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# INNOTRACK

Integrated Project (IP)

Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

# D 6.2.2 Benchmark of LCC tools

**"New and innovative tools and models: Benchmark of LCC tools and required improvements"**

**D6.2.3 is merged into this document**

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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

| | |
|---|---|
| ADIF | Administrador de Infraestructuras Ferroviarias (Spanish National Rail Administration) |
| CATLOC | Complete Analysis Tool for Logistics and Operations Costs (LCC tool developed by Systecon AB) |
| CBS | Cost Breakdown Structure |
| DB | Deutsche Bahn AG (German National Rail Administration) |
| D-LCC | LCC tool used by DB |
| FMEA | Failure Mode Effects Analysis |
| FRACAS | Failure Reporting Analysis, Corrective Action System |
| IM | Infrastructure manager |
| JBV | Jernbaneverket (Norwegian National Rail Administration) |
| LCC | Life Cycle Cost Analysis |
| LCCA | Life Cycle Cost |
| LCCWare | LCC tool developed by Isograph |
| LCM | Life Cycle Management (LCC tool used by ProRail) |
| LRU | Line Replaceable Unit |
| LSC | Life Support Cost |
| MDT | Mean Down Time |
| MTBF | Mean Time Between Failures |
| MTTF | Mean Time To Failure |
| MTTR | Mean Time To Repair |
| NPV | Net Present Value |
| NR | Network Rail (Britain's National Rail Administration) |
| OBB | Austrian National Rail Administration |
| ORLA | Optimal Repair Level Analysis |
| PBS | Product Breakdown Structure |
| PriFo | LCC tool developed by JBV |
| ProRail | Dutch National Rail Administration |
| RAMS | Reliability, Availability, Maintainability and Safety |
| RBD | Reliability Block Diagram |
| Relex LCC | LCC tool developed by Relex |
| SRU | Shop Replaceable Unit |
| T-SPA | Track Strategic Planning Application by NR |
| UNIDATA | LCC tool developed by UNIFE |
| UNIFE | Union of the European Railway Industries |
| UNILIFE | LCC tool developed by UNIFE |
| WBS | Work Breakdown Structure |

# 1. Executive Summary

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 optimise the track construction and get the return on investment (ROI) in a manageable timeframe. LCC and RAMS technology are two acknowledged methods for assisting the optimisation process.

The original purpose of deliverables D6.2.2 and D6.2.3 was to assess and improve the existing models and tools within each Infrastructure Manager. However, according to WP6.1 results, few IM's have established standards and models for LCC analysis. Furthermore, when LCC is in use, information available on current practices and models is still too scarce to be able to compare and analyse: it is extremely difficult to gather information on the precise LCC methodology applied, boundary conditions (technical and economical), cost categories and cost matrix, levels of detail etc. On the other hand, tools are not available for testing making impossible the task of producing a comparison and improvements in the few existing tools.

Therefore, the WP6.2 workgroup has decided to focus on available commercial tools to use on the future steps of the project. The use of commercial LCC application software will make easier the accomplishment of common analysis within different Infrastructure Managers and Suppliers, allowing the comparison of similar evaluations, with similar models, although with different (and confidential) inputs.

This report (D6.2.2/3) performed an analysis of the existing LCC commercial tools, assessing various aspects of each program. The goal was to evaluate the best features of each tool and identify which tool fits best the requirements for LCC modelling of railway infrastructure within SP6, as well as to recommend improvements to be performed within the project.

With the purpose of benchmarking LCC commercial tools, relevant information like software manuals and demo versions were requested to LCC software suppliers and additionally, a questionnaire was performed. A wide variety of tools, ranging from simple ones to sophisticated software packages were analysed. It was not achievable to have answers to the questionnaires from the suppliers, but it was possible to complete the study through the analysis of the manuals and demo versions provided.

From the analysis performed it was found that almost all software's addresses the basic features required for LCC modelling of railway infrastructure. Furthermore, based on a specific evaluation of the capability of each software regarding more than thirty criteria (answering more than 50 questions) it was possible to decide on two tools for further analysis in detail, in order to select the best-suited tool to use in INNOTRACK WP6.5.

Some key features to assess were defined and two identical models were built on the two selected tools to assess their capabilities on each key feature. A quantitative approach and scoring was defined and the results obtained made it possible to identify the best "performer" tool. Finally, a list of improvements were suggested to meet the interest of INNOTRACK LCC modelling: to improve the "Importability" of (all) variables from a database; to allow functions changing over time as input; to improve comparability and "check process" of inputs and detection of errors and to incorporate a Monte Carlo Simulation toolbox to perform a probabilistic analysis.

# 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.

The INNOTRACK project brings IM (infrastructure managers) and railway supply industry together, to investigate and evaluate leading edge track system technologies, adopting a controlled methodology to assess life cycle cost benefits of "track-technology solutions" and of a set of emerging railway hardware solutions. It will also support the overall sustainability of the railway sector, meeting needs such as the increase of track availability and network capacity.

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 optimise the track construction and get the return on investment (ROI) in a manageable timeframe. LCC and RAMS technology are two acknowledged methods for assisting the optimisation process.

The original purpose of deliverables D6.2.2 and D6.2.3 was to assess and improve the existing models and tools within each Infrastructure Manager. However, according to WP6.1 results, few IM's have established standards and models for LCC analysis. Furthermore, when LCC is in use, information available on current practices and models is still to scarce to be able to compare and analyse: it is extremely difficult to gather information on the precise LCC methodology applied, boundary conditions (technical and economical), cost categories and cost matrix, levels of detail etc. On the other hand, tools are not available for testing making impossible the task of producing a comparison and improvements in the few existing tools.

Therefore, the WP6.2 workgroup has decided to focus on available commercial tools to use on the future steps of the project. The use of commercial LCC application software will make easier the accomplishment of common analysis within different Infrastructure Managers and Suppliers, allowing the comparison of similar evaluations, with similar models, although with different (and confidential) inputs.

This report will be performed as an analysis of the existing LCC commercial tools, assessing various aspects of each programme. The goal is to evaluate the best features of each tool and identify which tool fits best the requirements for LCC modelling of railway infrastructure within SP6, as well as to recommend improvements to be performed within the project.

# 3. Benchmark of LCC tools

## 3.1 Activities

The following activities were carried out in order to accomplish the aim of this deliverable:

- Analysis of existing tools

- Definition of assessment indicators/criteria

- Preparation of questionnaires and gathering of information from software suppliers

- Benchmark of commercial tools (features and potentialities)

- Assessment of the best fitted tool towards SP6 activities

## 3.2 Time schedule

The time to furnish the report D6.2.2 and D6.2.3 was initially 9 months and 12 months from the start of the project. A first draft of D6.2.2 was completed in month 9. After the re-arrangement of the deliverables (redefinition of contents and merging of D6.2.2 and D6.2.3) the time schedule was changed to 15 months. The dissemination level of the report will be "public".

## 3.3 Risks

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

- Insufficiency of data collected from the suppliers (manuals);

- Inadequate involvements of Infrastructure managers and suppliers;

- Not common understanding of the questionnaires from the suppliers;

- No available evaluation licences to assess the tools.

## 3.4 Organisation and resources

Organisation and resources for this work package are given Table 1. ADIF is responsible for delivery of WP 6.2 which includes D6.2.2 and D6.2.3.

| Workpackage | 6.2 – Life Cycle Cost Methodology | | | Start date or starting event: | | | M1 |
|---|---|---|---|---|---|---|---|
| Participant id | | UIC | VAS | BV | ADIF | Alstom | NR | OBB |
| Person-months per participant | | 2.0 | 3.0 | 3.0 | 5.5 | 1.0 | 2.0 | 3.0 |
| Participant id | | DB | Corus | | | | | |
| Person-months per participant | | 6.0 | 1.0 | | | | | |

Table 1 - Organisation and resources                    Another partner in the working group is ProRail.

## 3.5 Information acquisition

Information on LCC was obtained from the following sources:

- Questionnaires were sent to the participants in INNOTRACK and LCC software Suppliers;

- Meetings with Infrastructure Managers and LCC software Suppliers;

- Published papers;

- European Projects (IMPROVERAIL; Prom@in;...)

- Internet search

- Software manuals were provided by D-LCC, CATLOC and LCC-Ware (UNIFE model was downloaded from the web). For Relex information was only possible through help function of demo version.

- Evaluation licences were provided by D-LCC, CATLOC and LCC-Ware (valid until July 2007)

- Webinar support was available for Relex.

