sensitivity cost analysis on speed, axle loads, tonnages etc. to compare the systems in terms of social economic effects as well as technical improvements. In this respect a system will be delivered and assessed not only fit for current use but also with the capability for significant improvement to future needs.

These main targets of this project and the future needs to be taken into account are:

- Reduced life cycle costs by 30%
- Improved travel time by 25-50%
- Doubling of passenger traffic and triple-freight by 2020
- Reduction of noise by 69dB freight and 83dB for high speed
- Increasing safety - reduced fatalities by 75%
- Increased axle loads
- Increased speeds
- Improved RAMS

A evaluation regarding the state of art result a low regularity of use of RAMS and LCC and no common understanding of different RAMS and LCC. To establish a common base of understanding of RAMS and terminology and methodology, a basic training workshop LCC has taken place on 26-27 February 2008 in Paris conducted by DB. The training contained the LCC methodology with theoretical background, results of the software benchmark, and exercises of test cases in LCC analysis with the software D-LCC.

3.1 Common boundary conditions and methods

To make an LCC-calculation there is a need to fix the appropriate boundary conditions and to identify the relevant costs and intervals during the whole life cycle of a product, that is to say:

- boundary conditions
- make clear what is within the calculation and what is not (s. In/Out Frame)
- a product break down structure (PBS)

- a cost break down structure (CBS)
- a cost model

The classic LCC phases are according to IEC 60300-3-3: concept and definition, design and development, production, installation, operation and maintenance and disposal. For operators another diversification is useful, because the phases are more orientated on producers. As purchasers the R&D costs are part of the purchasing costs and the IMs start with the installation. DB developed thus a cost block structure to allocate the overall cost to the important phases, explained in the following chapter.

With different projects DB changed the typical EN 50126 structure to the DB cost matrix (Figure 1), which fits to all the products. The main focus was herby on the unification of the used terms. This definition allows the comparison of each cost block of different calculations independent of the analyst. Also an important point is the standardized form of the useful explanations of the LCC, taking into account the data and uncertainties.

When applied to railway track LCC analysis, the cost matrix can be summarized as the example of Fig.1.

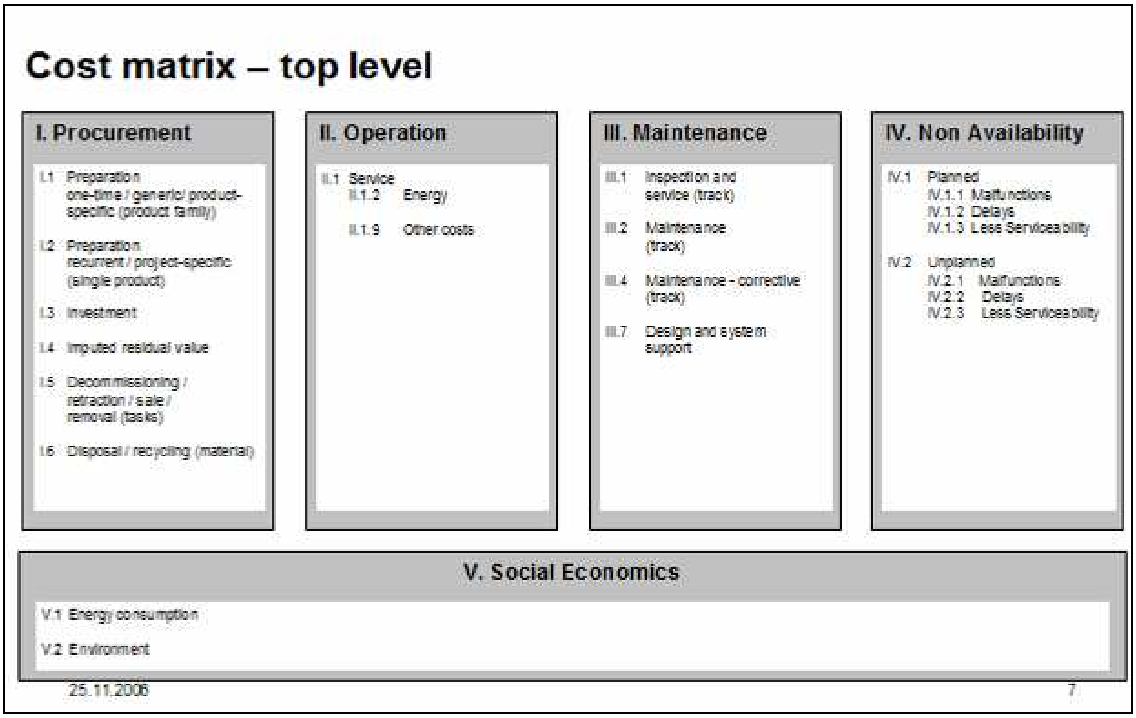

Fig. 1: Example of DB AG short version of LCC cost matrix for railway track analysis.

This standardised cost matrix for LCC used as basis for assessment, which describes all costs. National costs for national standards, safety or environmental protection which facilitate the international comparison of LCC and technical values have to be identified. Environmental cost needs to be considered while modelling LCC. 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.

To minimize the time and effort for LCC calculation the CBS in the LCC model related to the track components so that each component is marked with its own CBS as the following graph (fig. 2) shows. Within the generation of modular LCC model all the relevant costs of a component will be summarized the easy way instead of alternative way to sum-up the costs manually. So there is no need to select every relevant cost of the components and sum-up it in a complicated way.

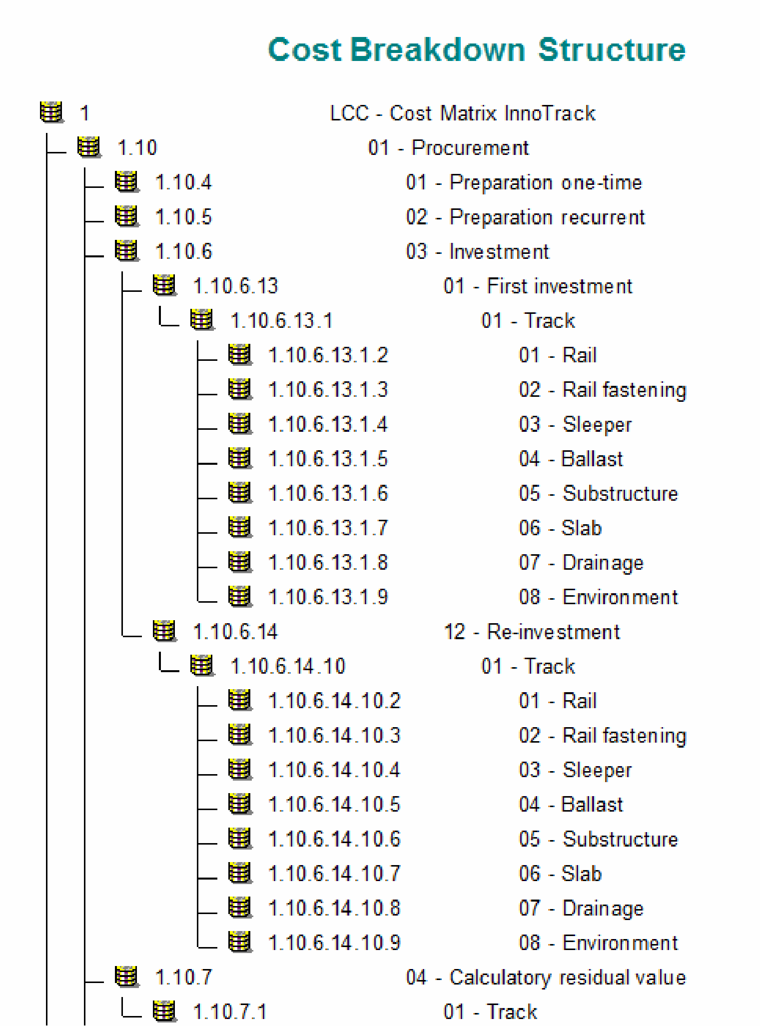

Fig. 2: Example of CBS

In order to estimate the total LCC, it is necessary to break it down into the cost elements. Each cost element is defined by its 3 dimensions:

- breakdown of the product to lower indenture levels (PBS)
- the cost category of applicable resources such as labor, materials, fuel, etc. (CBS)
- the time in the life cycle when the work/activity is to be carried out/ the costs occur – its life cycle Phases

The CBS is a tree structure of the duty and costs that occur along the entire life cycle of a product. The PBS is a hierarchical tree structure of components that make up a product that can help clarify what is to be delivered by the project and can help build a work breakdown structure (WBS). These two structures, the PBS and the CBS, are connected through cost equations, since each cost element depends on the used material, the parameters of the material, etc., until the lowest indenture level (Fig. 3) The PBS might include product characteristics and variables that can be used as input for those cost equations.

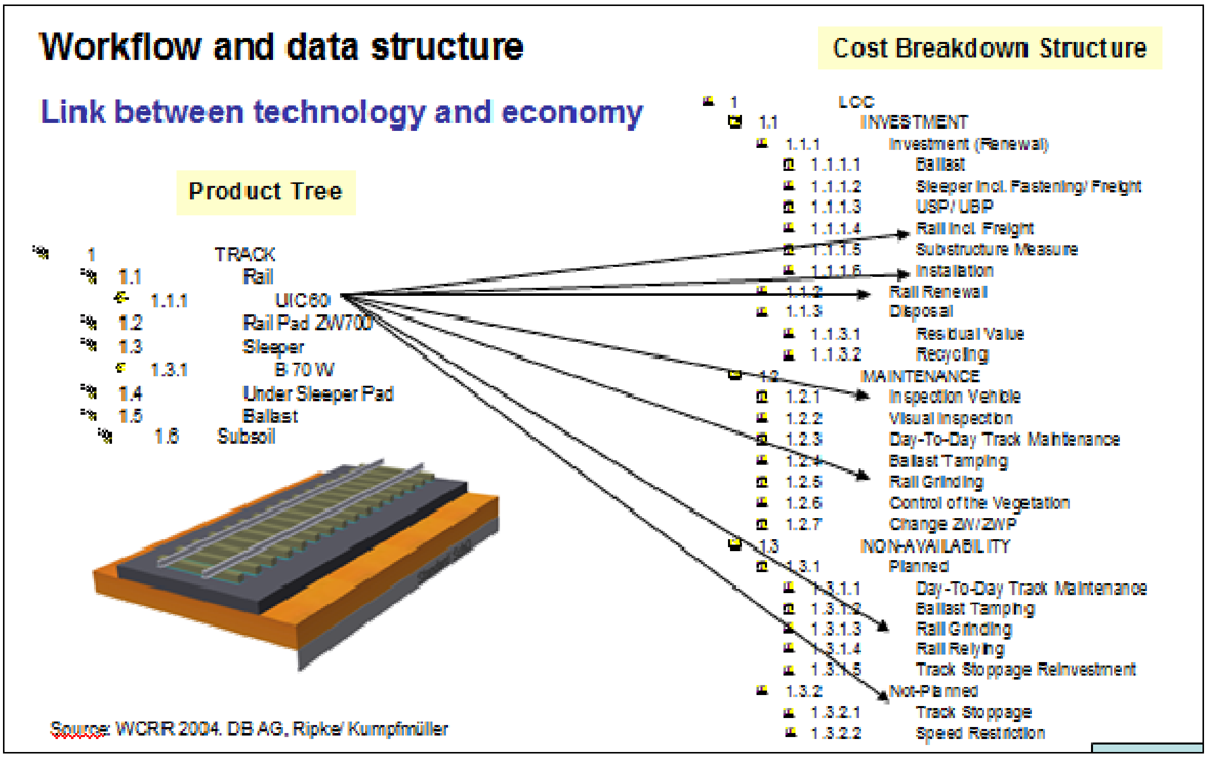

Fig. 3: example of a Product Breakdown Structure (PBS) and a Cost Breakdown Structure (CBS) (using D-LCC software application)

The graph below shows the PBS regarding Rail:

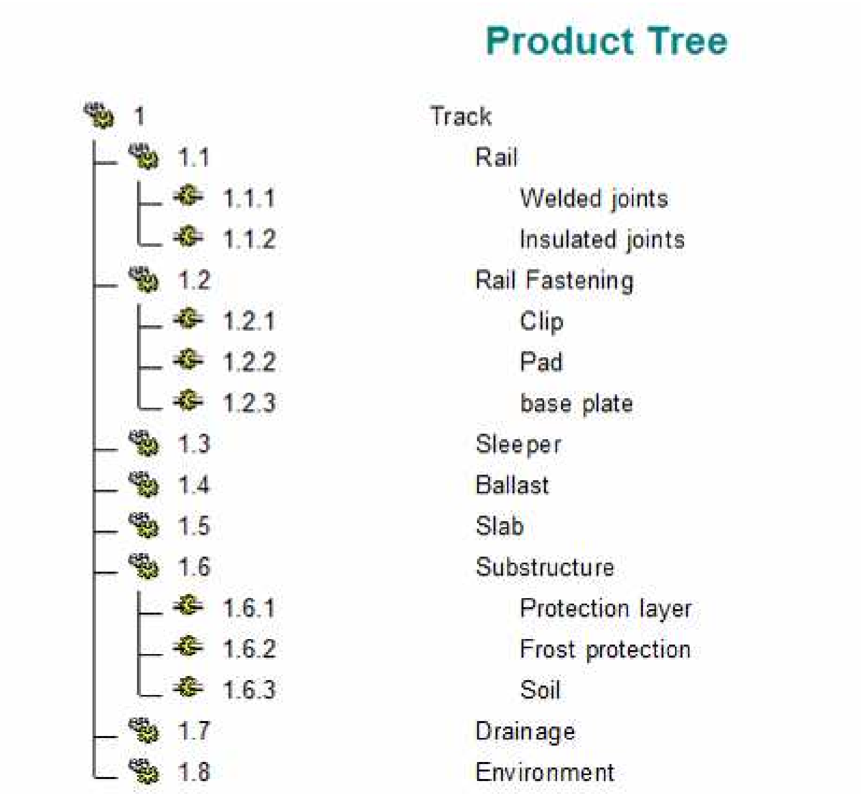

Fig. 4: example of a Product Breakdown Structure of modular LCC model Rail

The definition of the impact of each innovation should refer to what is new (general description) and an identification of which specific cost elements does the innovation affect (including the breakdown of this effect) within a reference cost matrix, as described in the following example (fig. 5). The result can be visualized as an In/Out Frame (fig.5) where one can identify those cost elements that will be part of the LCC calculation and, as a result, will require a detailed clarification and possible breakdown (if applicable). The In/Out Frame assures that the appropriate boundary conditions are fixed and the question what is within the calculation and what is not are made clear.