No supplier or IM filled the questionnaire sent about LCC features; as a result ADIF was responsible for fulfilling the questionnaire with the purpose of evaluating different aspects of each LCC program in relation to best practice.

# 3.6 Definition of assessment indicators/criteria to compare LCC tools

In order to assess the extent to which the LCC model provides realistic results, the first step is to accurately define assessment criteria/indicators. This step is essential to afterwards evaluate the different aspects of each LCC commercial tool in relation to best practice. In Annex I is available a brief description of the five LCC commercial tools analysed in this deliverable: Relex LCC; LCCWare; D-LCC; CATLOC and UNIFE-UNILIFE.

The WP6.2 workgroup defined that an LCC model should be assessed regarding the following features:

- Ease and flexible product/work breakdown structures (PBS/WBS) to allow multiple levels of detail, according to the decision-making needs and available data;

- Comparison with pre-existing LCC models to recognise the elementary cost elements. This measure aims to avoid the increase of the model's complexity due to redundant cost elements;

- The parameters that define LCC cost elements should allow the introduction of functions and statistical distributions in order to establish a range of potential results. This information can be used to evaluate how dangerous a straight formula can be to the project outputs;

- Interactions between cost elements should be provided in order to reach a more realist LCC process (e.g. investments in early stages can prevent maintenance work);

- Costs can change over time and consequently, it should be possible to define cost functions with different values at each time point in each time sequence (e.g. cost A enters in year 1 and then from year 5 up to year 8);

- LCC models should be able to trace the path of each parameter in the cost breakdown structure and its intervention degree in each cost element to evaluate the parameter importance in the global framework;

- LCC models should be able to perform comparisons between its inputs/outputs and historical data or reference values, obtaining a more calibrated model and preventing, for example, incorrect application of the regulation or errors due to incorrect data introduction;

- Another interesting feature that provides extra measure of flexibility to LCC analyses is the ability to compute element's life cycle costs using different operators (besides the addition operator);

- The ability to compute life cycle using variables with different weights can be helpful as parameters importance can vary regarding the period studied, alternative chosen as well as user's approach;

- As computing life cycle costs for a project can be computationally intensive, the model should be able to limit the computation time, allowing the user to perform only the minimum required (e.g. selecting specific periods and alternatives);

- Interactions with other software, like EXCEL or a RAMS program, may lead to a better calibrated LCC model and an improvement in its performance;

- The ability to perform a risk analysis i.e. a probabilistic sensitivity analysis of LCC parameters to evaluate the uncertainty inherent in the models, taking into consideration that this type of analysis leads to more feasible results then the deterministic sensitivity analysis;

- The identification of the cost drivers, by the LCC model, must be supported by conclusively reports with different modes of presentation (e.g. graphs, tables);

- It should provide reports for both total and detailed costs for any combination of Product Tree items and CBS elements in order to provide input to decision making in all phases of a product life cycle;

- Tests to input data and tracking errors features should be available in LCC models with the goal of providing more accurate LCC outputs;

- Application of financial and economic evaluation techniques like net present value (NPV), discounted cash flow (DCF), internal rate of return (IRR), depreciation and amortisation, opportunity costs, inflation, taxation, etc. should be possible with the tool;

- The ability to perform a target costing analysis should be possible in the tool, as it would enable the user to improve the decision-making process regarding design alternatives and to lead to the refinement of the design and ultimately, to come closer to the established cost targets.

## 3.7 Comparison between LCC tools

A wide variety of LCC commercial tools, ranging from simple ones to sophisticated software packages were analysed in this deliverable. Therefore, in Annex I is available a brief description of the five LCC commercial tools analysed in this deliverable: Relex LCC; LCCWare; D-LCC; CATLOC and UNIFE-UNILIFE.

The goal of performing a benchmark of LCC commercial tools is to evaluate various aspects of each program in relation to best practice. Therefore, in this chapter, a benchmark of the LCC tools based on the criteria defined in 3.5 will be performed with the aim to evaluate and to identify which LCC program fits best the requirements for LCC modelling of railway infrastructure within SP6.

In order to facilitate the benchmarking process, the criteria identified will be aggregated, depending on the LCC software performance, on the following topics:

- General features

- Main structures (CBS/PBS)

- Data/Results interaction with other software

- Data/Results accuracy

- Accounting techniques

The approach defined is to address the key specific questions and answer with the capability of each tool to meet those requirements. A more detailed table with all the questions and detailed answers will be available in the Annex II.

The results will allow having a clear picture of the most adequate tool for the on-going work: this benchmark of LCC tools may be a one-off document, but should be treated as a continuous process within SP6.

## 3.7.1    General features (see Annex II for further details)

As we can see in the Table 2, all LCC tools studied have a user friendly interface, allowing copy/paste functions and the majority allows copy/paste from one project to other. As we can see in Figure 1, D-LCC has an intuitive user interface for navigation through the project.
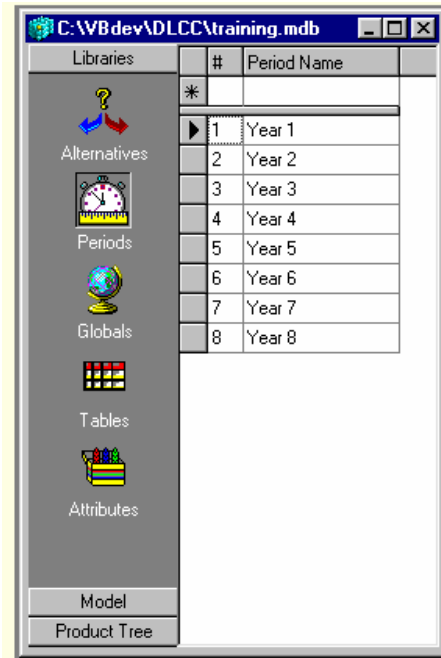
Figure 1 - Example of the Project Button Bar (D-LCC)

In what concerns undo/redo utilities it has to be pointed out that with D-LCC is not possible to do it. Even though CATLOC has undo/redo utilities, in this program a deleted value is permanent and cannot be undone yet; the deleted value is not saved to disk until the user selects the Save or Save As buttons.

| General features | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|
| User friendly interface? | ✓ | ✓ | ✓ | ✓ | ✓ |
| Allows copy/paste functions? | ✓ | ✓ | ✓ | ✓ | ✓ |
| Allows undo/redo functions? Multiple undo? | ✓ | ✓ | ✗ | ✓ | ✓ |
| Can manage different projects at the same time? | ✗ | ✗ | ✗ | ✓ | ✗ |
| Can you compare different alternatives within one single project? | ✓ | ✓ | ✓ | ✗ | -- |

Table 2 - General features

As we can see in Table 2, D-LCC is the only LCC commercial tool that is able to compare different alternatives within one single project. However, CATLOC allows the user to manage different projects at the same time.

## 3.7.2    Main structures (CBS/PBS) (see Annex II for further details)

In this chapter, life cycle cost breakdown structures of the products total LCC are being analysed by its flexibility to be tailored, according to the decision-making needs and available data.

Almost all LCC tools studied are spreadsheet-like, flexible and easy to tailor to each project needs, allowing drag-and-drop and cut-paste for copying and editing of CBS/PBS structures. Additionally, the majority programs provide graphical representation of the cost elements and allow several levels of detail.

| Main structures (CBS/PBS) | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|
| Is your program spreadsheet-like, flexible and easy to modify cost models for each CBS element? | ✓ | ✓ | ✓ | ✓ | ✗ |
| Does it allow drag-and-drop and cut-paste for copying and editing of CBS/PBS elements? | ✓ | ✓ | ✓ | ✓ | ✓ |
| Does it allow graphical representation of CBS providing convenient and fast data input and search? | ✓ | ✓ | ✓ | ✓ | ✗ |

Table 3 - Main structures (CBS/PBS)

Regarding UNIFE's software, as it is basically a excel workbook, the hierarchical breakdown of the cost elements is not easily tailored to meet each project requirements. Furthermore, UNIFE-UNILIFE does not allow graphical representation of CBS and consequently, does not provide a convenient and fast data input and search (see Table 3).

| Main structures (CBS/PBS) | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|
| Is able to perform comparisons with pre-existing LCC models to recognise the elementary cost elements? | ✗ | ✗ | ✗ | ✗ | ✗ |
| Is it possible to create user subroutines for specialised calculations? | ✓ | ✓ | ✗ | ✓ | ✓ |
| Can variables be stochastic? | ✗ | ✗ | ✗ | ✗ | ✗ |
| Is able to perform interactions between cost elements? | ✗ | ✗ | ✗ | ✗ | ✓ |
| Is it possible to define cost functions that change over time? | ✗ | ✗ | ✗ | ✓ | ✗ |

Table 4 - Main structures (CBS/PBS)

As we can see in the Table 4, no software is able to perform comparisons with pre-existing LCC models to recognise the elementary cost elements, not avoiding the increase of the model complexity due to redundant cost elements.