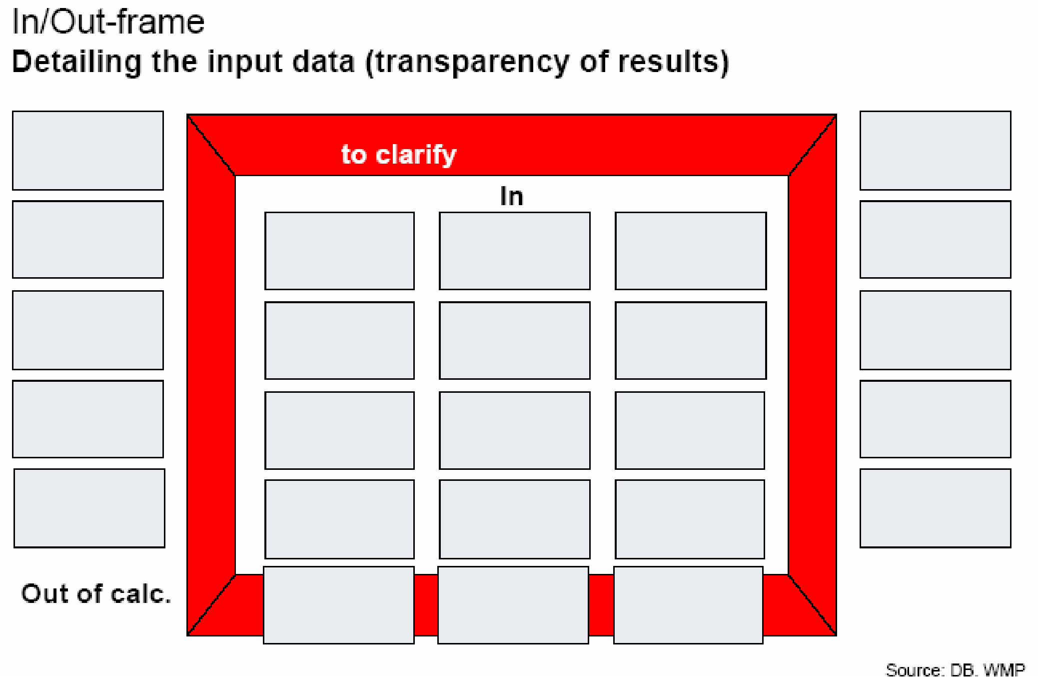

Fig. 5: In/Out Frame for identification of cost elements affected by the innovation (to be included on the LCC analysis).

Within a LCC analysis all payments – also future payments – will be referred to a reference date using the discount rate. The question was which discount rate and study period for the LCC calculation within Innotrack had to be taken into account and had to be fixed. For instance NR takes 6.5% as discount rate for infrastructure, DB 5.9%. In order to use a common discount rate and agreed study period for the LCC calculation, an evaluation needed to be done.

Economical boundary conditions are key factors on the results provided through LCCA. An in-depth evaluation of current practices concerning the discount rate and the time horizon on infrastructure project appraisal was performed. Most recent bibliography on the subject shows that, among the diversity of criteria and values adopted, there is a tendency to use reduced values for discounting combined with large periods of consideration. Based on a detailed theoretic analysis performed towards the definition of an unique criterion for discounting and the time horizon of LCCA has driven to the following decisions:

- 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 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)

These described boundary conditions are fixed and reported in WP6.2, deliverable D6.2.1 *Unique Boundary Condition*:

- common boundary conditions and methods are fixed
- cost matrix for infrastructure as basis for LCC analysis
- common *discount rate*
    - mean value of all IM's
    - public investments

- private investments
- InnoTrack - variation between low and upper values

The common boundary conditions for RAMS analysis of railway infrastructure (D6.3.1) and the requirements of RAMS analysis for infrastructure (D6.3.2) are also analyzed and defined respectively.

3.2 D-LCC as LCC Tool in Innotrack

As a result of the software benchmark in WP6.2 D-LCC was evaluated as the most suitable tool for Innotrack purposes. Besides the software D-LCC the benchmark considered the available tools like Relex-Lcc, LCC-ware, CATLOC and Unife-Unilife.

The benchmark has been carried out in WP 6.2 and described in D6.2.2 *Benchmark of LCC tools* with the following criteria:

- Basis – results of market analysis of WP 6.1
- Analysis of functionality vs. requirements
- Support
- Possible improvements
- Costs

The specific software D-LCC is designed to compare different solutions with respect to LCC optimisation, i. e. there will be the chance to compare all the calculations, to sum up and finally to extend the model as we have to calculate the full system. 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 timescale (life cycle phases).

Two training workshops held in Paris on basis of LCC and D-LCC. A basic training workshop LCC has taken place on 26-27 February 2008 in Paris conducted by DB. The training contained the LCC methodology with theoretical background, results of the software benchmark, and exercises of test cases in LCC analysis with the software D-LCC. Concerning the LCC tool a specific software training has taken place on 17th September 2008 in Paris. The software tool, import/export of data, modelling etc. have been some of the contents of the specific software training.

The required improvement of the LCC tool contains:

- General:
  - Incorporate a Monte-Carlo simulation toolbox → probabilistic output
  - Target cost as result
  - Annuity as result of NPV according to functions
  - Figures (today: Excel export): Full standard report
  - Database (reference, not to be deleted, only used)
  - Improve comparability and “check process” of inputs and detection of errors
  - Improve “Importability” of variables from database
  - Allow import of PBS data (is not on the improvement list, but we try to achieve it)
- Global:
  - extension name field
  - one more column for data source
  - one column for date
  - extension of number of globals to at least 10 000 or 64 000 to enable consistent numbering (is not on the improvement list, but we try to achieve it)

- CBS:
    - Improve Distribution functions / time dependent functions
    - Introducing stochastic variables and/or ability to directly input data from a risk analysis software
    - Allocation CBS costs to PBS (CBS is structured in PROCURMENT and MAINTENANCE – allocation to PBS, e.g. RAIL), important to identify costs drivers (both activities and components!)
- Formula:
    - Function INT is equivalent to rounding (round off), function “round up”
    - Restriction of characters within formula to be extended
- Table:
    - Import function table

Especially the improvement of the importability of variables and tables is an important feature for the work progress of generating LCC/RAMS models. For the time being the import needs more time, which makes it difficult.

3.3 Database and requirements

The main work for the LCC and RAMS analysis is to gather the relevant data. Track segments or track sections with major impact on life cycle costs are the basis for the work in Innotrack.

It is well known that the quality of RAMS related data is not sufficient in general and RAMS analysis needs more information. RAM(S) as method to get necessary LCC input data is one possibility; the other is to get the data as result of expert estimation (meeting, workshop), measurements, simulation and workshops combined with the purchase volume. Especially due to the age of the database in relation to the total life span of the track, a combination is useful or in most cases the only possibility to achieve reasonable data.

The following diagram shows schematically the accepted workflow for gathering data in the project. Start point of the analysis were the technical issues worked out during the IM’s workshops of the different railways involved in the project. During the workshops the IM’s should select up to 3 sites, which should relate to the technical issues. From a “global view” taking into account the track layout, track design and operational parameters segmentation should be carried out for those routes and the cost driving segments should be identified. The comparison between all IM’s lead either to “European cost driving segments” or to a question of best practise. For the identified cost driving segments detailed data should be gathered and provided to the technical subprojects for further analysis and technical optimisation. The workflow is described on the next page.

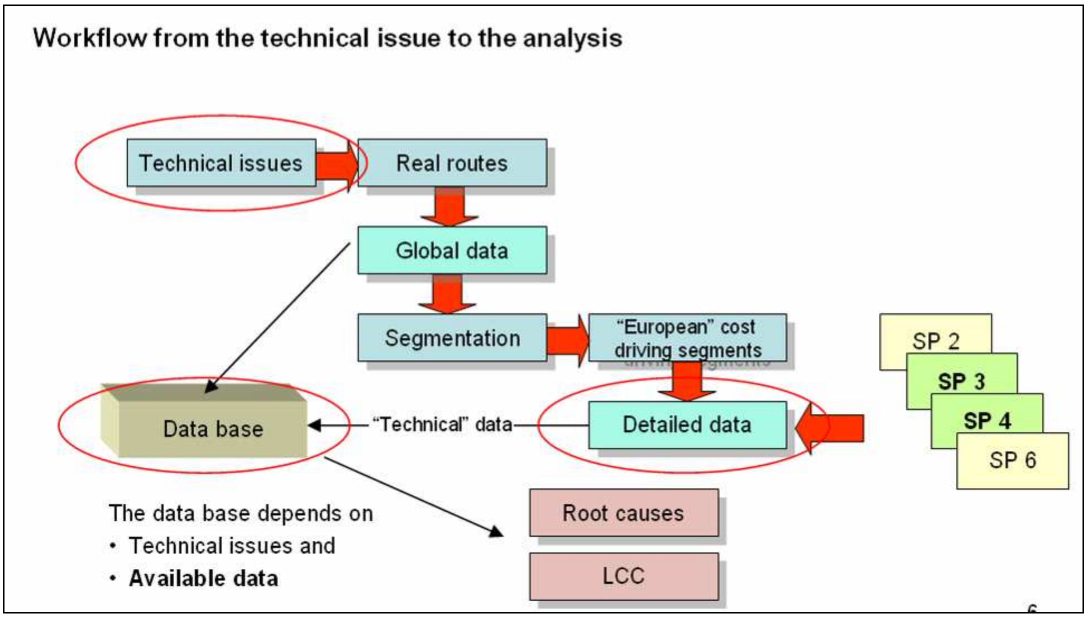

Fig. 6: workflow from technical issue to the analysis

Regarding the development of database for LCC and RAMS analysis in WP6.2 a cost structure for the main maintenance activities has been developed in order to gather data from IM's and to establish a database for calculation. There are examples defined how the cost data and cycles should be organized.

Asset	Maintenance Volumes		"Average" (network) cost		"Best practice" cost	
	Activity	Units	Cost (euros)	Description of boundary conditions	Cost (euros)	Description of boundary conditions
Rail	Grinding	track km	....	Maintenance method: ...... Possession time: .... Length of intervention:	....	Maintenance method: ...... Possession time: .... Length of intervention: ....
...	...	...	...	...	...	...

Fig. 7: example for cost database structure (source: WP6.2 - Status report 11.11.2008.ppt)

	Global n°	Cost element	Description of cost	Boundary conditions
Maintenance activity	G205	Grinding cost 0,3	Cost of grinding per km of track, with average metal removal of .... mm	Track possession: 4 to 5h ....
Material/component cost	G314	....		....

Fig. 8: example of variable "Global" numbering to facilitate cost import (source: WP6.2 - Status report 11.11.2008.ppt)

It is intended to send the revised questionnaire and to arrange interviews with IM's to gather data regarding cost figures, technical reference and optimized system (contact persons, see minutes of meeting Madrid 27th of March and Ref. 4).

As a first step it is intended to take mean values as basis for comparable LCC analysis. Within WP6.5 there is a proposal to collect the data in terms of export-templates (see chapter 4) and to import and to incorporate into the model afterwards.

But we have to be aware about the existing problems in gathering data for LCC analysis:

- Availability and quality of technical and economical data for existing systems
- Validity of data for innovations (new systems)
- Estimation of technical performance of new systems or components
- Estimation of economical data for new system
- Estimation of Non-Availabilities costs; unforeseen costs like reduction of passengers, loss of good will due to train

It is stated that it is still very difficult to rise non-availability costs. There are also differences in each nation in rising the costs related to non-availability. It is a difficult issue, because it depends amongst other factors on the way of thinking and the philosophy respectively to deal with it. On the other hand the relevance depends on the amount and impact respectively of these costs.

4. Building LCC models

4.1 Definition of reference systems & innovations for each SP

LCC is performed in order to evaluate investment alternatives. The specific software D-LCC is designed to compare different solutions with respect to LCC optimization, i. e. there will be a chance to compare all the calculations, to sum up and finally to extend the model as we have to evaluate the entire system. To achieve this aim a LCC template has been sent out to the SP leaders to be filled in with required information and data to develop the LCC model based on each SP. This contains the definition of relevant data and parameter requirements (to be delivered by SP1-5) in the field of LCC and RAMS as input to the LCC model. On the basis of the provided results the design of a proper LCC model with the essential key issues can be carried out (in D-LCC), that will meet all requirements of each SP and any particular project respectively.

Looking at the graph below, the LCC template requires a detailed description of reference cases, innovations/optimizations and future requirements (s. Annex A 6.1).

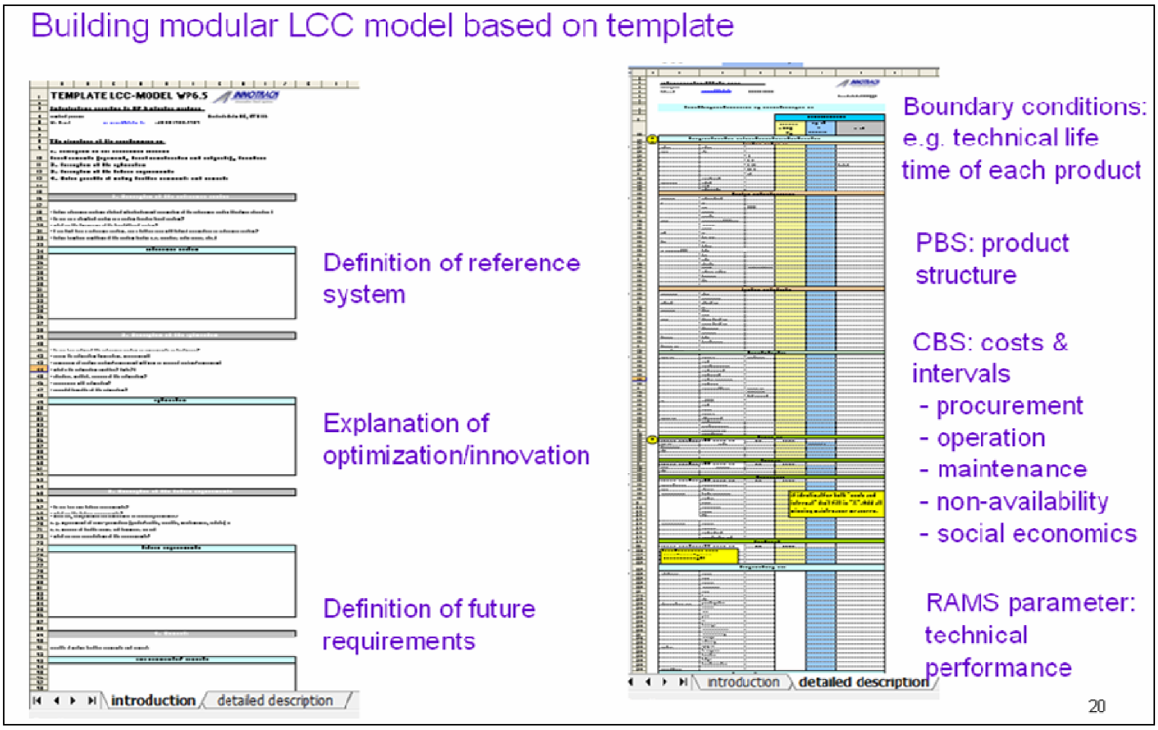

Fig. 9: First version of template for reference case, innovation/optimization and future requirements

The LCC template prepared by DB based on excel sheet contains an introduction part for the description of the base case, innovation and future requirements and a second part for detailed description of technical and cost structure and all relevant input data for RAMS and LCC analysis.