Another important feature, present in tree out of five programs studied, is the ability to create subroutines for specialised calculations, saving time to users as cost elements can be much alike (see Table 4).

Giving the fact that UNIFE-UNILIFE is basically an Excel worksheet, it allows relations between cost elements and therefore, provides a more realistic LCCA (e.g. investments in early stages can prevent maintenance work).

As we can see in the Table 4, it is not possible to introduce stochastic variables in any program. Therefore, it is not possible to establish a range of potential results, bearing in mind the uncertainty of certain inputs.

 Concerning the definition of the cost elements, only CATLOC has the ability to define cost functions that change over time (e.g. cost A enters in year 1 and then from year 5 up to year 8) due to the fact that all cost atoms and parameters costs can be defined for a combination of the five dimensions: material (systems and items in the material breakdown structure); task (corrective and preventive tasks performed on the technical system); resource (resources required for operation and maintenance of the systems); station (stations where systems are operated and maintenance is performed) and time (the time periods of interest). Therefore, with CATLOC the cost atom "repair costs for items at a station a given year", would be defined in the material, station and time dimensions. Nevertheless, in Relex LCC, LCCWare and D-LCC at least it is possible to define a variable that changes over time or over different alternatives.

In relation to the ability to perform interactions between cost elements, only UNIFE's software could allow it, as it is essentially a excel workbook (see Table 4).

As we can see in Table 5, D-LCC, Relex LCC and CATLOC allow the user to trace the path of each parameter in the cost breakdown structure.

| Main structures (CBS/PBS) | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|
| Is it possible to trace the path of each parameter in the CBS? | ✓ | ✗ | ✓ | ✓ | ✗ |
| Is it possible to estimate a parameter's intervention degree in each CBS element? | ✗ | ✗ | ✗ | ✓ | ✗ |
| Is your software able to perform comparisons between its inputs/outputs and historical data or reference values? | ✓ | ✗ | ✗ | ✓ | ✗ |

Table 5 - Main structures (CBS/PBS)


As we can see in Figure 2, when the user is trying to delete a global variable, D-LCC provides the user a list of CBS components and corresponding formulas where the global variable is included, enabling the user to trace the path of each parameter in the CBS.
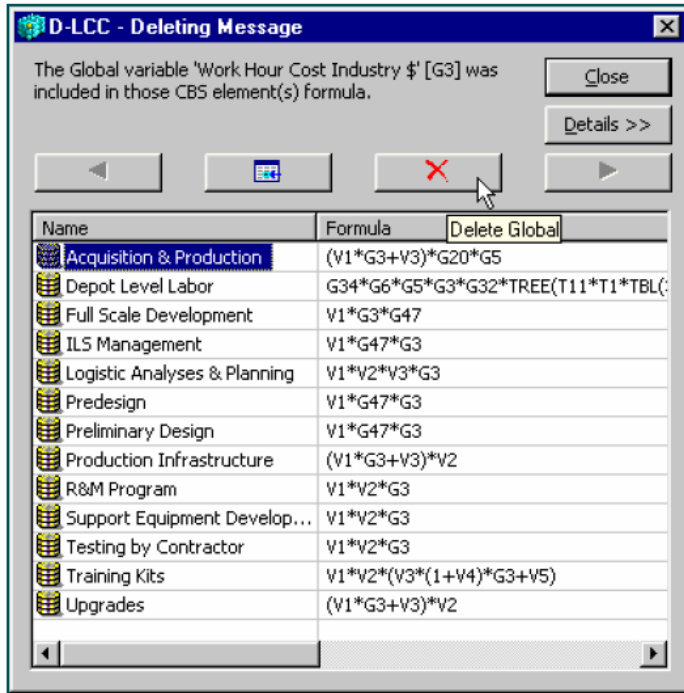
Figure 2 - Example of the Delete Global Dialog (D-LCC)

However, only CATLOC is able to estimate a parameter's intervention degree in each CBS element. As we can see in the Figure 3, in CATLOC the resulting costs can be shown as graphs with spring patterns revealing which costs are affected by a specific parameter and its intervention degree.
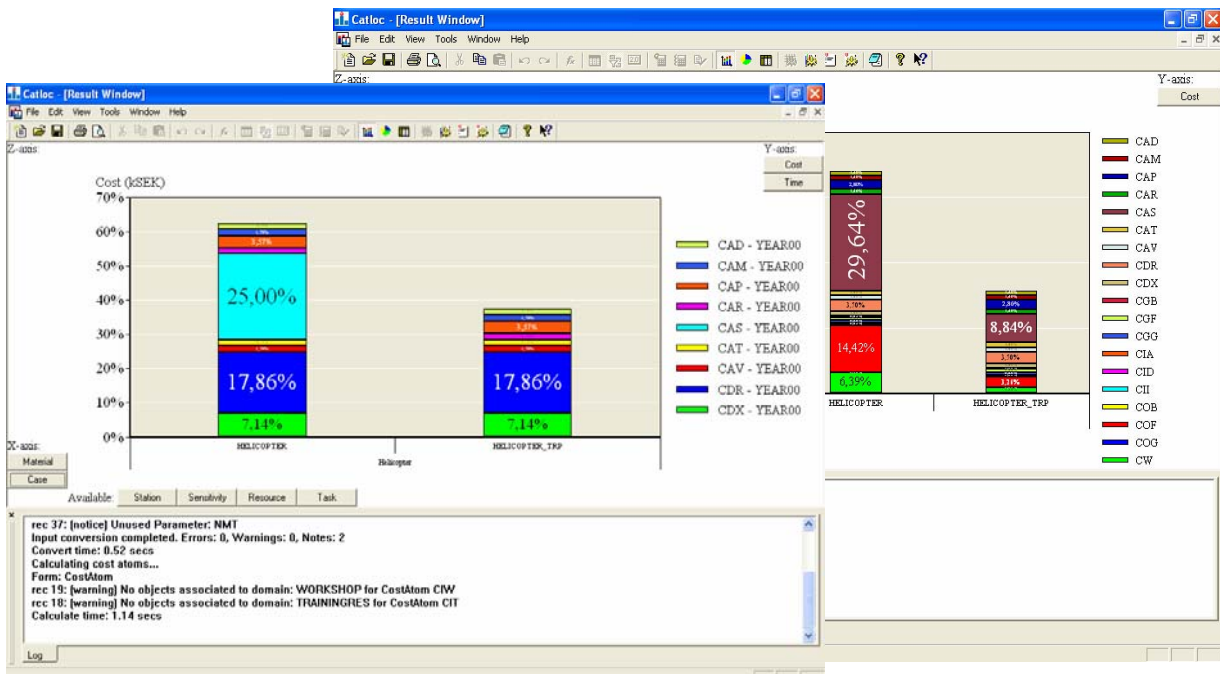


Figure 3 - Examples of bar graphs with several parameter's intervention degree (CATLOC)

The ability to perform comparisons between its inputs/outputs and historical data or reference values is a quite important feature as it can prevent, for example, incorrect application of the regulation or errors due to

incorrect data introduction, leading the user to a more calibrated model. As we can see in Table 5, no more than two programs, Relex LCC and CATLOC, are able to perform comparisons between its inputs/outputs and historical data or reference values.

On the one hand, Relex LCC has an utility named Filters that can be applied to limit the items included when importing/exporting data, but also can be used with fields attached to dependent lists and to group and sort selected items (see Figure 4).
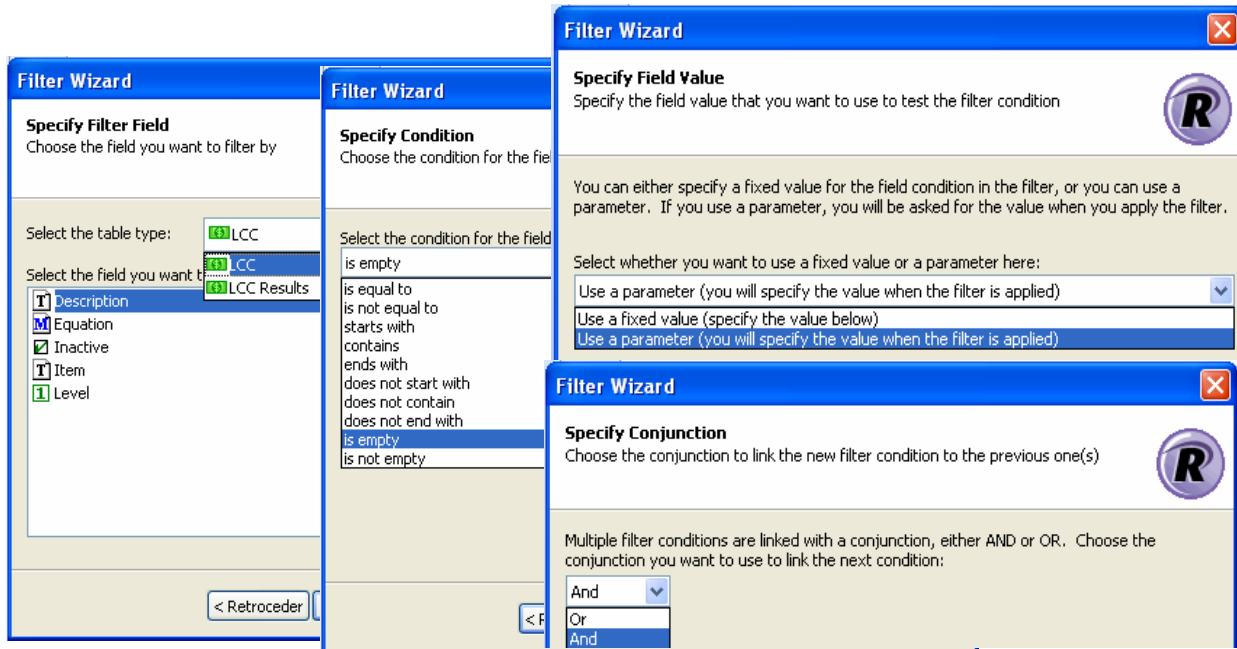


Figure 4 - Examples of the Filter wizard (Relex LCC)

On the other hand, CATLOC checks if a record with the same key already exists when the user is trying to import data and if so, the existing record is updated with the values from the database. Fields that are empty in the imported record do not erase an existing value in the CATLOC table. If no matching key is found, a new record is appended.

Both D-LCC and UNIFE-UNILIFE allow the user to compute i.e. gather element's life cycle costs using different operators, besides the addition operator, providing an extra measure of flexibility to the LCC tool (by looking at the Figure 5 this might become clearer).



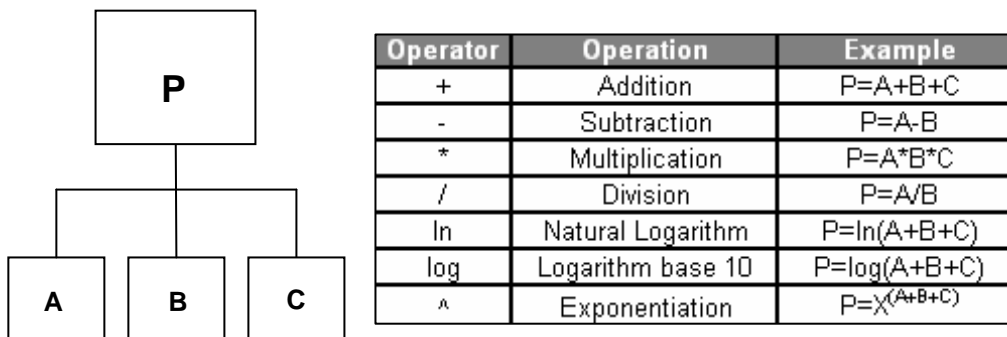| Operator | Operation | Example |
|----------|-----------|---------|
| + | Addition | P=A+B+C |
| - | Subtraction | P=A-B |
| * | Multiplication | P=A*B*C |
| / | Division | P=A/B |
| ln | Natural Logarithm | P=ln(A+B+C) |
| log | Logarithm base 10 | P=log(A+B+C) |
| ^ | Exponentiation | $P=X^{(A+B+C)}$ |

Figure 5 - Example of the available operators and their impact on the life cycle computation (D-LCC)

Additionally, D-LCC is able to calculate life cycle using variables with different weights, for example, the user is able to define a global variable called "Discount Rate" that has weights increasing from 0.0 to 1.0 over the planning horizon (see Table 6).

| Main structures (CBS/PBS) | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|
| Is it possible to compute element's life cycle costs using different operators? | ✘ | ✘ | ✔ | ✘ | ✔ |
| Is your program able to compute life cycle using variables with different weights? | ✘ | ✘ | ✔ | ✘ | ✘ |
| Is your program able to limit the computation time? | ✔ | ✔ | ✔ | ✔ | ✘ |

Table 6 - Main structures (CBS/PBS)

Furthermore, with D-LCC is also possible to limit the computation time by checking the Fast Calculation where the minimum number of operations required is the product of the number of tree elements, periods and alternatives. As computing life cycle costs for a project can be computationally intensive, the ability to limit the computation time is very useful feature.

## 3.7.3    Data/Results interaction with other software (see Annex II for further details)

As we can see in the Table 7, all LCC tools studied are able to import data from MS Excel and MS Access. However, CATLOC can not easily export its results to MS Excel and MS Access (observed while testing it).

| Data/Results interaction with other software | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|
| Import data from | | | | | |
| MS Excel | ✔ | ✔ | ✔ | ✔ | ✔ |
| MS Access | ✔ | ✔ | ✔ | ✔ | ✔ |
| Export data from | | | | | |
| MS Excel | ✔ | ✔ | ✔ | ✘ | ✔ |
| MS Access | ✔ | ✔ | ✔ | ✘ | ✔ |
| Can the imported data be up-dated automatically? | ✔ | ✘ | ✘ | ✘ | ✘ |

Table 7 - Data/Results interaction with other software

Furthermore, there are some LCC applications like Relex LCC that belongs to a software package with a diverse set of reliability analysis software tools, allowing import/export between the modules that go from prediction calculations to complex system modelling to spares optimisation tools. Additionally, Relex LCC is able to connect to other powerful databases such as Oracle (see further details on Annex I). Another example is the D-LCC software that although is not part of a software package, its inputs/outputs are compatible with other Advanced Logistics Developments packages for Reliability, Maintainability and Logistics Analysis such as RAM Commander.

As we can see in Table 7, from the LCC tools studied, only the Relex application is able to up-dated automatically imported data. An interesting and useful program included is the RelImEx.exe, a program for importing and exporting data automatically using the Windows Scheduled Task Wizard. Nevertheless, settings for an import or export have to be saved first in an Import/Export Template file i.e. data must be inserted manually one time in an Import/Export Template file, in order to allow it to be updated later.

## 3.7.4    Data/Results accuracy (see Annex II for further details)

Concerning the identification of the cost drivers, the majority of the programs are able to perform a sensitivity analysis in order to make out the critical parameters and its effect in the CBS elements. The exception is UNIFE's software. However, no software studied is able to perform a risk analysis i.e. a probabilistic sensitivity analysis using, for example, the Monte Carlo simulation technique to LCC parameters, in order to evaluate the uncertainty inherent in the models (see Table 8). This type of analysis would lead the LCC model to more feasible results then the deterministic sensitivity analysis.

| Data/Results accuracy | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|:---:|:---:|:---:|:---:|:---:|
| Is your program able to perform a standard sensitivity analysis? | ✓ | ✓ | ✓ | ✓ | ✗ |
| Is your program able to perform a risk analysis to LCC parameters? | ✗ | ✗ | ✗ | ✗ | ✗ |
| Is your program able to notify the user if the alternatives in study have or have not the same level of detail and boundary conditions? | ✗ | ✗ | ✗ | ✗ | ✗ |
| Is your program able to identify the cost drivers with conclusively reports with different modes of presentation? | ✓ | ✓ | ✓ | ✓ | ✗ |
| Does it provide reports for both total and detailed costs for any combination of Product Tree items and CBS elements? | ✓ | ✓ | ✓ | ✓ | ✗ |

Table 8 - Data/Results accuracy

As we can see in Table 8, no software studied is able to notify the user if the alternatives in study have or have not the same level of detail and boundary conditions. This feature would be very useful as comparison of options with no similar criteria may significantly change the order of the alternatives.