I. The introduction part of the LCC template has the following structure and questions:

1. Description of the reference system: track elements (alignment, track construction and subgrade), boundary conditions and track condition

- definition of reference system: a detailed introduction and explanation of the reference system (technical structure)
- description if standard system is used or a certain track or track section
- description of the dimensions of the track/track section
- if no reference system is used, description of a fictitious case with defined parameters as reference system

- definition of boundary conditions of the system (loading e.g. collective, radius curve, etc.)

2. Description of the optimization/innovation
   - description if an optimised reference system or components or technology has been developed
   - explanation of the optimisation (innovation, improvement)
   - description of the comparison of existing system/component with new or improved system/component
   - explanation of what the optimization is aimed for and why
   - description of the strategy, method and process of the optimisation
   - description of the experiences with optimisation
   - explanation of the expected benefits of the optimization

3. Description of the future requirements
   - description of future requirements (if any)
   - description of which field, components are concerned by these requirements
   - improvement of rams-parameters or e.g. increase of traffic volume, load tonnage, axle load
   - description of the expectations of the requirements

II. The detailed part has the following structure in order to collect the required data as input for LCC and RAMS analysis:
   - track characteristics – Alignment (gradient, curve, cant of the track)
   - track elements - Track construction and subgrade (superstructure type, rail, sleeper, pads, fastenings, ballast, components of S&C, subgrade, constructions, drainage etc.)
   - definition of boundary conditions (requirements in the field of LCC and RAMS, traffic volume, influence of increasing tonnage, speed and axle load, environmental impact)
   - mark effected costs (investment, operation, maintenance activities and strategies, non-availability); in general costs and intervals to build the CBS
   - state the interactions between SP's and the effects of a SP on the other SP (dependency/interaction between components)

The first step is the identification of each innovation to be assessed and its impact, a definition of the reference solution with which the innovation will be compared with (reference systems/base cases), and the definition of the boundary conditions. Additionally to support this step relevant data and parameters requirements regarding the PBS (technical structure of a system or component), the CBS (costs and intervals of investment and maintenance) and future needs and requirements (increased tonnage, increased speed, increased axle load, future environment) have to be delivered by SP1-5 as input to LCC model.

4.2 Responses to the LCC template

There were some difficulties to define the reference or base cases and to deliver the required data, e. g. the definition of boundary conditions for the base cases and the innovations, availability of data for base cases. Just a short summary of the base cases resulted from the responses and personal meetings were therefore conducted by WP6.5 with SP leaders:

- SP2: Track Support Structure: six cases are defined, in progress
- SP3: Switches & Crossings: three cases defined, in progress

- SP4: Rails and Welding: four cases defined, in progress
- SP5: Logserv: three cases, link to SP2, SP3 and SP4

The completed base cases are included in the Annex A 6.2.

We have received all the responses. In many cases they contain just general information, enough to build the LCC model but not enough to carry out LCC calculations because of lack of (cost) data. The LCC models are generated and finished, the LCC calculation will be carried out as soon as the needed cost data are provided.

Wali Nawabi (DB) is responsible for the LCC models for Track, Arne Nissen (BV) is responsible for the LCC models for S&C's. But additional support is needed for the reviewing and documentation of the generated LCC models as well as for the validation of the technical data. This currently remains an open question.

4.3 Basis for an LCC model

In the following the basis for generating LCC models are for the Track. So far the first set of the parameters has been defined by description of base cases and optimizations and the boundary conditions based on the LCC template. As a next the step the structure of the LCC model needs to be fixed by identifying the Global parameters and Tables with consistent ID's (s. Annex 6.3).

Global Variable (Global) is a variable influencing numerous elements in the Cost Breakdown Structure (CBS) and/or valid for the entire CBS. Using global variables, you make information available to all CBS items. A Table is used in D-LCC for two purposes, for defining a step-wise function (numeric Table) and defining a correspondence between the qualitative attribute and a numeric value (attribute Table). D-LCC Tables Library is a facility for defining both types of Tables.

Structure of LCC model on basis of track components:

Track

Modules		ID	Sub components - sub systems			
	Track	100	System			
	Rail	150	weld	insulated, welded j.	inclination	
	Rail fastening	200	pad	clip		
	Sleeper	250				
	Ballast	300				
	Substructure	350		protection layer	soil	
	Slab	400	plate	HBL		
	Drainage	450				
	Environment protection	500	wall	gabion	on slab	
	S & C's	600		Control	DLD	Blade

Switches & Crossings

Modules		ID	Sub components - sub systems					
	Switches	700	System	Blade	Rail	Sleeper	Fastening s.	Stock rail
	Crossings	750	System	Frog (fixed)	Rail	Sleeper	Rail pad	Wing rail
	DLD	800						
	Control Device	850						
	Heating	900						
	Point rod	950						
	Point mechanism	1000						
	Check rail	1050						

Fig. 10: Definition of structure of LCC model for track components

Looking at the graph above, the structure of the LCC model with Globals and Tables is fixed with respect to track components. For the modular LCC models for SP2 to SP5 in D-LCC Globals containing costs items and technical parameters have been identified. As basis for the LCC models and in terms of comparison of different cases a common base of numbering with a fixed structure of Globals and Tables has been defined (s figure 11), , e. g. Track starts with the ID of 100 to 149, Rail starts with 150 up to 199 etc.. This consistent ID's for Globals and Tables are valid for all track components (rail, ballast, sleeper, fastening, substructure, slab, drainage, environment).

Track						
ID			ID			Comments
100	Investment	**total investment costs**	***110***	Re-investment	**total re-investment costs**	
101		material cost	*111*		material cost	
102		transportation cost	*112*		transportation cost	
103		installation cost	*113*		installation cost	
104		planning	*114*		planning	
105		disposal	*115*		disposal	
106		spare parts	*116*		spare parts	
107			*117*			
108			*118*			
109		others	*119*		others	special costs, e.g. for removal of embedded rail
			ID			
			120	Maintenance	**total maintenance cost [€/m/a]**	
			121		Tamping intervall [a]	
			122		Shift cost [€/shft]	machine dependent
			123		Tamping performance [m/h]	machine dependent
			124		Start up & shut down time [h]	machine dependent
			125			
			126			

Fig. 11: Definition of common Globals and Tables for Track

In the next step the defined Globals and Tables have been be exported to an excel-sheet to be sent to SP2-SP5 to input with necessary data (as the figure 12 shows):

GlobNumber	GlobName	GlobValue	GlobUnit	GlobSource	GlobDate	Explanation	Comments
1	Time						
101	Number of periods	40	-				
150	Investment Rail [€/m]		[€/m]				
151	IN-Material Rail [€/m]		[€/m]				
152	IN-Transport Rail [€/m]		[€/m]				
153	IN-Installation Rail [€/m		[€/m]				
154	IN-Planning Rail [€/m]		[€/m]				
155	IN-Spare parts Rail [€/m]		[€/m]				
159	IN-Others Rail [€/m]		[€/m]				
160	Reinvestment Rail [€/m]		[€/m]				
161	RI-Material Rail [€/m]		[€/m]				
162	RI-Transport Rail [€/m]		[€/m]				
163	RI-Installation Rail [€/m		[€/m]				
164	RI-Planning Rail [€/m]		[€/m]				
165	RI-Spare parts Rail [€/m]		[€/m]				
166	RI-Disposal Rail [€/m]		[€/m]				
169	RI-Others Rail [€/m]		[€/m]				
170	CM-Maintenance Rail [€/m]		[€/m]				

Fig. 12: Excel-sheet to export of Globals and Tables

In the excel-sheets there are fixed cells, which can't be changed, and cells that have to be filled by the SP's, either using global or detailed values. Values that are well known and available could be given in detail and be broken down into the individual cost elements. But if the cost values could not be indicated clearly so a total value should be provided. For instance, the investment costs could be given in detailed distributed in material cost, transportation cost, installation cost, cost for planning, disposal and spare parts or just as a total investment cost. There are added columns in the sheets also the possibility for adding comments, source and dates used for documentation. The filled excel-sheets will be checked and then imported into the LCC model. Additional Globals are taken into account by model improvements. LCC calculation will be carried out on basis of the populated templates.

The import of the upcoming data required in the excel-sheets will be checked and then imported, as soon as the required improvement import function of D-LCC is available by ALD (see improvement list regarding D-LCC chapter 3.2). Up to now the importability of variables from database needs more effort and has to be improved.

Generation of Expressions (Formula) in D-LCC:

A document for generation and documentation of the formulas (expressions in D-LCC) is also prepared and will be available. This document contains the explanation of each variable in the expressions and the following results so that every formula is traceable and easy to follow, as the following examples show:

Nr.	Element Name	Formula	Explanation
01	Procurement		
1	Preparation one-time		
2	Preparation recurrent		
3	Investment		
	First Investment: Rail ind. Freight	c(Rail) = f1 (life time) +f2 (material cost) +f3 (installation) +f4 (freight)	

Fig. 13: explanation of formula (example)

Nr.	Element Name	Formula	Explanation
01	Procurement		
1	Preparation one-time		
2	Preparation recurrent		
3	Investment		
	First Investment: Rail ind. Freight	TBL(1,G195-G1)*(G151+G152+G153+G154)	TBL1: Invest-Table (0,5 bis -0,5 =1) G1: Time (0-40y.); G151: Material Cost: Alternative G152: Transportation Cost: Alternative G153: Installation Cost: Alternative G154: Preparation+planning Cost: Alternative G195: Time-Change (const.=0)

Fig. 14: generation of formula (example)

Review, Documentation and validation of the LCC models:

Besides the documentation of the LCC models the review of the generated LCC models is also very important. Every generated LCC model should be checked before carrying out the calculation. To get significant and resilient results of Life cycle costing a good data quality and the validation of the input data are necessary. The relevant technical data regarding the system performance (like TLT, installation, maintenance interval, maintenance activities etc.) given by SP's and IM's needed to be validated in order to assure the completeness and plausibility of LCC/RAMS input data. The level of the validation is to be determined, either full validation (e. g. in depth technical validation such as that being carried out for BBEST) or review validation (i. e. confirming the validation already carried out within the work package).

But additional support is needed for the reviewing of the generated LCC models, validation and documentation. This remains still an open question and has to be fixed.

SP6 deliver the LCC model with the defined boundary conditions and fixed structure of Globals in D-LCC. Each IM make LCC calculations itself and is responsible for the provided data by the SP's. The outcome of the conducted LCC calculations will be IM specific and national results based on national data. IM's are responsible for the reference systems (base cases), SP's for the innovations/optimizations.

4.4 LCC model for Rail and Welding (SP4)

Cases for Rail and Welding

The LCC calculation for Rail is divided into 5 different cases.

1) Study of degradation of actual and new rail steels & joints
2) Validation of tolerances and limits for rails & joints
3) Innovative laboratory tests of rail steel grades & joints
4) Innovative inspection techniques
5) Validation of new maintenance processes

The reference system consists of all parts of the track made of rail steel: straight lines, curves, switches. Regarding Maintenance it is the present situation of rail maintenance that defines the reference system (see in detail D4.5.1). Today it is mainly a corrective maintenance action based on observation and experience. Thus materials, technical structure, dimension, lubrication and loading are taken as fixed. All parameters except corrugation characteristics, insulating gap, inclination depth, axle load, speed and steel grade are considered to be constant.

In summary, the innovations aim to save (maintenance) costs and to increase reliability and availability of the track by optimizing:

- steel grade use
- maintenance (interval and strategy); the improvement will be the shift from corrective to preventive maintenance by introducing intervention cycles, metal removal requirements and specific target profiles
- materials and costs
- the ability to identify material defects in order to minimize the operational disruptions caused by inspections through the use of innovative inspection techniques and predictive capability

A complete LCC model has been generated and successful tested in D-LCC for the case of use of hardened rails. The reference system regarding the use of rail grades must have the same technical structure, dimension, lubrication and loading like the improved system beside the rail grade itself. As a boundary condition there is a dependency between radius classes and rail grade:

radius — reference System:
- < 300 m: R350HT
- 300-700 m: R260
- 700-1500 m: R260
- 1500-5000 m: R260
- > 5000 m: R260

optimised System:
- < 300 m: R400HT
- 300-700 m: R350HT
- 700-1500 m: R350HT
- 1500-5000 m: R350HT
- > 5000 m: R350HT

Cost-Breakdown-Structure (CBS):

According to the cost-matrix the costs for Procurement, Operation, Maintenance and Non-Availability are considered within the CBS, in detail:

1. Procurement:
   (1) Preparation one-time
   (2) Preparation recurrent
   (3) Investment:
      a) First Investment
      b) Reinvestment
   (4) Calculatory Residual Value
   (5) Disposal/Recycling

2. Operation:
   (1) Service

3. Maintenance:
   (1) Preparation one-time
   (2) Inspection, Diagnostics
   (3) Service
   (4) Preventive-Maintenance
      a) Replacement
      b) Grinding

c) Tamping

d) Lubrication

(5) Corrective Maintenance

a) Replacement (Fault Clearence)

b) Grinding

c) Tamping

d) Rail Break

e) Lateral Buckling

f) Others

4. Non-Availability:

(1) Planned

a) Reinvestment

b) Preventive Activity

(2) Unplanned

a) Corrective Maintenance

b) Delays

c) Stoppage, Speed limitation

Product-Breakdown-Structure (PBS):

Within the LCC model the track is divided in the following subsystems:

- Rail
- Rail Fastening
- Sleeper
- Ballast
- Substructure
- (Joints)

SP4 being responsible for Rail and Welding has to deliver the needed data for the LCC calculation. These include the technical and economical parameters like the boundary conditions and cost figures that are affected by the respective base case and innovations within SP4. With the provided technical data the technical structure (PBS) of the system should be built up, e. g. it should contain details of the components, the technical life time of the components, information regarding track characteristics (sections with amount of curve and straight line), the boundary conditions the system is operated etc. For the CBS data is needed in terms of relevant costs and frequency of activities, e.g. cost and interval of maintenance activities, intervention cycles, shift performance. In the case of SP4 there are further values required regarding degradation rates, RCF-crack-growth-rate, max. limit for grinding, planned intervention.

If there are no data available and exact values can't be provided, an estimation of expected activities and costs at least should be done. The development LCC models and the LCC analysis afterwards will be based on the provided data.

The process of building the LCC model for the embedded rail system of Balfour Beatty (BBEST) is going on. The slab track system is to be compared with the ballasted track. A questionnaire has been already sent to Balfour Beatty (Charles Penny) requiring technical parameters and cost data. The LCC calculation will be carried out based on the provided data of Balfour Beatty (s. chapter 4.5).

4.5 BBEST vs. ballasted track

One of the completed LCC model is the embedded rail system of Balfour Beatty (BBEST) which is to be compared with a ballasted track. A questionnaire has been sent to Balfour Beatty Rail requiring technical parameters and cost data. The boundary conditions have to be identified, the total cost from the phase of installation, operation and maintenance until the disposal of the system needed to be provided by Balfour Beatty Rail. The LCC calculation will be carried out based on the provided data (s. Annex 6.4).

An overview about the benefits (key points) of the BBEST slab track system:

- Low installation cost – fewer components
- Reduced maintenance – can get longer life can grind/wear down to 24mm, twice the 12mm on UIC rail
- Rail can be replaced by jacking out rail, cutting out and re-welding a new section back in
- Better inspection – Ultrasonics can inspect whole rail section, rather than just rail head
- Derailment containment with concrete guard
- Reduced weight compared to ballast – reducing impact on substructure

The LCC evaluation will consider two scenarios, one for high speed line (passenger traffic, max. speed 300 km/h) and one for mixed traffic line (mixed traffic, max. speed e. g. 160 km/h).

Of course, the ability to meet all the requirements in terms of technical and economic issues has to be assured for the embedded rail system. If a system has not the fitness for use, e. g. problems with installation or high maintenance costs based on experiences, it will not be appropriate to be assessed or even installed. There are experiences with BBEST on existing trials in Crewe (passenger traffic) and Mediana, Spain (5 years freight traffic) and tests carried out in Munich. The technical data of the BB embedded slab track bases on these mentioned trials and testings and not on long-standing experiences to deliver sufficient performance data for LCC and RAMS. In this course there are some of the open questions regarding:

- life time of the components?
- range of temperature for the installation?
- identifying cracks in the shell/pad
- stresses in the rail, rail pads wear, corrugations, corrosion

SP1 should report findings, as well as estimated confidence limits on these to feed into the LCC process.

There will be another trial of BBEST on a DB route in Waghäusl which is already approved by DB. The trial will last at least 2 years. To achieve the maximum potential from the trial the following criteria should be considered in construction and7or measured during trial:

- Moisture ingress
- Vibration
- Noise
- Track quality, gauge, lateral and vertical displacement of rail
- Study of different elastomer stiffness and the effects on noise vibration and rail wear

4.6 LCC model for S&C's

Cases for S&Cs

The LCC calculation for S&C is divided into 3 different cases.

6) Improved performance of crossings and switch-blades by using new material and better design
7) Improved performance of driving and locking devices (DLD)
8) Use of monitoring equipment to improve system reliability as well as fault finding capability

All three cases can be calculated by the same basic model but with the use of different parameters.

Reference system

The reference system is based on a single S&C placed on a mixed traffic line. Traffic load (MGT/year) is probably the most important factor for S&C degradation. The model so far has used two parameters to describe the relationship between deterioration and traffic load.

$$f = f_{10} * \left(\frac{T'}{10} \right)^{\beta} \quad (1)$$

where

f – frequency of maintenance at T' MGT/year

f_{10} – frequency of maintenance at 10 MGT/year

β – parameter for dependence (with value 2 the time dependence is linear and with value 1 there is no time dependence). Sweden has used values of 1,3 – 1,6

T' – Gross tonnage per year

To establish f_{10}, a value for maintenance frequency at 20 years age is estimated (assuming 40 years technical lifetime, 20 years is the middle value). The relation between f_{10} and the measured frequency is shown in equation (1).

Other dependencies of for instance axle load, speed have not been incorporated in the model and must be treated as separate cases with different input parameters.

CBS

CBS are formulas based on the investment, service and maintenance that normally is done. For instance corrective maintenance can be calculated by

$$C_{CM} = 8760 * (C_W * N_W * (LDT + MTTR) + C_E + C_M) / MTBF$$

C_{CM} –	Annual cost for corrective maintenance
8760 –	number of hours per year
C_W –	Cost for maintenance worker per hour
N_W –	Number of maintenance workers needed for the work
LDT –	Logistic delay time, time that is used beside the actual repair time because of travel, administration and waiting
MTTR –	Mean Time To Restoration (Repair)
C_E –	Cost for equipment
C_M –	Cost for material

MTBF – Mean Time Between Failures

Investment

Investment is incorporated as four different costs. Material cost, labour cost during installation, equipment cost and added cost for changes of the station area. The last cost can be due to changes of type of S&C when replacing an existing S&C with a larger S&C than before

Service

No service cost has been incorporated in the model. Example of service/operation cost is electric heating cost and snow removal cost.

Maintenance

Calculation of maintenance cost is described later.

Termination

No calculation termination has been included in the model.

Subsystem

The S&C can be divided into many subsystems. The following parts have been incorporated in the LCC-model.

- Switch blade
- Frog
- Switch point machine (DLD)
- Switch blade position detector
- Stock rail
- Check rail
- Heating system
- Sleepers
- Fasteners/pads
- Ballast
- Monitoring system
- Other

Maintenance actions

Maintenance is divided into preventive and corrective maintenance. The actions for preventive maintenance is based on measured and visual inspection and the corrective maintenance is based on failures reported that can affect the traffic directly. Therefore some corrective maintenance will induce train delays as well.

Each maintenance action is described by the following parameters

- Frequency (number of actions per year)
- Repair time (MTTR)
- Cost for machines/equipment
- Cost for spare parts

Some more general parameters are

- Logistic delay time
- Probability that a corrective maintenance will lead to train delay
- Train delay time per stopping failure

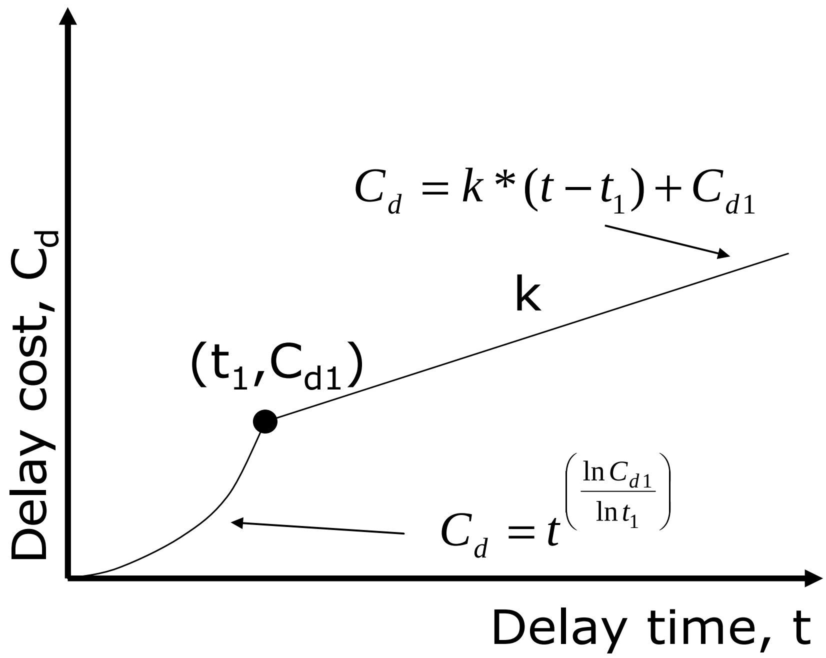

Figure 15: Cost model for train delay cost

Preventive maintenance

Preventive maintenance for S&Cs can be divided into more general actions such as

- Grinding
- Tamping

and more specific actions that is local for the S&Cs

- Welding
- Small maintenance activities(<= 15 minutes)
- Renewal of subsystem
- Repair
- Others

The local actions are described on subsystem level as the general actions is calculated for the whole turnout.

Corrective maintenance

- Small maintenance activities(<= 15 minutes)
- Repair
- Others

Train delay

Train delay can be incorporated by using three parameters for cost and give the train delay time for corrective maintenance. No train delay is calculated for preventive maintenance actions.

LCC-model

A LCC-model has been built in D-LCC. The model for S&C has been built a differently than for rail while there is problems in using a large number of parameters as globals.

The cost model has been subdivided into the 3 parts acquisition (LLCA), operation and maintenance (LSC) and termination cost (LCT). The operation and maintenance phase has been divided into corrective maintenance (CYCM), preventive maintenance (CYPM and PPM), consequence cost (LUC) and inspection cost (CYINSP).

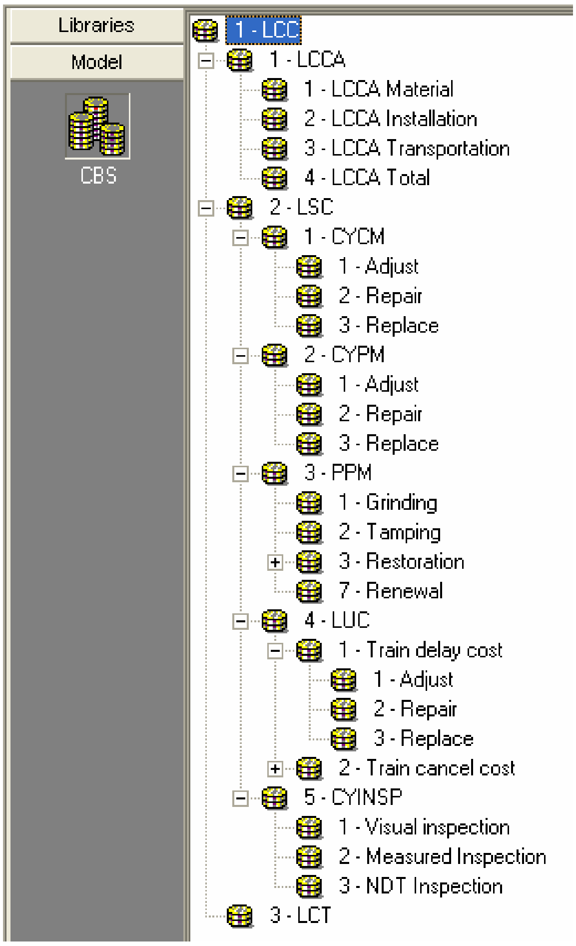

Figure 16: Cost breakdown structure for S&C-model

Data for the model is both entered in the global table (with the benefit of being possible to import from Excel) or in the product tree (PBS) (which makes the formulas much easier to write, but the values must be written into the D-LCC program).

#	Global Variable Name	Distribution	Value
31	Grinding cost/shift	Constant	24000
32	No of ground S&C/h	Constant	2
33	Prep time grinding [h]	Constant	0,5
34	Grinding Interval [MGT]	Alternative	
35	Tamping cost/shift	Constant	32000
36	No of tamped S&C/h	Constant	1
37	Prep time tamping [h]	Constant	0,2
38	Tamping Interval [MGT]	Alternative	
41	Length of a shift [h]	Constant	8

Alternative	All Periods
Normal	75
Invention	75

Figure 17a: Global variables for grinding & tamping

PM Repair MTBM:	56900
PM Repair MTTR:	6
PM Repair MWT:	1
PM Repair Equipment:	0
PM Repair Material:	0
PM Replace MTBM :	
PM Replace MTTR:	
PM Replace MWT:	
PM Replace Equipment:	
PM Replace Material:	
PM Large repair MTBM:	123400
PM Large repair MTTR:	30
PM Large repair MWT:	1
PM Large repair Equipmen:	0
PM Large repair Material:	24840

Figure 17b: Local variables for preventive maintenance of a crossing

Example of global parameters is tamping and grinding (Figure 17a). Only the interval is assumed to be different between the alternatives. Example of local variables in the product tree is preventive maintenance of the subsystem crossing (Figure 17b). Every parameter here can be changed between the alternatives.

To calculate for instance the grinding cost a formula is placed in the cost break down structure (CBS).

$$\underbrace{G31/G41*(1/G32+G33)}_{\mathrm{I}}*(\underbrace{INT((G1+1)*G16/G34)-INT(G1*G16/G34)}_{\mathrm{II}}) \quad (2)$$

Where

G1 – year

G16 – Traffic load per year in MGT

The first part calculates the cost for grinding an S&C. The second part is calculating if the S&C will be ground during a particular year. The result can be checked in a result graph.

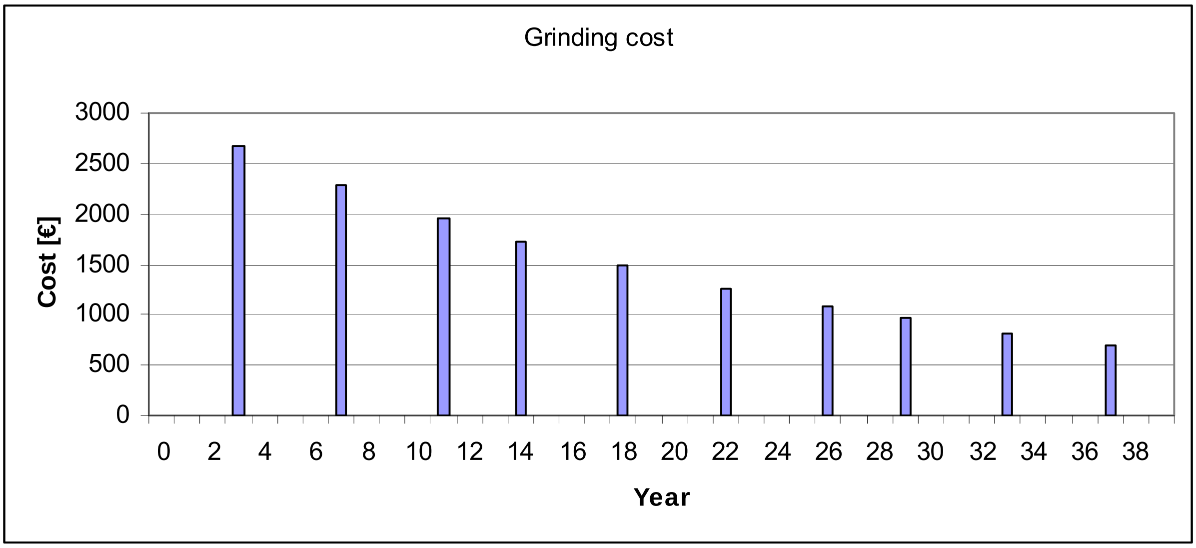

Figure 18: Cost for grinding spread over the whole life cycle (Calculated with the NPV-value).

Figure 19 and 20 show the calculation of a Swedish S&C compared to an invention with better design of crossing and switch blade which is assumed to lower the maintenance rate with 30 %. The total cost is a sum of acquisition (LCCA), operation and maintenance (LSC-Life support cost) and termination cost (LCT, is not calculated in this example). The maintenance phase is studied more in detail in figure 20.

Figure 21 show how the cost varies depending on annual load from (10-30 MGT/year). The figure show that with very low load the improvement is not of any benefit.

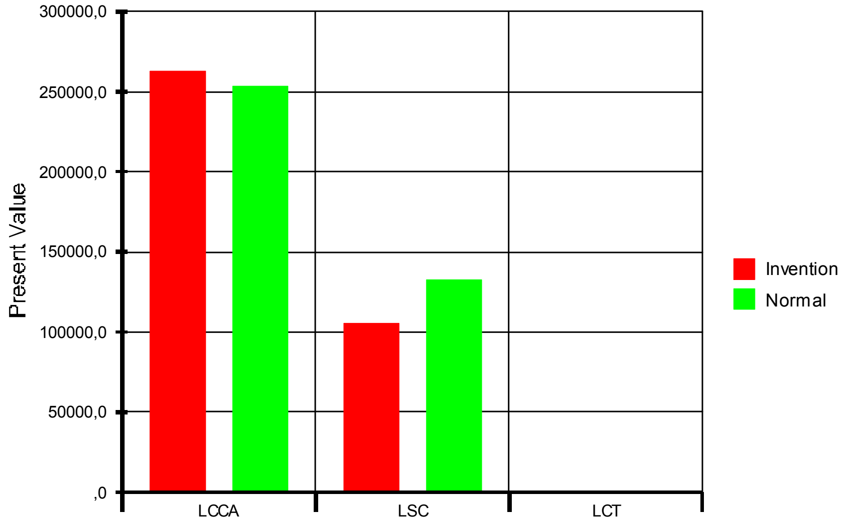

Figure 19: LCC for normal BV-S&C and an improved S&C with 30 % better performance for switch-blade and crossing. An increased accusation cost and lowered life support cost can be seen in the figure.