Regarding the identification of the cost drivers, all programs except the UNIFE-UNILIFE are able to recognise the cost drivers with conclusively reports with different modes of presentation and also to provide reports for both total and detailed costs for any combination of Product Tree items and CBS elements (see Table 8).

| Data/Results accuracy | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|
| Is your program able to track errors in input data? | ✓ | ✗ | ✗ | ✓ | ✓ |
| Is your program able to track errors in CBS equations? | ✓ | ✓ | ✓ | ✓ | ✗ |

Table 9 - Data/Results accuracy

As we can see in the Table 9, in relation to the ability to track errors in input data, UNIFE-UNILIFE, Relex LCC and CATLOC are able to do it. In UNIFE's LCC application, there is an error checking facility to identify errors in the data fields, to verify if any rule for entering data has been broken. Relex LCC has a feature named Filters that allows the user to define criteria to limit the items included when importing and exporting data preventing, for example, incorrect application of the regulation or errors due to incorrect data introduction. Additionally, CATLOC can detect errors and inconsistencies in input data, only when performing a test or in the calculation phase.

On the topic of tracking errors in CBS equations, as we can see in the Table 9, UNIFE-UNILIFE is not able to verify data validity. In D-LCC it is only possible to check the validity of the CBS when the user runs the Cost Calculation. In such case, a message will appear to notify the user if the calculation is performed successfully or not. If the calculation failed, a list of the errors is displayed showing the CBS element causing the error (see Figure 6).
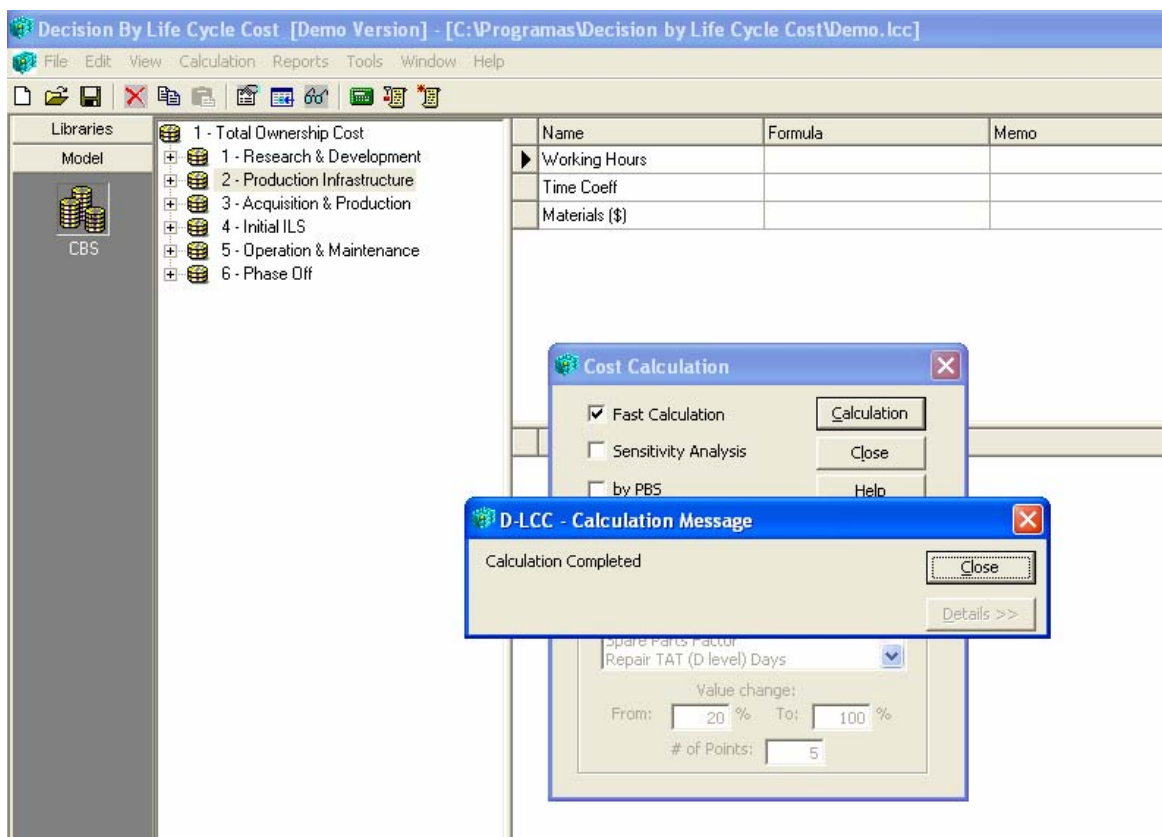


Figure 6 - Examples of the Calculation Message (D-LCC)

Concerning Relex LCC, there is an option in the Equation Editor tab named Verify whose function is to validate cost equations by verifying its input data and if the calculation is invalid, information about the error appears in a dialog box. In LCCWare there is available a debug facility that allows the user to insert breakpoints, step through cost function code and examine variable values. Regarding CATLOC, there is an error tracking possibility that can be activated during the test phase or the calculation phase and the errors and inconsistencies in input data detected are echoed to the log window.

### 3.7.5    Accounting features (see Annex II for further details)

In this deliverable, design to cost is defined as a management strategy and supporting methodology to achieve an affordable product by setting a target cost. Consequently, target cost is defined in this deliverable as an independent design parameter that needs to be achieved during the development of a product. The key of targeting cost is to emphasise management of product costs during development, not merely accumulating costs as designs are completed, allowing the decision-maker to focus on the cost elements that do not meet the target and then, to consider different alternative processes while it is still early enough in the development cycle to introduce new processes.

| Accounting features | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|
| Does the tool allow target costing? | ✖ | ✖ | ✖ | ✖ | ✖ |

Table 10 - Accounting features

As we can see in the Table 10, no software provides a utility to perform a target costing analysis, not allowing the user to improve the decision-making process regarding design alternatives and to lead to the refinement of the design in order to come closer to the established cost targets.

## 3.8  Summary and selection of tools for testing

Basically, any Life Cycle Cost software has to provide input to decision making in all phases of a product's life cycle, by evaluating and/or optimising the life cycle cost of a product.

With the purpose of benchmarking LCC commercial tools, relevant information like software manuals and demo versions were requested to LCC software suppliers and additionally, a questionnaire was sent to them. A wide variety of tools, ranging from simple ones to sophisticated software packages were analysed in this deliverable.

Based on the information available, the following conclusions can be drawn:

- Almost all software's addresses the basic features required for LCC modelling of railway infrastructure;

- Among more than thirty criteria the following topics were considered to be key to differentiate the performance of the tools:

    i.    The ability to compare different alternatives within one single project is only available in D-LCC;

    ii.    On the one hand the ability to define cost functions that changes over time is only present in CATLOC, as in this application all cost atoms and parameters costs can be defined for a combination of five dimensions: material; task; resource; station and time. On the other hand, to insert such a function in CATLOC is highly complex, due to the fact that all the dimensions have to be inserted as well. Nevertheless, in Relex LCC, LCCWare and D-LCC at least it is possible to define a variable that changes over time or over different alternatives;

iii.   The possibility to trace the path of each parameter in the CBS components and corresponding formulas can be provided by D-LCC, CATLOC and Relex LCC. However, the D-LCC is the most intuitive one;

iv.   The option to perform comparisons between its inputs/outputs and historical data or reference values can be performed by Relex LCC and CATLOC. On the one hand, Relex LCC has a feature named Filters that can be applied to limit the items included when importing/exporting data. On the other hand, CATLOC checks if a record with the same key already exists when the user is trying to import data and if so, the existing record is updated with the values from the database;

v.   Regarding import/export features, all LCC tools studied are able to import data from MS Excel and MS Access. However, CATLOC can not export (at least easily) its results to MS Excel and MS Access as it was observed while testing it.

vi.   The ability to provide reports for both total and detailed costs for any combination of Product Tree items and CBS elements is available in all LCC commercial tools studied, excluding the UNIFE-UNILIFE application. Though, in this subject, D-LCC is the most intuitive and well-designed user interface;

vii.   The facility to track errors in input data is present in UNIFE-UNILIFE, Relex LCC and CATLOC. In UNIFE's LCC application, there is an error checking facility to verify if any rule for entering data has been broken. In what concerns Relex LCC software, there is a feature named Filters that allows the user to define criteria to limit the items included when importing and exporting data preventing, for example, incorrect application of the regulation or errors due to incorrect data introduction. Additionally, CATLOC can detect errors and inconsistencies in input data, only when performing a test or in the calculation phase;

viii.   The possibility to track errors in CBS equations can be performed by all LCC commercial tools studied, apart from the UNIFE-UNILIFE software. In D-LCC is possible to check it when the user runs the Cost Calculation. Regarding Relex LCC, there is an option in the Equation Editor tab whose function is to validate cost equations by verifying its input data. Concerning LCCWare, there is available a debug facility that allows the user to insert breakpoints, step through cost function code and examine variable values. In CATLOC, there is an error tracking possibility that can be activated during the test or calculation phase to detect errors and inconsistencies in input data;

Based on the results of the analysis performed, the WP6.2 workgroup decided that CATLOC and D-LCC were the LCC programs selected to be evaluated more profoundly, not only due to their good results in the benchmark but also, due to the support of both software companies to provide deeper information about their products and their willingness, in the future, to make improvements in their LCC programs to meet INNOTRACK requirements.

# 4. Assessment of selected tools

Based on the comparison performed in chapter 3, it was decided to go deeper into the cross-comparison between the D-LCC and CATLOC software applications, aiming to identify the most appropriated LCC program for the INNOTRACK project, to apply in WP6.5.

## 4.1 Features and methodology to assess selected tools

To assess in detail the selected tools, a more limited group of features was identified as being the most relevant for the INNOTRACK project. Four degrees of relevance were defined: medium; high; very high; extremely high (table 11). In this case, relevance represents how important each feature is concerning the requirements for the LCC analysis to perform in future steps of the INNOTRACK project.

| Features | Degree of Relevance | | | |
|---|---|---|---|---|
| | Medium | High | Very High | Extremely High |
| **Input** | | | | |
| ● Variables (all) → INNOTRACK database | | | ✓ | |
| ● Formulas | ✓ | | | |
| ● PBS | ✓ | | | |
| ● CBS | ✓ | | | |
| ● Statistical distributions | | | ✓ | |
| ● Functions changing over time | | | ✓ | |
| **Output** | | | | |
| ● Export results to MS Excel (post-process) | | | | ✓ |
| ● Cost aggregation output | ✓ | | | |
| ● Breakdown options | ✓ | | | |
| ● Check inputs, errors detection | | | ✓ | |
| ● Results allocated to periods | | ✓ | | |
| **Failure detection (import, input, calculation)** | ✓ | | | |
| **Alternatives (within and comparisons)** | | ✓ | | |
| **Multiple projects (copy/paste/comparison)** | | ✓ | | |
| **Sensitivity analysis (over time period)** | | | | ✓ |
| **User-friendliness** | | ✓ | | |
| **Capability of introducing improvements/support** | | | | ✓ |
| **Licence and support Cost** | | | | ✓ |

Table 11 – Main features to assess and degree of Relevance of these features to INNOTRACK purposes

As it can be seen in the Table 11, the most relevant LCC features are the ones that enable the user to export results to MS Excel and to perform a sensitivity analysis over time period. Also software licenses and support costs, as well as the capability to produce improvements that meet INNOTRACK requirements were

considered features of highest importance, since it is found highly recommendable to have all partners and suppliers using the software on the next stages of the project.

Other very relevant features found are the ones that could allow to: import (all) the variables belonging to INNOTRACK databases, including statistical distributions; to introduce functions changing over time; to check inputs and detect errors on the oputput process and the capability to perform a sensitivity analysis over time period.

To evaluate the performance of each tool, the following methodology was applied:

- Two identical models were built (from zero) on the two selected tools: one example of switch and one example of a plain track section

- The main features defined in previous table 11 were assessed one by one during the building of the model and the analysis process

- To help clarifying the evaluation and the decision making process, a quantitative approach and scoring was defined as follows:

  - A score was given from 1 (poor), 2 (average) to 3 (good) to represent the capability of each tool regarding the specific feature to be assessed

  - The score obtained was multiplied by a weighted factor representing the relevance of the feature, with the following criteria: 1 (medium), 2 (high), 3 (very high) and 4 (extremely high). The resulting weight of each feature is shown in table 12.

| Features | Weight | Features | Weight |
|---|---|---|---|
| **Input** |  | **Output (cont.)** |  |
| ● Variables (all) → INNOTRACK database | 3 | ● Check inputs, errors detection | 3 |
| ● Formulas | 1 | ● Results allocated to periods | 2 |
| ● PBS | 1 | **Failure detection (import, input, calculation)** | 1 |
| ● CBS | 1 | **Alternatives (within and comparisons)** | 2 |
| ● Statistical distributions | 3 | **Multiple projects (copy/paste/comparison)** | 2 |
| ● Functions changing over time | 1 | **Sensitivity analysis (over time period)** | 4 |
| **Output** |  | **User-friendliness** | 2 |
| ● Export results to MS Excel (post-process) | 4 | **Capability of introducing improvements/support** | 4 |
| ● Cost aggregation output | 1 | **Licence and support Cost** | 4 |
| ● Breakdown options | 1 |  |  |

Table 12 – Degree of Relevance of the features to INNOTRACK purposes and corresponding load

The tests were done by two members of the WP6.2 workgroup (one from ADIF and the other from DB), and the evaluation was the result of the convergence between the findings done firstly at an individual level and in secondly, at a team level.

It should be highlighted that this assessment was not made in order to find which tool is best suited *per se* as a software to use for LCC analysis in rail industry, but only to assess the most suitable regarding INNOTRACK requirements and specifically SP6 objectives and restrictions (e.g. need to have a tool for each partner in order directly input confidential data such as unit cost, budget and time restrictions of the project,...).

## 4.2 Results

Based on the tests performed in chapter 4.2 a table with the ranking the performance of each D-LCC and CATLOC features was drawn (see Table 13).

| Features | D-LCC | CATLOC |
|---|---|---|
| **Input** | | |
| ● Variables (all) → INNOTRACK database | 2* | 1 |
| ● Formulas | 1 | 1 |
| ● PBS | 3 | 2 |
| ● CBS | 3 | 1 |
| ● Statistical distributions | 1* | 1* |
| ● Functions changing over time | 2 | 2 |
| **Output** | | |
| ● Export results to MS Excel (post-process) | 3 | 1 |
| ● Cost aggregation output | 3 | 2 |
| ● Breakdown options | 3 | 3 |
| ● Check inputs, errors detection | 3 | 3 |
| ● Results allocated to periods | 3 | 2 |
| **Failure detection (import, input, calculation)** | 2 | 3 |
| **Alternatives (within and comparisons)** | 3 | 1 |
| **Multiple projects (copy/paste/comparison)** | 1 | 2 |
| **Sensitivity analysis (over time period)** | 2 | 2 |
| **User-friendliness** | 2 | 1 |
| **Capability of introducing improvements/support** | ? | ? |
| **Licence and support Cost** | ? | ? |

(*) Feature possible to improve, depending on the budget

(?) No information was available (at the moment the analysis was performed) to accurately assess this particular feature.

Table 13 – Ranking the performance of each D-LCC and CATLOC features

As mentioned, the use of weights helped to quantify the importance of each feature and also to get a clearer picture of what is the most suitable LCC software for INNOTRACK purposes.

The Final Score takes into account both the individual performance of each LCC software feature and the degree of relevance of each feature to INNOTRACK purposes (see Table 14). For example, for the user-friendliness tool, on the one hand D-LCC scored 4 (2*2=4), on the other and CATLOC scored 2 (1*2=2).

| Features | Feature's Load | D-LCC | Total (by feature) | CATLOC | Total (by feature) |
|---|---|---|---|---|---|
| **Input** | | | | | |
| ● Variables (all) → INNOTRACK database | 3 | 2* | 6 | 1 | 3 |
| ● Formulas | 1 | 1 | 1 | 1 | 1 |
| ● PBS | 1 | 3 | 3 | 2 | 2 |
| ● CBS | 1 | 3 | 3 | 1 | 1 |
| ● Statistical distributions | 3 | 1* | 3 | 1* | 3 |
| ● Functions changing over time | 1 | 2 | 2 | 2 | 2 |
| **Output** | | | | | |
| ● Export results to MS Excel (post-process) | 4 | 3 | 12 | 1 | 4 |
| ● Cost aggregation output | 1 | 3 | 3 | 2 | 2 |
| ● Breakdown options | 1 | 3 | 3 | 3 | 3 |
| ● Check inputs, errors detection | 3 | 3 | 9 | 3 | 9 |
| ● Results allocated to periods | 2 | 3 | 6 | 2 | 4 |
| **Failure detection (import, input, calculation)** | 1 | 2 | 2 | 3 | 3 |
| **Alternatives (within and comparisons)** | 2 | 3 | 6 | 1 | 2 |
| **Multiple projects (copy/paste/comparison)** | 2 | 1 | 2 | 2 | 4 |
| **Sensitivity analysis (over time period)** | 4 | 2 | 8 | 2 | 8 |
| **User-friendliness** | 2 | 2 | 4 | 1 | 2 |
| **Capability of introducing improvements/support** | 4 | ? | ? | ? | ? |
| **Licence and support Cost** | 4 | ? | ? | ? | ? |
| | | **Final Score** | **73** | **Final Score** | **53** |

(*) Feature possible to improve, depending on the budget.