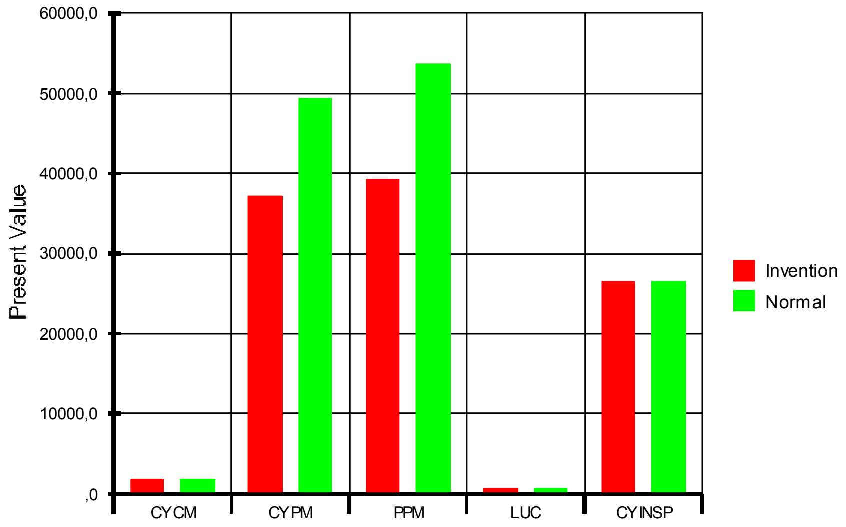

Figure 20: LSC for normal BV-S&C and an improved S&C with 30 % better performance for switch-blade and crossing

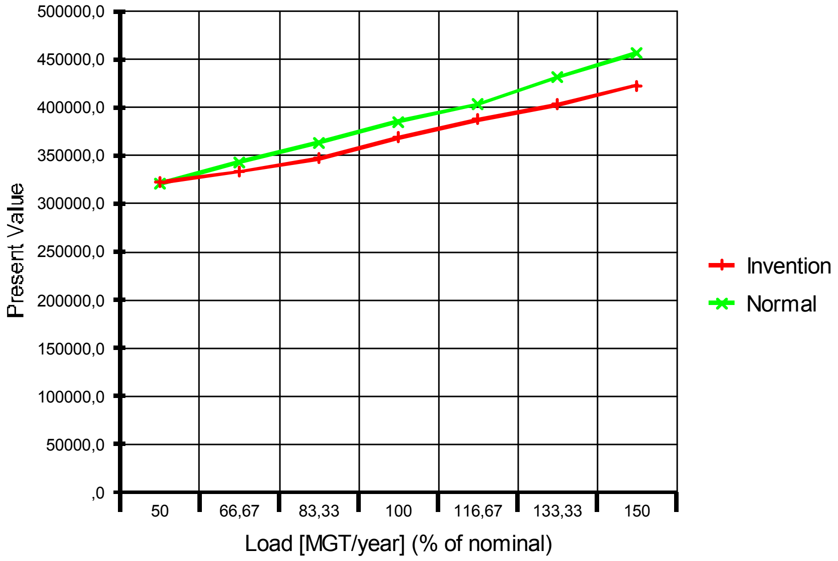

Figure 21: Sensitivity analysis for a normal BV-S&C and an improved S&C with 30 % better performance for switch-blade and crossing

5. Conclusions

As an overall measurable objective, through the innovations and changes provided by INNOTRACK, the IMs are expecting from INNOTRACK a 30% LCC reduction of track-related costs. The track costs, the major cost component for IMs have not significantly decreased in the last 30 years. To reduce the overall LCC we need a low install cost as well as reduced maintenance costs. LCC is an appropriate method to identify cost drivers in investment projects and for decision making through economic assessment and comparison of different systems. RAMS technology is a recognised management and engineering discipline to guarantee the specified functionality of a product over its' complete live cycle. In addition to costs, noise pollution also has become a crucial issue for railway operations. Both issues can only be tackled by increasing R&D and standardisation at European level. This is addressed by the EC White Paper on Transport (September 2002) that sets ambitious targets for railway operations.

The general definitions and requirements for LCC and RAMS analysis are developed and fixed, there are common boundary conditions and LCC and RAMS methodology, an applicable LCC tool and the structure to gather and harmonize data.

So far the basis for generation of modular LCC models is defined. Reference systems and innovations for each SP with defined boundary conditions resulted from the response to the LCC template of the modular LCC models by the SP's. As a next step the relevant cost data need to be gathered based on the defined cost categories and structure in order to fulfill the requirement of making LCC calculations. Regarding the implementation of the LCC models in the tool a common base of numbering of parameters (Globals) has been fixed. Thus the structure of Globals and Tables are fixed by consistent ID in the tool and can't be changed, but added and filled with value. The consistent numbering and definition of parameters (Globals) is available for all participants who are going to make LCC calculations for the purpose of having a common base for evaluation and comparison. For the defined base cases and innovations the necessary values will be collected from the SP's e. g. by using the export-templates as described in chapter 4.3. In SP6 not just the base for Life Cycle assessment will be developed but also the LCC analysis for SP1 to SP5 will be carried out including the comparable LCC analysis.

The LCC models are generated and finished with some exceptions, the LCC calculation will be carried out as soon as the needed cost data are provided. In many cases the currently provided responses are not sufficient to carry out LCC calculation because of lack of (cost) data. The first LCC calculation is going be made for the BB embedded slab track to be compared with a ballasted track. For this purpose a questionnaire to BBRail requiring technical parameters and cost data for BBEST has been prepared. LCC calculation will be carried out as soon as the requested input data made available by BBRail.

WP6.5 will deliver the LCC model with the defined boundary conditions and fixed structure of parameters (Globals in D-LCC). Thus the needed basis for carrying out LCC analysis is developed. Each IM can make his own LCC calculation with the support of SP6. The SP's have to deliver the relevant data regarding the innovations whereas the IM's are responsible for the reference systems (base cases). It should be in the interest of the IM's to do the evaluation in order to reduce the LCC and to optimize the track construction.

In addition to the taken actions the review and documentation of LCC models are important tasks to be done. For this purpose support is needed and to be defined. Also the validation of technical data provided by SP's and IM's regarding their defined reference systems and innovations is important. The validation assures the completeness and plausibility of LCC/RAMS input data. It will confirm the system performance and contributes to deliver technically and economically validated solutions. This emphasises the importance of (SP1) validation in this project and the history behind Innotrack only being accepted by IM's if there was the (SP1) validation of innovations.

This deliverable reports the current work progress concerning the development of modular LCC and RAMS models for SP2 to SP5. Further work will be done in terms of LCC calculation for the assessment of technical and economical effects of innovations.

Also a Guideline for LCC/RAMS analysis will follow within Work Package 6.5. A team for developing the Guidance is already fixed and will contribute to this work. Gregor Hirsch (VS), Frank Norbert (VAS) and Anton Lamper (ProRail) will support the development of Guidance for LCC/RAMS analysis (D6.5.4). DB will take the part of the lead management for coordination and management tasks.

6. Annexes (optional)

6.1 LCC template

6.1.1 Introduction part of the LCC template:

TEMPLATE LCC-MODEL WP6.5

INNOTRACK
Innovative Track Systems

Introduction: regarding to SP 6 industry meetings

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Wali Nawabi wali.nawabi@bahn.de +49 89 1308-3287

The structure of the questionnaire is:

1. description of the reference system:
track elements (alignment, track construction and subgrade), boundary conditions and track condition
2. description of the optimisation
3. description of the future requirements
4. Note: possibility of making further comments and remarks

1. Description of the reference system

- define reference system: a detailed introduction and explanation of the reference system (technical structure)
- do you use a standard system or a certain track or track section?
- what are the dimensions of the track/track section?
- if you don't have a reference system, use a fictitious case with defined parameters as reference system?
- define boundary conditions of the system (loading e.g. collective, radius curve, etc.)

reference system

2. Description of the optimisation

- do you have optimised the reference system or components or technology?
- explain the optimisation (innovation, improvement)
- comparison of existing system/component with new or improved system/component
- what is the optimisation aimed for? (why?)
- strategy, method, process of the optimisation?
- experiences with optimisation?
- expected benefits of the optimisation?

optimisation

3. Description of the future requirements

- do you have any future requirements?
- what are the future requirements?
- which field, components are concerned by these requirements?

'e. g. improvement of rams-parameters (quality/reliability, availability, maintenance, safety) or
'e. g. increase of traffic volume, load tonnage, axle load

- what are your expectations of the requirements?

future requirements

4. Remarks

possibility of making further comments and remarks

any comments/ remarks

6.1.2 Part for input data regarding LCC and RAMS

Introduction: regarding to SP 6 industry meetings

contact person:
Wali Nawabi wali.nawabi@bahn.de +49 89 1308-3287

Deutsche Bahn AG, VTZ 116

Detailed description of the reference system, optimization and future requirements

			SP2, SP3, SP4, SP5		
			reference system (SP1 + Spx)	**optimized system (alternative 1)**	**remarks**
PBS	**Description of the track elements, boundary conditions and track condition**				
Track elements - Alignment					
straight line	gradient				
curve	radius				
		<300 m	x		
		300 - 700 m	x		
		700 - 1500 m	x		ProRail 3.000m
		1500 - 5000 m	x		
		>5000 m			
	cant of the track				
transition curve	clothoid				
	sinusoid				
	cubic parabel				
Track elements - Track construction					
superstructure	type (ballast, slab track)				
rail	type				
	profile	E2, E1			
	inclination				
	steel grade				
sleeper	type (steel, concrete, S&C hollow)				
	mean span				
	fastening				
pads	type				
	dynamic stiffness				
ballast	type				
	thickness				
components of a S & C	Blade				
	Frog				
	stock rail				
	check rail				
	point rod	mechanic/ hydraulic			
	switch point machine				
	Monitoring system				
	Others				
Track elements - Subgrade					
protective layer	sub-layer				
	frost protective layer				
earthwork	embankment				
	cut				
contruction	bridge				
	tunnel				
transitions	bridge/embankment				
	tunnel/embankment				
	bridge/tunnel				
	level crosing				
drainage	ditches				
	deep drainage				
different settlements					
special characteristics					
Boundary Conditions					
requirements	service life-time	unit of the lif cycle			
	periods				
	restrictions during installation				
	regarding availability				
	regarding reliability				
	regarding maintenance				
	regarding safety				
	construction with best lcc	low investment			
		high availability			
		high maintainability			
traffic	load (MGT)				
	speed				
	type of line				
	traffic volume				
environment	solid-borne-sound				
	sound insulation				
	atmospheric influence				
	national requirements				
	special charasteristics				

CBS

Procurement					
Examaples - note complete ! Please add missing elements.		**costs**	**interval**		
investment	e. g. Rail	x	x	extension of life time	
disposa/recycling					
others					
Operation					
Examaples - note complete ! Please add missing elements.		**costs**	**interval**		
service	e. g. energy	x	x		
others					
Maintenance					
Examaples - note complete ! Please add missing elements.		**costs**	**interval**		
inspection/diagnostic	control of vegetation	x	x		
service	lubrication				
maintenance (repair)	day-to-day maintenance				
	rail grinding				
	tamping				
	fault clearence				
	renewal				
	Others				
maintenance strategy	corrective				
	preventive				
	condition-based				
	planned/predetermnied				
Non-Availability					
Examaples - note complete ! Please add missing elements.		**costs**	**interval**		
Description of the optimisation					
methods, process	installation				
	transport				
	operation				
	maintenance				
	service				
	disposal				
	others				
objectives of the optimisation	quality of the product				
	alternatives				
	materials				
	process				
	costs				
	data storage				
	maintenance interval				
	maintenance strategy				
	monitoring system				
	technology				
conditions	equipment				
	human-power				
	know-how				
	budget				
	boundary conditions				
expected benefits					
Description of the future requirements					
regarding lcc	low investment				
	high availability				
	high maintainability				
regarding rams	availability				
	reliability				
	maintenance				
	safety				
materials					
process					
costs					
data storage					
technology					
boundary conditions					
traffic (load, speed)					
	increas of number of the trains				
	increase of load tonnage				
	increase of axle tonnage				
failure					
equipment	e. g. monitoring system				

if identical for both "costs and interval" don't fill in "X". Add all missing maintenance measures.

due to III. Maintenance measures; mention, if shortened possession time or extension of length (shift m).

6.2 Overview base cases and innovations based on the responses

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WP 6.5 LCC and RAMS analysis

Base Cases and innovations for Modular LCC Model

Deutsche Bahn AG

Wali Nawabi

Munich, 11.11.2008

Sixth Framework Programme

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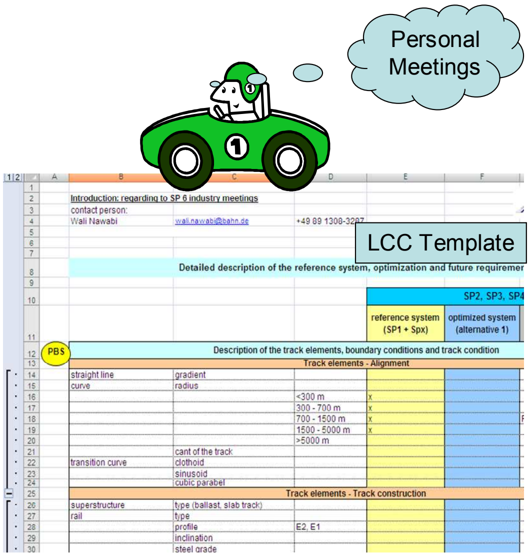
WP 6.5 LCC and RAMS analysis



Definition of base cases SP2 – SP5

- **SP2: Track Support Structure**
  six cases, in progress,
  one case nearly finished (BBEST)
- **SP3: Switches & Crossings**
  three cases defined, in progress
- **SP4: Rails and Welding**
  four cases defined, in progress
- **SP5: Logserv**
  three cases, link to SP2, SP3 and SP4

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SP2: Track Support Structure

As there are three reference cases identified in the SP2 (WP2.2):

1. **Low bearing zone** (Carolina Meier-Hirmer, SNCF)
2. **Soil strengthening under existing railway embankment** (Alexander Smekal, BV)
3. **Transition zone** (Miguel Rodriguez, ADIF)

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SP2: Track Support Structure

1. **Low bearing zone**

- the reference track is a certain existing track section of the French National rail network (the Chambéry-Montmélian two track line)
- the section is a double track of 7 kilometers length inside the Alpes
- ballasted track, mixed traffic, constant tonnage 14 MT/year for each direction, 140 km/h, number of trains: 60 trains/day for each direction
- subsoil problem (track bed): improvement of platform should be done because of drainage problems and probably increase of traffic
- huge maintenance activities, repeated track levelling

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SP2: Track Support Structure

1. Low bearing zone

- there is so far no optimization of this reference system
- maintenance experts think that the track could be improved by doing an subsoil improvement in order to solve the drainage problem
- the renewal of the superstructure had not the expected effects, the problem still remains
- improvement of maintenance: more efficient with less costs
- other improvements proposals: subgrade improvements methods (columns, geotextile)
- future requirement: developing measurements tools in order to identify the subsoil problems at early stage (before renewal of superstructure) as a future requirement

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SP2: Track Support Structure

2. Soil strengthening under existing railway embankment

- Full scale test - installation of 10 rows of lime cement column walls - strengthening of 14 m of subsoil under existing railway embankment
- Existing track is placed on ca 3,5 embankment founded on very soft organic clay. Control calculation of stability have shown stability factor close 1 in comparison with required safety factor 1,5. Stability of embankment and subsoil has to be secured before the line is open for higher axle load (from 22,5 t to 25 t).
- Several strengthening methods have been studied to increase the stability but have not proved satisfactory.
  - excavation of existing embankment and soil strengthening using traditional vertical lime cement columns
  - in many cases so called loading berms are used. Those extra surcharge usually cause additional settlements and deterioration of track geometry.