(?) No information was available (at the moment the analysis was performed) to accurately assess this particular feature.

Table 14 – Final Score of the LCC softwares

According to the results obtained (Table 14), D-LCC seems to be the most suitable LCC software regarding INNOTRACK purposes[1]. However price/support negotiation is still being conducted with the software provider (Advanced Logistics Developments Ltd.) in order to accurately define the feasibility of broadly use the tool among the SP6 partners, on one hand, and on the other hand to also define the costs of upgrading the tool incorporating some of the required improvements identified in the next section.

## 4.3 Required improvements

While testing the tools presented in this report, some weaknesses were detected regarding the needs of LCC capabilities in order to meet INNOTRACK purposes and thus, some improvements would be needed. Based on the information available, the following main specific features should be improved or implemented:

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[1] Even though the assessment indicates that D-LCC has the higher score, this does not mean that D-LCC is the best LCC software (only the most convenient to reach INNOTRACK SP6 objectives).

- Improve "Importability" of (all) variables from INNOTRACK database (*);

- Allow as inputs stochastic variables, statistical distributions and/or ability to directly import data from a risk analysis software;

- Allow as input functions changing over time (*);

- Improve comparability and "check process" of inputs and detection of errors;

- Incorporate a Monte Carlo Simulation toolbox to obtain a probabilistic output (*);

- Include a target costing feature.

Among those, the most important features were identified (market with an (*)) and a negotiation will be performed with the supplier of the selected tool in order to evaluate the possibility to develop the mentioned improvements and still apply the resulting new and innovative tool within the framework and time schedules of WP6.5.

The importability features both of different parameters from an external database (variables, degradation rates, tables, unit cost values, etc.) are a key issue to make possible (and easy) the use of the same (or equivalent) models by different partners within INNOTRACK. By improving the import functions of the tools, the incorporation of variations on the parameters values within the different Infrastructure Managers and Suppliers would be easily performed by filling a pre-defined external database or spreadsheet and importing it to the model. This feature and the relation with the databases will be discussed in more detail within Deliverable 6.4.

On the other hand, it is also necessary to allow the introduction of functions that change over time to easily incorporate, for example, the variability of maintenance works intervals. This feature would strongly improve the modelling process and time avoiding unnecessary and excessive use of tables and complex formulations.

Finally, it is also very important that LCC programs include tools to simplify the introduction of probabilistic analysis, enabling if possible to perform Monte-Carlo simulations. This technique allows to have a more complete picture of all possible outputs, combining the probability distributions of uncertain variables. The advantage with Monte Carlo simulation is that it allows estimating the uncertainty in each input variable and predicting the impact of that variable on the outputs. However, the incorporation of Monte-Carlo simulation into existing deterministic LCC software is not an easy task since it should require a profound modification in both input and output modules.

At last, even if not referred as critical as the others, another feature that would be interesting to improve (for practical use) would be the ability to perform comparisons between inputs/outputs and historical data or reference values. This feature would prevent, for example, incorrect application of the regulation or errors due to incorrect data introduction. One way of preventing, for example, incorrect application of the requirements or errors due to incorrect data introduction could be by defining assessment criteria/indicators to verify if any rule for entering data has been broken. This option would help limiting the items included when importing and exporting data and so, providing more accurate outputs.

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* Feature possible to improve, depending on the budget.

# 5. Conclusions

With the purpose of benchmarking LCC commercial tools, relevant information like software manuals and demo versions were requested to LCC software suppliers and additionally, a questionnaire was performed. A wide variety of tools, ranging from simple ones to sophisticated software packages were analysed. It was not achievable to have answers to the questionnaires from the suppliers, but it was possible to complete the study through the analysis of the manuals and demo versions provided.

Based on the information available, the following conclusions can be drawn:

- Almost all software's addresses the basic features required for LCC modelling of railway infrastructure

- Among more than thirty criteria (assessed with more than 50 questions) the following topics were considered to be key to differentiate the performance of the tools:

    • The ability to compare different alternatives within one single project;

    • The ability to define cost functions that changes over time;

    • The possibility to trace the path of each parameter in the CBS components and corresponding formulas;

    • The option to perform comparisons between its inputs/outputs and historical data or reference values;

    • Import/export features

    • The ability to provide reports for both total and detailed costs for any combination of Product Tree items and CBS elements;

    • The facility to track errors in input data;

    • The possibility to track errors in CBS equations;

- Based on the results of the benchmark two tools were selected by the WP6.2 workgroup to perform a more detailed assessment, in order to define the best-suited tool to use in INNOTRACK WP6.5. Some key features to assess were defined and two identical models were built on the two selected tools to assess their capabilities on each key feature.

- A quantitative approach and scoring was defined and the results obtained made it possible to identify the best "performer" tool, the D-LOC.

- At last some important features for future LCCA developments not covered were recommended for development for future use within the project:

    - Improvement of "Importability" of (all) variables from a database

    - Allow as input functions changing over time

    - Improve comparability and "check process" of inputs and detection of errors;

    - Incorporate a Monte Carlo Simulation toolbox to perform a probabilistic analysis

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# 7. Annexes

# Annex I: Description of LCC commercial tools

A LCC model is mainly defined by its cost elements, cost structures and input parameters, which are consequently designed to support activities associated with the life cycle cost of a product, taking into consideration each one requirements.

Using a LCC application as a support tool in the decision making process should make easier the estimation and comparison of costs during a product life cycle as well as the identification of the cost drivers.

A wide variety of tools, ranging from simple ones to sophisticated software packages will be analysed in this deliverable.

## UNIFE-UNILIFE (UNIFE, Belgium)

UNIFE-UNILIFE is a LCC Interface Software Model created for the use of UNIFE members and the rail supply industry. Basically, this software application consists in two Microsoft EXCEL workbooks, UNILIFE and UNIDATA, containing several spreadsheets that were designed to be used for collecting data for LCC analysis of rolling stock trains and fixed installation systems (plant/line), allowing the user to compare different equipment offers or design options (see Figure A).
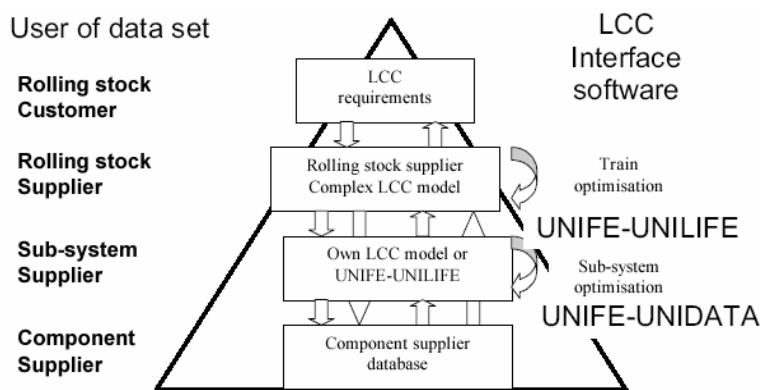


Figure A – Use of UNILIFE and UNIDATA for data transfer. Definition of user groups

In UNIDATA workbook are collected data for life cycle costs calculations while in UNILIFE life cycle costs are calculated. Therefore, UNILIFE is a software application designed to collect data and also to give the user a first analysis of LLC or Life Support Cost (LSC) for sub-systems and items of equipment (it is recommended not to exceed 2000 items). Additionally, it also includes some ability to perform reability analysis and register tools used for maintenance.

As mentioned in UNIFE-UNILIFE guidelines, this software is designed to communicate Life Cycle Cost information and while performing some error checks is not based on a universally accepted calculation method. It is mostly a data transmission tool and as such any indicated values of LCC calculated by the software is purely for comparison purposes.

In the Figure B is presented resulting cost breakdown in operating costs and investments. These results can be given as total cost and discounted cost. As we can see in the same figure, the LSC (Life Support Cost) part includes PM (Preventive Maintenance), CM (Corrective Maintenance) and energy cost and additionally, can be recognised according to different train configurations.