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SP2: Track Support Structure

2. Soil strengthening under existing railway embankment

- New method using inclined lime cement columns installed in walls has been suggested and tested as a full scale test (10 walls). Only vertical columns have been used before.
- Soil improvement under existing railway that can be carried out without traffic interruption.
- Good experience, no need for tamping up to now (3 months after test installation), no limits for railway operation during installation as regards train speed and axle loads.
- The full scale test is under evaluation measurements and testing is still in progress and will be finished the next year (2009).

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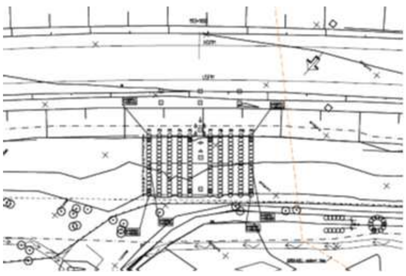
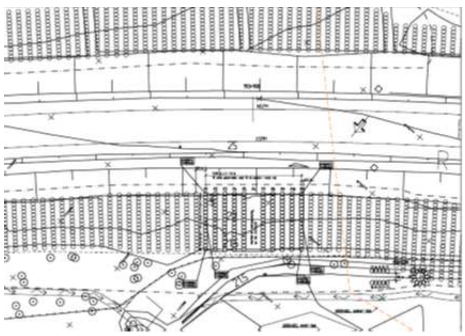
SP2: Track Support Structure

2. Soil strengthening under existing railway embankment

Full scale test (performed within INNOTRACK SP2) - Installation of inclined lime/cement column walls





The total strengthening of subsoil under railway bank which can be performed in the future

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SP2: Track Support Structure

2. Soil strengthening under existing railway embankment

Full scale test (performed within INNOTRACK SP2) - Installation of inclined lime/cement column walls

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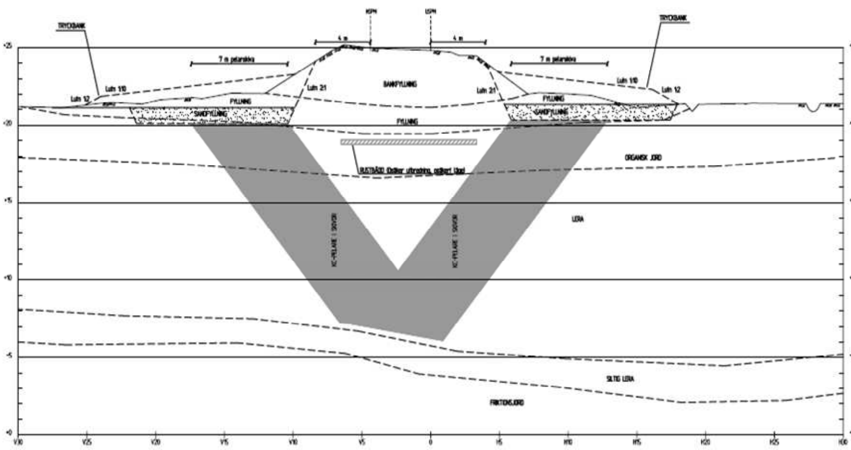
SP2 – Track Support Structure

Examples of improvements: Inclined deep Lime/Cement walls with deep mixing in Sweden

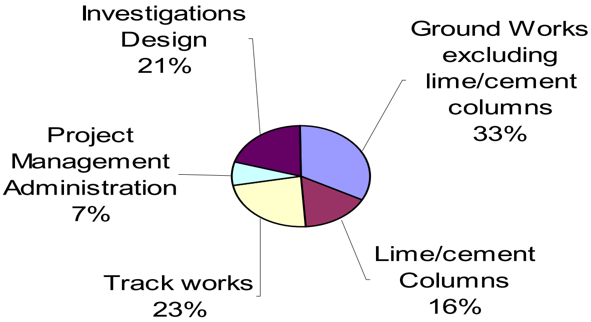


SP2 – Track Support Structure

Inclined deep cement mixing in Sweden

Time schedule and costs

Total schedule:	Three months
Deep mixing:	Two weeks
Traffic interruption:	Three weeks



SP2: Track Support Structure

3. Transition zone

- transition zone at underpass between concrete block and an embankment with an abrupt stiffness changes. The reference system is a section of conventional ballasted track without transition zone. Passenger and freight traffic.
- Zone with a strong limitation of speed (10 km/h)
- Based on the results of the geotechnical study undertaken, the type and extension of the improvement treatment have been defined.
- Track stiffness measurements to measure the loads and deformations at the real transition zone and to compare the results before and after the improvement.
- Improvement of only 32 m of the embankment, at both sides of the concrete block, by replacing 2,5 m from lower part of the slepper with QS-3 type material reinforce with two layer of geogrid. Ballast at both sides and over the concrete block should be replaced by a 35 cm thick layer of high quality ballast.
- Objectives: to reduce the maintenance cost and to remove the strong limitation of speed; a consistent and acceptable track stiffness.

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3. Transition zone

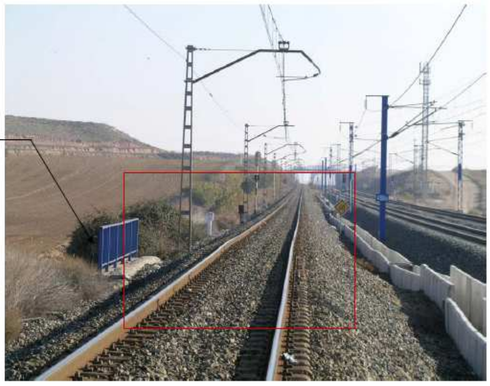
int-sp2-07-100108-f-Rodriguez-ADIF 2.2.p

Location test site

Embankment with an underpass in the conventional line Zaragoza – Barcelona
K.P. 173+300 – K.P. 173+950

Transition zone at underpass (Between structure and embankment)

Track Foundation



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3. Transition zone

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3. Transition zone

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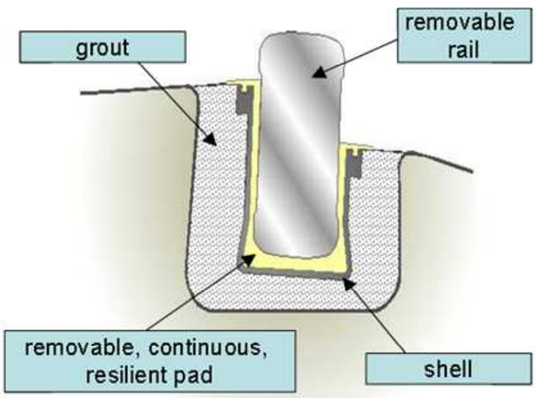
SP2 – Superstructure Optimisation

Innovative Track Forms - BBEST



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SP3: Switches & Crossings

As there are three reference cases identified in the SP3:

- **SP3.1: Switch blade and Crossings** (Wolfgang Groenlund, DB)
- **SP3.2: Driving and Locking Devices** (Roland Bänsch, Contraffic)
- **SP3.3: Innovative Monitoring Systems** (Samuel Salas, VCSA)

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SP3.1: Switches & Crossings

- optimization of frogs and blades (design & material):
  - **switch blade zone**
    - vertical elasticity at the area of switching zone (Banverket)
    - horizontal elasticity at the area of switching zone (DB)
  - **crossings**
    - design/geometry of crossings in the overflow area for EW 60-500 1:12 (DB)
    - vertical elasticity at the common crossing assembly for EW 60-500 1:12 (DB) und UIC60-760-1:15 (Banverket)
    - optimization of materials for crossings by compared testing of different materials on a test plant in Kirchmöser

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SP3.1: Switches & Crossings

1. Switch blades

- **horizontal elasticity / vertical elasticity** at the area of switching zone
- switch with W-fastenings with "lower" (normal) horizontal stiffness (with angular guide plate of plastic)
- heavy duty conditions regarding tonnage; switch located in a curve (worst case)
- optimization:
  - to optimize the **horizontal blade elasticity / vertical blade stiffness**
  - fastenings with higher horizontal stiffness to increase lifetime of blade and stock rail (with angular guide plate of steel = Ks-fastening)
  - options for optimization of maintenance: limit values, best practice and optimization of lubrication

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SP3.1: Switches & Crossings

- the optimization of **maintenance** (procedure, intervals, strategies):
  - definition of limited values for crossings for grinding, welding
  - finding **best practice** by comparison of maintenance and repair strategies of other IMs on the base of questionnaires under the consideration of different boundary conditions.
  - optimisation of **lubrication** of switches (questionnaires to the IMs, testing of lube oil instead of grease)

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SP3.1: Switches & Crossings

1. Switch blades

- **vertical elasticity** at the area of switching zone (BV)
- BV: UIC 60-760-1:15
- TLT of switch blade:?
- mixed traffic; 50.000 t/d
- switch blade on a straight line, not in a curve

- BV: Optimization**:** optimized **vertical blade stiffness:**
- general: definition of limit values for maintenance actions (i.e. grinding, welding of switches)
- no angular guide plate
- Pandrol --> data?

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SP3.1: Switches & Crossings

2. Crossings

- design/geometry of crossings in the overflow area for EW 60-500 1:12 (DB)
- vertical elasticity at the common crossing assembly for EW 60-500 1:12 (DB) and UIC60-760-1:15 (BV)
- optimization of materials for crossings by compared testing of different materials on a test plant in Kirchmöser
- frog material: bainitic steel 1400-1500 MPa, normal stiffness
- TLT: depends on loading; TLT to be referred to testing track on test plant in Haste/Germany
- DB: optimized frog geometry and vertical frog stiffness
- frog material: manganese ?, normal stiffness
- straight line, mixed traffic; 50.000 t/d
- optimized vertical frog stiffness

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SP3.2: Driving and Locking Devices (DLD)

- ❑ Manufacturing of innovative DLD
- ❑ the application of innovative driving and locking systems
- ❑ sleeper Hollow for DLD
- ❑ digital interface for communication with interlocking system
- ❑ minimizing inspection of DLD’s (longer inspection intervals)

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SP3.3: Monitoring systems

- ❑ reference system: turnout without monitoring system
- ❑ UIC 60-760-1:15 (Banverket); UIC 60-500-1:12 (DB) as main example for SP3;
- ❑ technical life time: 15 y. (crossings), 15 y. (switches), 30 y. (other components)
- ❑ components: switch blade, frog, point rod, point mechanism, check rail, stock rail, DLD, fastenings, sleepers
- ❑ strategical turnouts in network knots;
- ❑ every type of traffic line (high speed, mixed traffic, freight traffic, regional traffic)
- ❑ type of track: ballast or slab track
- ❑ mechanical or hydraulical point machine with several driving rods;
- ❑ locking device; detection devices;
- ❑ heating system: gas or electrical;
- ❑ interactions between SP2, 4 and 5.

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SP3.3: Monitoring systems

- optimized system: turnout with monitoring system
- optimization of costs of monitoring systems
- reduction of inspection needs
- reduction of failure rate
- increase of technical life time of the components
- increase of preventive maintenance
- decrease of corrective maintenance

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SP4: Rails and Welding

- **SP4.1 Study of degradation of actual and new rail steels & joints** (VAS: Peter Pointner, Hans-Peter Brantner; CORUS: Jai Jaiswal)
- **SP4.2 Validation of tolerances and limits for rails & joints** (Anders Ekberg, Chalmers)
- **SP4.3: Innovative laboratory tests of rail steel grades & joints** (Detlev Ullrich, DB)
- **SP4.4: Innovative inspection techniques** (Louis Girardi, SNCF)
- **SP4.5: Validation of new maintenance processes** (Wolfgang Schöch, SPENO)
- **SP4.6: Innovative welding processes** (Steffen Altendorf, R. Gehrmann, Goldschmidt)

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SP4.1 Study of degradation of actual and new rail steels & joints

- the innovations included so far are the extended use of hardened rails and a improved maintenance strategy
- hardened rails
  - dependence between radius classes and rail grade
  - optimizing of steel grade extended use of hardened rails
  - strategy identical but the frequency of the maintenance activities will be different
  - optimizing materials and costs
- maintenance strategy
  - optimizing of maintenance (interval & strategy) and welding
    shift from corrective to preventive maintenance, probably a combined maintenance and monitoring

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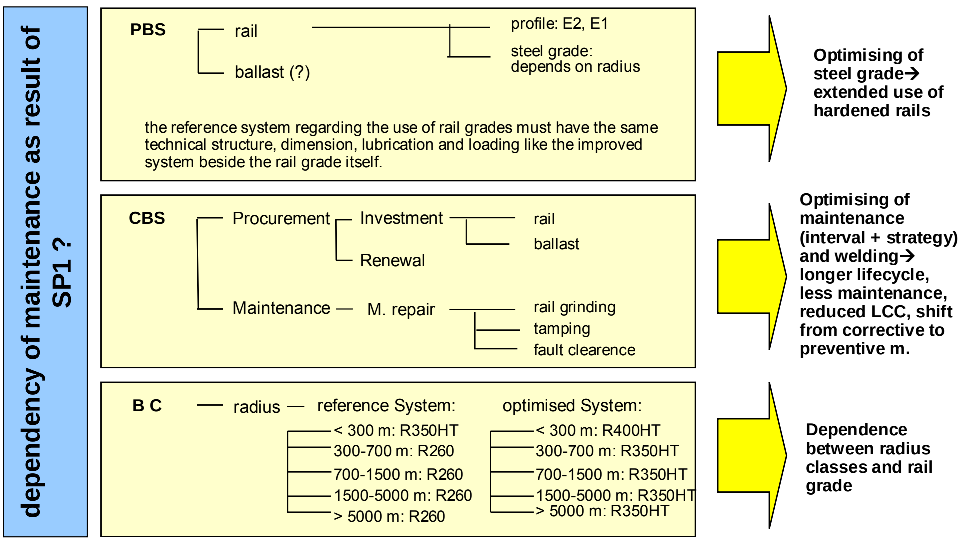
SP4: Description of track elements, PBS, CBS and BC (boundary condition)



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SP4.2: Validation of tolerances and limits for rails & joints

- 5 identified areas where the research is likely to give LCC gains
    - corrugation
    - insulated joints
    - squat
    - wheel flats
    - influence of rail hardness on wear

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SP4.2: Validation of tolerances and limits for rails & joints

- corrugation
    - A (more or less) **tangent track with corrugation of a certain amplitude** operated by a vehicle of a certain axle load, at a certain speed etc. All parameters except corrugation characteristics, axle load and speed are considered to be constant for each case studied.
    - The operational optimization rests on the evaluated **influence of corrugation on deterioration**. Based on this information it is for certain operational conditions possible to optimize maintenance limits (e.g. allowed corrugation spectra), maintenance practices (e.g. grinding), maintenance processes (e.g. intervention intervals), and operational conditions (e.g. speed and axle loads).
    - The optimization will reduce costs (grinding costs, cost of replacing cracked rails), decrease traffic disturbances, shift from emergency to planned maintenance and increase reliability and availability. To some extent also safety will be improved (due to less risk of fractures).

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SP4.2: Validation of tolerances and limits for rails & joints

- insulated joints
    - Insulated joint with **a certain insulating gap and a certain dip**. Currently there are differences in adopted insulating gaps and allowed inclination dips throughout Europe. In the study all features except insulating gap, inclination depth and operational conditions (i.e. train speed, normal and lateral load etc) will be presumed constant. Examples of current values are insulating gaps 4mm (Sweden), 6 mm (Netherlands) and allowed dips 4-5 mm unloaded (Sweden) and 10 mm loaded (Netherlands).
    - The operational optimization rests on the evaluated **influence of insulating gap, joint dip and operational parameters on deterioration**. Based on this information it is for certain operational conditions possible to optimize maintenance limits (e.g. allowed joint dip), maintenance practices (e.g. tamping, grinding), maintenance processes (e.g. intervention intervals), and prescribed geometries (e.g. insulating gaps).

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SP4.2: Validation of tolerances and limits for rails & joints

- squat
    - A (more or less) **tangent track with a certain steel grade contains squats** of a certain character operated by a vehicle of a certain axle load, at a certain speed etc. All parameters except these are considered to be constant.
    - The operational optimization rests on the evaluated **influence of squats on deterioration and (possibly) the growth rate of squats**. Based on this information it is for certain operational conditions possible to optimize maintenance limits (e.g. allowed squat size etc), maintenance practices (e.g. grinding), maintenance processes (e.g. intervention intervals), and operational conditions (e.g. speed, axle loads and steel grades).

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SP4.2: Validation of tolerances and limits for rails & joints

- wheel flats
  - The impact of wheels with wheel flats on the degradation of rails is considered. Worst-case scenarios (for different operational conditions) of wheel-flat geometry, axle load, speed etc are considered. All parameters except worst-case force history (corresponding to a certain operation scenario) are considered to be constant.
  - The operational optimization rests on the evaluated **influence of the wheel flat on rail crack initiation, growth and fracture**. Based on this information it is for a certain operational conditions possible to optimize maintenance processes (e.g. intervention levels, wheel maintenance levels) and operational restrictions (e.g. alarm limits for Wheel Impact Load Detectors).

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SP4.2: Validation of tolerances and limits for rails & joints

- influence of rail hardness on wear
  - The wear of a loaded wheel–rail interface of a certain material combination is considered. All parameters except steel grade of wheel and rail (and possibly load) are considered to be constant.
  - The operational optimization rests on the evaluated **influence of the wheel and rail steel grades on wear**. Based on this information it is for a certain operational conditions possible to optimize steel grade use (e.g. in curves or curved lines), maintenance practices (e.g. grinding), maintenance processes (e.g. intervention intervals), and operational conditions (e.g. speed, axle loads etc). This is closely related to the work in WP4.1 and the LCC evaluation should be compared (WP4.1–test sites; WP4.2–laboratory tests and numerical simulations).

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SP4.3: Innovative laboratory tests of rail steel grades & joints

- the reference system are all parts of the track which consist of rail steel: straight lines, curves, switches.
- the aim of the WP is **to improve testing methods** in order to gain time and to save money for the tests. (As in-situ-testing of e. g. new steel grades will take a lot of time).
- the optimization consists of **test procedures** by which the advantage of rail material with respect to wear and RCF can be quickly estimated under specific loads.
- the method of optimization is to improve the method of optimization. It consists in a partly **substitution of in-situ-testing by laboratory testing**. A second aim is to fit rail steel grades to the local requirements of the track. The benefit is a gain of time at introducing improved, low-maintenance steel grades.

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SP4.4: Innovative inspection techniques

- a core part of any strategy for planned rail maintenance is **the ability to identify material defects**
- in WP4.4 the focus is on critical evaluation of **innovative non-destructive test methods** for identifying and quantifying factors that have an influence on the **rail/joint degradation**, such as defects, rail geometries, etc. The work will be supported by the tolerances established in WP4.2
- WP4.4 has a strong interaction with SP5 and SP6 in that traditional rail and joint inspections and maintenance disturb operations. One core aim of WP4.4 is thus to **minimize the operational disruptions caused by inspections** through the use of **innovative inspection techniques** and predictive capability
- a successful WP4.4 will provide less obtrusive and cost efficient detection of parameters of influence for rail and joint degradation

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SP4.5: Validation of new maintenance processes

- maintenance strategy
  - the reference system is the present situation of rail maintenance (see in detail D4.5.1). Today it is mainly a corrective maintenance action based on observation and experience. Thus materials, technical structure, dimension, lubrication and loading are taken as fixed.
  - optimization: the improvement will be the shift from corrective to preventive maintenance by introducing intervention cycles, metal removal requirements and specific target profiles. With an enhanced proactive planning existing technology can be exploited much more efficiently (site logistics and sequencing).
  - preventive rail grinding will keep the balance between fatigue and wear development. Initiated cracks will not reach the state of fast crack propagation and thus the total rail life will increase.
  - in order to establish a preventive strategy a transition phase containing the corrective work needs to be planned.

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SP4.5: Validation of new maintenance processes

- lubrication
  - for selected locations with severe degradation (wear, surface initiated RCF, corrugations) we assume **non lubricated conditions for the reference system**. Furthermore the reference system is the present situation of rail maintenance (see in detail D4.5.1). Today it is mainly a corrective maintenance action based on observation and experience. Thus materials, technical structure, dimension and loading are taken as fixed.
  - optimization: the improvement will be **a local application of lubrication.** This might either be oil based lubrication or solid-phase based friction modifier. A significant reduction of wear rate, the time to crack initiation and probably non-appearance of corrugation could be expected.

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SP4.6: Innovative welding processes

- In this respect, there are three developments of interest:
    - Narrow Heat Affected Zone
    - Invisible Weld – Controlled Profiled Weld
    - Improved gas pressure welding.
    - A further development of interest is the use of Gas Pressure Welding (GPW) to provide a solid phase weld in place of the current casting process of alumino-thermic welding. Although the technology of GPW is well established and widely used in Japan, it has not penetrated the European railways because of perceived inconsistent performance.

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SP4: Rails and Welding – Questions and missing data

- PBS:
    - which track elements are involved? Only the rail?
    - details of technical life time of the components?
    - function of alignment (radius, inclination…)?
    - track sections with amount of curve and straight line?
- CBS - Maintenance:
    - interval of maintenance activities, intervention cycles?
    - shift performance?
    - maintenance procedure, type of grinding…
    - required values:
        - degradation rates [mm/t]: depending on rail grade and tonnage
        - RCF-crack-growth-rate [mm/t]: depending on rail grade and tonnage
        - max. limit for grinding [mm]: national, depending on rail profile; lateral & vertical wear
        - planned intervention [mm]: interdependence between grinding interval, TLT and operation with grinding machine

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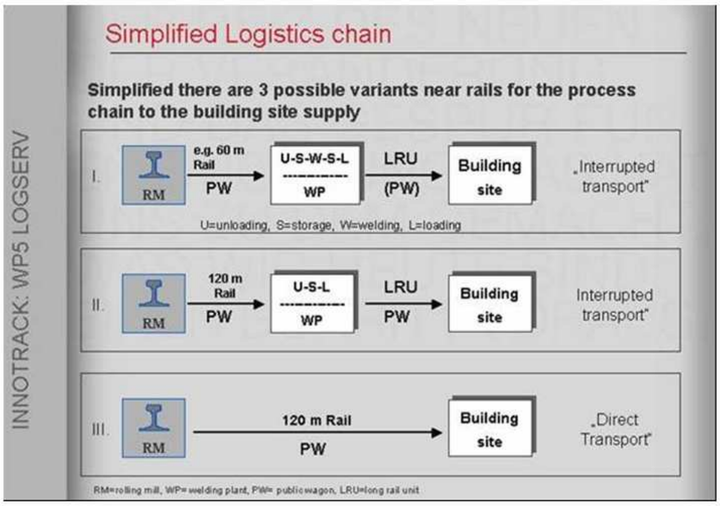
SP 5: Logistics
Key question is: Which has the lowest LCC under what circumstances?



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SP 5: Logistics
Identified: Seven Success-Critical Areas

A	B	C
Market Strategies	Long Term Funding and Strategic Planning	Work programming

D	E	F
Management and Logistics	Contracting Strategies	Rules and Regulations

G
Plant

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SP 5: Logistics
Crossing success-critical areas with track components related WP

	WP5.3 Logistics & Support	WP5.4 Logistics & S&C	WP5.5 Logistics & Rails&Welding
Market Strategies			
Long Term Funding and Strategic Planning			
Work programming			
Project Management and Logistics			
Contracting Strategies			
Rules and Regulations			
Plant			

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SP 5: Logistics
A – Market Strategies

- IMs are responsible for make/buy decisions
- Strategic step in structuring markets
- No point in IMs and contractors competing for position; we propose a relationship where tasks are done by those who add most value
- Needs a true understanding of long-term costs and openness of dialogue

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SP 5: Logistics
E - Contracting Strategies

- The most efficient contracts for IMs and their contractors will tend to:
  - be longer term
  - be output oriented
  - be incentivised to drive efficiency
  - share risk and reward allocation equitably
  - share the benefits of innovation equitably
  - be based on open and honest communications
  - be based on fair tender procedures that include sensible timescales and documentation of adequate quality
- Depending to some extent on individual markets

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SP 5: Logistics
E - Contracting Strategies

- Based on WP5.1 conclusions on best practices, recommendations will be issued
  - to be tested, for validation purposes and possible adjustments
- Validation procedure to be developed
  - will list the validation criteria
  - with participating IM’s (DB, NR)
  - in accordance with the work environment and safety rules in force in Germany and UK

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INNOTRACK
Innovative Track Systems

SP 5: Logistics
Basis of WP5.3, 5.4, 5.5

- Development of WP5.3 to WP5.5 is based on:
  - Output of WP5.1
  - Output of SP2, SP3, SP4

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Innovative Track Systems

SP5: Logistics for track maintenance & renewal (Logserv)

As there are four reference cases identified in the SP5:

- **Logistics and Support**
- **Logistics and Switches & Crossings**
- **Logistics and Rail**

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SP5: Logistics for track maintenance & renewal (Logserv)

- Logistics and Rail
  - for rail it is the use of short rail length (18 or 36 m)
  - installation and use of longer rails (>108 m, max. 120 m)
  - reduction of welding points
- Logistics and Support
  - rebuilding of existing track with good soil conditions as well as for weak/bad situation of the support with ballasted track
  - line is in operation - no interruption of traffic
  - high speed, high tonnage/load, focus on installation process (installation rate)
  - the improvements of the support: concerning an existing track (ballast)
  - SP5 is asked for different logistic methods/solutions

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INNOTRACK Innovative Track Systems

SP5: Logistics for track maintenance & renewal (Logserv)

- Logistics and Switches & Crossings
  - pre-assembled plug and play turnout solution (to make switches faster to install, minimization of downtime)
  - migration costs (new equipments, handling, regulations etc.)
  - investment costs for slab track (length of the slab track section, only for section of the switches)
  - transition construction? (consideration in the investment and maintenance); problem with transition between slab and ballasted track should be addressed
  - the access of the site (from rail side): max. length approx. 30 m
  - type of the site (description of the site): mixed traffic line?
  - installation time (restrictions after installation, interruptions...)
  - maintenance activities (tamping, grinding? --> SP3)
  - disposal/recycling of old switches
  - transportation and installation costs

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6.3 Structure of LCC models (Globals and Tables)

Structure of LCC models on basis of track components:

Track

Modules		ID	Sub components - sub systems			
	Track	100	System			
	Rail	150	weld	insulated, welded j.	inclination	
	Rail fastening	200	pad	clip		
	Sleeper	250				
	Ballast	300				
	Substructure	350		protection layer	soil	
	Slab	400	plate	HBL		
	Drainage	450				
	Environment protection	500	wall	gabion	on slab	
	S & C's	600		Control	DLD	Blade

Switches & Crossings

Modules		ID	Sub components - sub systems					
	Switches	700	System	Blade	Rail	Sleeper	Fastening s.	Stock rail
	Crossings	750	System	Frog (fixed)	Rail	Sleeper	Rail pad	Wing rail
	DLD	800						
	Control Device	850						
	Heating	900						
	Point rod	950						
	Point mechanism	1000						
	Check rail	1050						

ID of Globals:

Type	Abbreviation
Alternatives	**AL**
Periods	**PE**
Globals	**GL**
Tables	**TA**
Attributes	**AT**
Suppliers	**SU**

Distribution for globals	Abbreviation
Constant	**CO**
Alternative	**AL**
Period	**PE**
Alternativ/Period	**AP**

G1-10	*1*	**Time**	PE	Number of period (year)
	2	**Number of periods**		
	3	**Last period**	CO	Last period, used for calculation of residual value
	4	**One for first period**		
	5	**Zero for first period**	PE	0 for first period, 1 for remaining periods
	6	**Zero for last period**	GL/P	0 for last period, 1 for remaining periods
	7	**One for last period**	GL/CO	
	8	**Alternatives**	GL /AL	
	9	**Technical Life Time (TLT) [a]**	GL /AL	Technical Life time
	10	**Load factor**	GL/CO	Load factor; used for increasing or decreasing track loads
G11-20	*11*	**Reference length**	GL/CO	Length of section
	12	**Total length of track**	GL/CO	
	13	**Single or double track**	GL/CO	
	14	**Type of line (Category)**	GL/CO	Mixed, High speed, Freight Traffic
	15	**Speed [km/h]**	GL/CO	
	16	**Tonnage [GT/d], [MGT]**	GL/CO	Traffic loading
	17	**Max. axle load**	GL/CO	
	18	**Number of trains**	GL/CO	Traffic volume
	19	**Time for installation [h]**	GL/CO	
	20	**Distance between site & plants**	GL/CO	
G21-30	*21*	**R<300 m [m]**	GL/AL	Radius classes
	22	**R 300-700 m [m]**	GL/AL	
	23	**R 700-1500 m [m]**	GL/AL	add. Table liftetime(f)=radius
	24	**R 1500-5000 m [m]**	GL/AL	
	25	**R>5000 m [m]**	GL/AL	
	26	**S&C Radius 190-300 m [#]**	GL/AL	
	27	**S&C Radius 500-600 m [#]**	GL/AL	

	28 **S&C Radius 760 m [#]**	GL/AL	
	29 **S&C Radius > 760 m [#]**	GL/AL	
	30 **Joints [#]**	GL/AL	insulated block j., welded j.
G31-40	***31*** **Grinding cost per shift [€/shift]**	GL - GL/AL	depending on procedure or machine
	32 **Grinding length per hour [m]**	GL - GL/AL	depending on procedure or machine
	33 **Time for pre and post preparation for grinding [h]**	GL - GL/AL	depending on procedure or machine
	34 **Grinding Interval**	GL - GL/AP	depending on steel grade, tonnage, speed
	35 **Tamping cost per shift [€]**	GL - GL/AL	depending on procedure or machine
	36 **Tamping length per hour [m]**	GL - GL/AL	depending on procedure or machine
	37 **Time for pre and post preparation for tamping [h]**	GL - GL/AL	depending on procedure or machine
	38 **Tamping Interval**	GL - GL/CO	
	39 **Tamping performance [m/h]**	GL/AL	depending on machine
	40 **Qualityindex [ ]**	GL/AL	machine dependent
G41-50	***41*** **Length of a shift [h]**	GL/CO	8 hours
	42 **Possession Time [h]**	GL/CO	6 hours
	43 **Time for start up & shut down [h]**	GL/CO	1 hour
	44 **Mean time interval [a]**	GL /AL	Standard: 3; Innovation: 4
	45 **Nom. Effort per shift [m]**	GL/CO	e.g. 3500 m
	46 **Machine, equipment cost [€]**	GL/CO	
	47 **Work hour cost [€]**	GL/CO	
	48 **Nr. of persons per action**	GL/CO	
	49 **Usage cost [€]**	GL/CO	e.g. usage of equipment, monitoring system
	50 **Train delay cost [€/min]**	GL/CO	

G51-60	***51*** **Train delay hours [h]**	GL/CO	
	52 **MTBF**	GL/CO	Mean Time Between Failure
	53 **MTBM**	GL/CO	Mean Time Between Maintenance
	54 **Failure rate [λ]**	GL/CO	
	55 **MTTR**	GL/CO	Mean Time to Repair
	56 **MDT**	GL/CO	Mean Down Time
	57 **MMH**	GL/CO	Mean Maintenance Hours
	58 **Hazard Rate**	GL/CO	
	59 **Number of derailment due to asset [#]**	GL/CO	
	60 **Number of accidents [#]**	GL/CO	

ID of Tables:

Tables							
	ID	Meaning	Comments		ID	Meaning	Comments
T1-10	*1*	**Invest**	for investment at the first year	T31-40	***31***	**Maintenance_Strategy**	depending on Maint. Strategy
	2	**Round up**	Round up using a table		*32*	**Maintenance_Cat.**	depending on Track Category
	3	**Incidence isolation**	one for t=0, zero for all other cases, used in equations a-b=0		*33*	**Maintenance_Constr.**	depending on Construction
	4	**One for PE > 2**	one for periodnumber greater than two, used for maintenance activities in the first years		*34*	**Maintenance_Superstr**	depending on Superstructure
	5	**One for PE > 3**	one for periodnumber greater than three, used for maintenance activities in the first years		*35*		
	6	**Table Zero**	one for periodnumber 0		*36*		
	7	**IF-Table**	one for periodnumber 0 to 999		*37*		
	8	**Nullstelle**			*38*		
	9				*39*		
	10				*40*		

T11-20	*11*	**Life Time Rail_Rail**	depending on Rail type
	12	**Life Time Rail_Cat.**	depending on Track Category
	13	**Life Time Rail_Maint.**	depending on Maint. Strategy
	14		
	15	**Cst_scale f._Rail**	depending on Rail type
	16	**Cst_scale f._Cat.**	depending on Track Category
	17	**Cst_scale f._Maint.**	depending on Maint. Strategy
	18	**Cst_scale f._Constr.**	depending on Construction
	19		
	20		
T21-30	*21*	**Inspection interval**	depending on Track Category
	22	**Inspection_Speed**	depending on Speed
	23	**Inspection_Special**	depending on special characteristic
	24		
	25		
	26		
	27		
	28		
	29		
	30		
T41-50	*41*	**Grinding_Machine**	depending on Grinding machine
	42	**Grinding_Maint.**	depending on Maint. Strategy
	43	**Grinding_Cat.**	depending on Track Category
	44	**Tamping_Machine**	depending on Tamping machine
	45	**Tamping_Maint.**	depending on Maint. Strategy
	46	**Pre-post time Tamping**	depending on Maint. Strategy
	47		
	48		
	49		
	50		
T51-60	*51*	**Wear rate_Rail**	depending on Rail type
	52	**Wear rate_Tonnage**	depending on Tonnage
	53	**Wear rate_Radius**	depending on Radius
	54		
	55	**Crack-gr. rate_Rail**	depending on Rail type
	56	**Crack-gr. rate_Tonnage**	depending on Tonnage
	57	**Crack-gr. rate_Radius**	depending on Radius
	58	**Max. metal removal**	depending on Rail type
	59	**Pl. intervention_TLT**	depending on Life time
	60	**Pl. intervention_Gr.**	depending on Grinding

ID of Global Parameters for Track (as an example):

ID			Type
100	Investment	**total investment costs**	
101		material cost	GL/AL
102		transportation cost	GL/AL
103		installation cost	GL/AL
104		preparation and planning	GL/CO
105		disposal	GL/AL
106		spare parts	GL/AL
107		scrap value	GL/AL
108		add. measurements (subsoil)	GL/AL
109		others	

ID			Type	Comments
110	Re-investment	**total re-investment costs**		
111		material cost	GL/AL	
112		transportation cost	GL/AL	
113		installation cost	GL/AL	
114		planning	GL/CO	
115		disposal	GL/AL	
116		spare parts	GL/AL	
117			GL/AL	
118			GL/AL	
119		others		special costs, e.g. for removal of embedded rail

ID				
120	Maintenance	**total maintenance costs [€/m/a]**		
121		Inspection/Diagnostic costs [€]	GL/CO	
122		Inspection/Diagnostic interval [a]	GL/CO	
123		Service costs [€]	GL/CO	snow removal, leaves--> as annual costs
124		Service interval [a]	GL/CO	
125		Lubrication costs [€]	GL/AL	
126		Replacement	GL/AL	replacement of a part
127		Small maintenance activities	GL/AL	
128				
129		others		

ID				
130	Maintenance	**total maintenance costs [€/m/a]**		
131		Levelling cost [€/m]		
132		Leveling length [m]		
133		Leveling issue [1/100km]		
134		Fault clearence cost [€]	GL/AL	
135		Rail Break	GL/AL	number and costs
136		Lateral buckling	GL/AL	distortion of track
137		spare parts	GL/AL	
138				
139		others		special costs, e.g. for removal of embedded rail

ID				
140	*Others*	**total other costs [€/m/a]**		
141		N-A due to reinvestment	GL/AL	planned Non-Availability
142		N-A due to preventive (planned) activity	GL/AL	costs due to malfunctions, delays, less serviceability, stoppage, speed restriction
143		N-A due to corrective (unplanned) activity	GL/AL	costs due to malfunctions, delays, less serviceability, stoppage, speed restriction
144		Time of depreciation		
145				
146				
147				
148				
149		others		

ID of Global Parameters for Rail (as an example):

ID			Type
150	Investment	**total investment costs**	
151		material cost	GL/AL
152		transportation cost	GL/AL
153		installation cost	GL/AL
154		preparation and planning	GL/CO
155		disposal	GL/AL
156		spare parts	GL/AL
157		scrap value [€/m]	GL/AL
158		add. measurements (subsoil)	GL/AL
159		others	

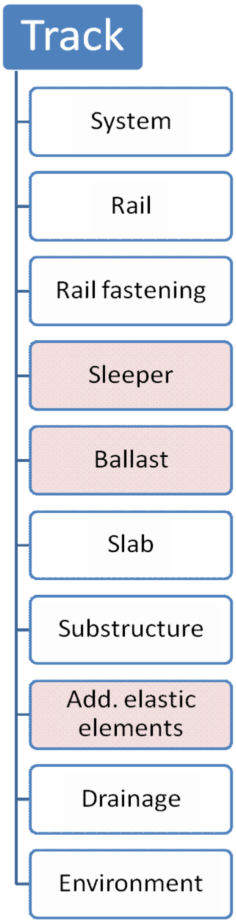
ID			Type	Comments
160	Re-investment	**total re-investment costs**		**rail, weld, insulated joints**
161		material cost	GL/AL	Cst Rail
162		transportation cost	GL/AL	
163		installation cost	GL/AL	Cst installation
164		planning	GL/CO	
165		disposal	GL/AL	
166		spare parts	GL/AL	
167			GL/AL	
168			GL/AL	
169		others		special costs, e.g. for removal of embedded rail max 20 ID's

ID				
170	Maintenance	**total maintenance costs [€/m/a]**	**GL/AL**	
171		inspection costs [€/m]	GL/CO	
172		inspection interval [a]	GL/CO	
173		service costs [€]	GL/CO	
174		service interval [a]	GL/CO	
175		renewal cost [€/m]	GL/AL	if not include in re-invest, for DB l < 1000m; material, transport, TLT, length per shift, cost per shift
176		replacement	GL/AL	
177		small maintenance activities	GL/AL	
178		welding cost [€/unit]	GL/AL	
179		control of vegetation	GL/CO	
180	Maintenance	**total add. maintenance costs [€/m/a]**		
181		costs due to regulations of each country	GL/CO	
182		costs due to add. special requirements	GL/CO	
183		Man hour cost [€]	GL/CO	
184		Fault clearence cost [€]	GL/AL	
185		Rail Break	GL/AL	number and costs
186		Lateral buckling	GL/AL	distortion of track
187		spare parts	GL/AL	
188		Rail adjustment	GL/AL	
189		others		

ID				
190	*Others*	**total additional costs [€/m/a]**		
191		N-A due to reinvestment	GL/AL	planned Non-Availability
192		N-A due to preventive (planned) activity	GL/AL	costs due to malfunctions, delays, less serviceability, stoppage, speed restriction
193		N-A due to corrective (unplanned) activity	GL/AL	costs due to malfunctions, delays, less serviceability, stoppage, speed restriction
194		Time of depreciation	GL/AL	
195		Time-Change	GL/CO	
196				
197				
198				
199				

6.4 Questionnaire for BBEST

Explanation of structure, components and costs blocks



Cost, maintenance activities and frequencies to the system e.g. for tamping
Costs not included in other elements (e.g. for the whole system)

Cost, maintenance activities, and frequencies related to the rail

Cost, maintenance activities, and frequencies related to the rail fastening

Cost, maintenance activities, and frequencies related to the sleeper,
may be relevant for transition construction if other sleepers necessary

Cost, maintenance activities, and frequencies related to the sleeper,
not relevant for slab track

Cost, maintenance activities, and frequencies related to the rail

Cost, maintenance activities, and frequencies related to the rail

Cost, maintenance activities, and frequencies related to the add. elastic elements,
may be relevant for transition construction

Additional cost, maintenance activities, and frequencies related to the drainage

Additional cost, maintenance activities, and frequencies related to environmentel sustainability

For the calculation of LCC we need the cost for the procurement, either separately for the components of the system, which may be necessary for validation, or summarized for the system

The first investment should include all cost for the product - ready-for-use -. This means cost for material, transport, installation ... have to be included.

Detail your cost items if possible for validation

UNITS

Cost should be given in [€/track m]

Frequencies of maintenance in [years or mgt] (see boundary conditions)

Separate cost related to maintenance in:
- Activity [description of activity like grinding, pre- and post-preparation]
- Type of machine [name of machine]
- Frequency [a or mgt]
- total cost per shift including pre-, post-preparation and safeguarding [€/shift]
- working lenght per hour [m/h]
- Time for preparation [h]
- Time for post-processing [h]

For each component we need

- their life time and the re-investment cost
- the time for renewal

Extend the tables if necessary

Boundary conditions

The selected technical boundary conditions are red colored and marked with a ✓

	Selected	Explanation
Reference system		
Ballasted track	✓	
Slab track		
Track category		
P300	✓	Passenger traffic , max. speed 300 km/h
P230		Passenger traffic , max. speed 230 km/h
M230		Mixed traffic , max. speed 230 km/h
M160		Mixed traffic , max. speed 230 km/h
Single track		
Double track	✓	
Track segments		
straight line	✓	
curve	✓	
< 300 m		
300-700 m		
700-1500 m		
1500-5000 m	✓	
> 5000 m		
Lenght of track [km]	100	
Mean tonnage per day		
50000 t	✓	18.3 mgt/a
75000 t		27,4 mgt/a
100000 t		36,5 mgt/a
Environmental sustainability		
Equal to reference system	✓	
Better than reference system		

Slab track on earthwork - straight line

Extend the tables if necessary
Mark if you do not have data, but expect activities or cost

	00 - System					
Cost/m of whole system or additional costs/m not included in other elements	**01 - Procurement**					
		01 - Preparation one-time				
		02 - Preparation recurrent				
		03 - Investment				
			01 - First investment			all costs ready- for-use, either detailed (necessary for validation) or summarized as first investment
					Material	
					Transport	
					Installation	
					Spare parts	
					Inspection equipment	
					...	
					Installation time	**Please estimate in either case the time for installation of the system**
			12 - Re-investment			all costs for re-investment, either detailed (good for validation) or summarized in re- investment , provide life time and the time needed for installation
					Material	
					Transport	
					Installation	
					Life time	**Please estimate in either case the life time of the system**
					Renewal time	**Please estimate in either case the time for renewal of the system, including the deinstallation of the old system**
		05 - Decommissioning				
		06 - Disposal and recycling				
	02 - Operation					not relevant
		01 - Service				
Cost/m of whole system or additional costs/m not included in other elements	**03 - Maintenance**					
		01 - Preparation one-time				
		02 - Inspection				Enter additional inspection activities and related costs, use minus sign in case of cost saving
				Activity		
				Cost [m track]		
		03 - Service				not relevant
		04 - Preventive maintenance				Indicate the type of maintenance you expect
			01 - Condition based			One set of parameter for each failure mode
				Description of failure mode		Describe the possible failure mode and the inspection to detect the degradation
				Description of activity		
				Frequency [a or mgt]		
				Type of machine		
				Total cost per shift including pre-, post-preparation and safeguarding [€/shift]		
				Working lenght per hour [m/h]		
				Time for preparation [h]		
				Time for postprocessing [h]		
			02 - Pre-determined			
				see above		
			03 - Priority based			
				see above		
		06 - Corrective maintenance				
			01 - Deferred			
				see above		
			02 - Immediate			
				see above		
	04 - Non-Availability					we will discuss this later
		1 - Planned				
		2 - Unplanned				
	05 - Social Economics					we will discuss this later
		01 - Environment				
		02 - Energy consumption				

The same structure is in the questionnaire for further components (like Rail, Rail Fastening, Substructure, Slab, Drainage and Environment-Sound insulation) and with the consideration of curve and transition zone.