Key data and calculations are performed on "Equipment Data", "Corrective Maintenance" and "Preventive Maintenance" spreadsheets, with a row for each item/PM activity. With the purpose of collecting all costs not specifically maintenance driven, such as investment, energy and yearly costs, it is necessary to fulfil the spreadsheet "Miscellaneous Costs".
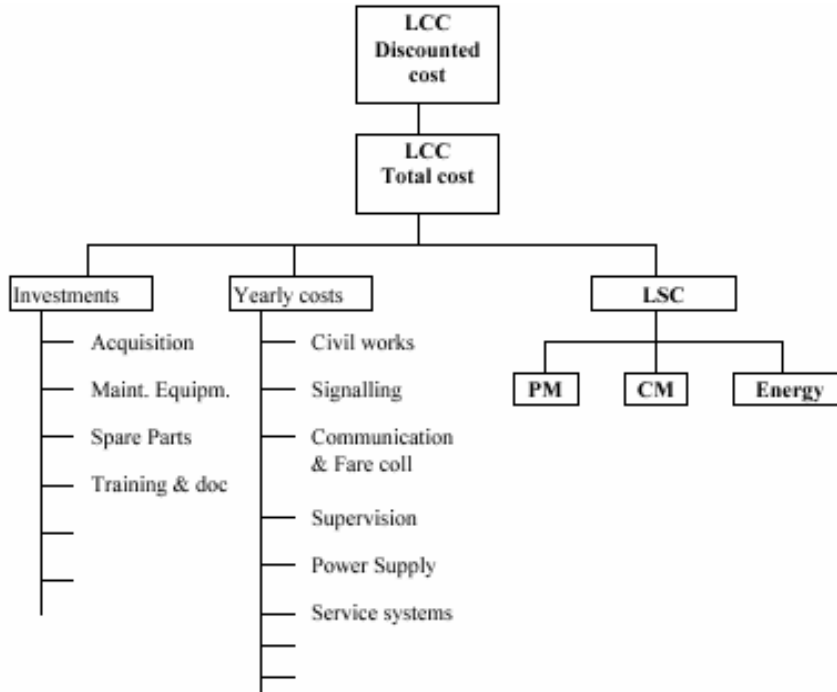


Figure B – UNIFE-UNILIFE model

In fact, this application is more focused on maintenance cost calculation and uses either mean time between failures (MTBF) or failure rate to estimate Corrective Maintenance along with distance or time to compute Preventive Maintenance. In case of failure, it is necessary to identify the type of maintenance required. Therefore, it is mandatory to define if the item is exchanged in the train/plant/line (Line Replaceable Unit - LRU) or in the component workshop (Shop Replaceable Unit - SRU) as we can see in Figure C. In the last case, exchange time does not affect down time of train (train/plant/line). Additionally, it is necessary to indicate if the replaced unit is repairable or not (see Figure 3).



Figure C – Example of the Corrective Maintenance sheet and possible items exchange/repair combinations

As we can see in the Figure C, by defining exchangeable and repairable it is possible to compute material costs for both corrective and preventive maintenance costs.

This software is able to track errors in input data as it has an error checking facility that verifies if any rule for entering data has been broken.

It is the aim of UNIFE-UNILIFE to be set up for a project by (Rolling Stock) Supplier Reliability Engineer according to customer and Supplier requirements, and afterwards to be sent out to sub-suppliers and component suppliers in a request for data. After entering data and analyses, Sub-supplier Reliability Engineer (or Component supplier Reliability Engineer) should send UNIFE-UNILIFE back to Supplier Reliability Engineer. It should be remarked that many of the definitions, like who is the customer and who is the supplier is defined and noted in UNIFE-UNILIFE by the Project Reliability Engineer.

Depending on the user, UNIFE-UNILIFE has different rights of use as follows:

- The Project Reliability Engineer enters project data and global data in green cells;

- The UNILIFE file used for data request shall be renamed using the project and sub-system identification as the baseline for the file name;

- The Reliability Engineer for the sub-system or component supplier enters data into yellow cells in Equipment data/CM (Corrective Maintenance), PM (Preventive Maintenance), Maintenance equipment and Miscellaneous data, spreadsheets.

In order to keep the UNIFE-UNILIFE simply and suitable for most users, there are some requirements that were not fulfil. According to the UNLIFE/UNIDATA user's guide the more typical limitations are:

- Calculations are made just for one train configuration (at the time);

- Includes only one man-hour cost;

- Does not take into account cycle based CM failure.

Other limitation detected in this software application is related with the PBS/CBS. As an EXCEL workbook, UNIFE-UNILIFE does not have a basic PBS/CBS tree representation not allowing the user to easily visualise input data position (see Figure D).



Figure D – UNLIFE/UNIDATA PBS and CBS examples

Furthermore, its CBS does not incorporate the time scale (life cycle phases) as we can see in the Figure 4. Without time intervals, this software is forced to use, for example, a constant discount rate to calculate the

net present value of an investment, making a less realistic cost computation. An economic analysis along with other financial aspects such as capital costs or depreciation are not included, as well, in this LCC tool.

Above and beyond, this software is not able to perform a sensitivity analysis to make out the critical parameters and its effect in the CBS elements, not allowing the identification of each project cost drivers.

Bearing in mind that calculating life cycle costs for a project can be computationally intensive, the non-ability to limit the computation time is other restriction present in it.

# CATLOC (Systecon AB, Sweden)

Systecon has pioneered the development of LCC methods and tools over the last 30 years, and CATLOC (Complete Analysis Tool for Logistics and Operations Costs) is the most recent. This software is described as very flexible allowing the user to tailor the LCC model to match the needs of any industry or project phase. Besides, being designed mainly to support the activities associated with the LCC methodology, CATLOC is told to add great value to areas such as logistics support analysis and systems engineering.

As the cost breakdown structure does not follow a predefined tree structure since it is fully user define, a set of standard template models is supplied, in order to simplify the effort of building a LCC model.

The calculation model in CATLOC is constructed by the use of cost atoms (the lowest level in the LCC tree) and parameters that are defined in a five dimensional space that consists of: material, tasks, stations, resources and time. These dimensions will allow the user to slice a total cost according to the different systems, spares, bases, repair tasks etc. included in the model. Both Cost Atoms and Parameters can de defined with a specific value or a functional expression while Cost Aggregates are always calculated as the sum of cost atoms or other aggregated costs, since Cost aggregates are used to build up the cost breakdown structure.

CATLOC is a very intuitive and easy-to-use software application as it allows the user, with only a few mouse clicks, to distribute quickly and easily the resulting costs over time, across stations, resources, material types and tasks, or any combination of these dimensions. This graphical analysis environment greatly facilitates the estimation and comparison of costs of different contractors, alternative system designs or logistics support solutions, as well as to identify cost drivers. By looking at the Figure E this might become clearer the way different graphics are automatically generated with single click.
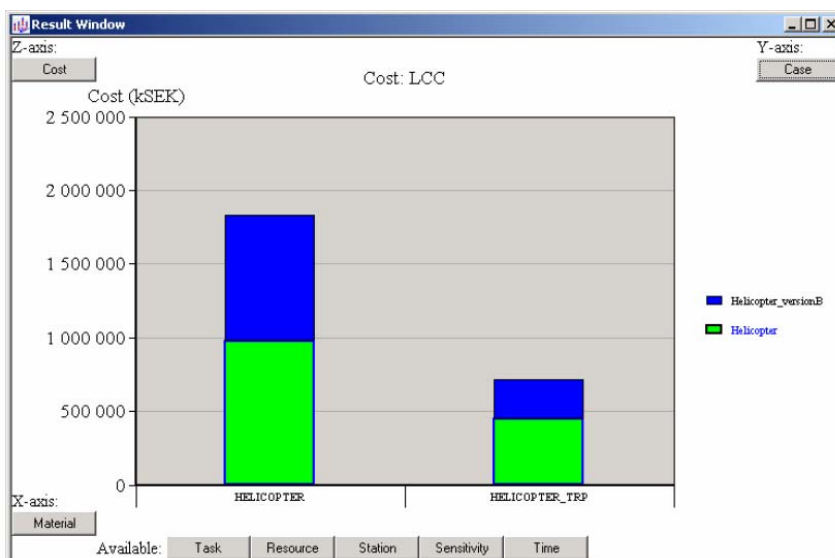


Figure E – LCC (z axis) from two helicopter versions (y axis) manufactured with identical materials (x axis)

The program has the ability to define cost functions that change over time (e.g. cost A enters in year 1 and then from year 5 up to year 8) due to the fact that all cost atoms and parameters costs can be defined for a combination of the five dimensions mentioned. For example, with CATLOC the cost atom "repair costs for items at a station a given year", would be defined in the material, station and time dimensions.

One of the most useful and advanced features in this software is the possibility of error tracking during the test or calculation phase as we can see in Figure F. In such cases, by double clicking the row displaying an error message, a warning or a notice, a log window containing errors and inconsistencies in input data is displayed (see Figure F).
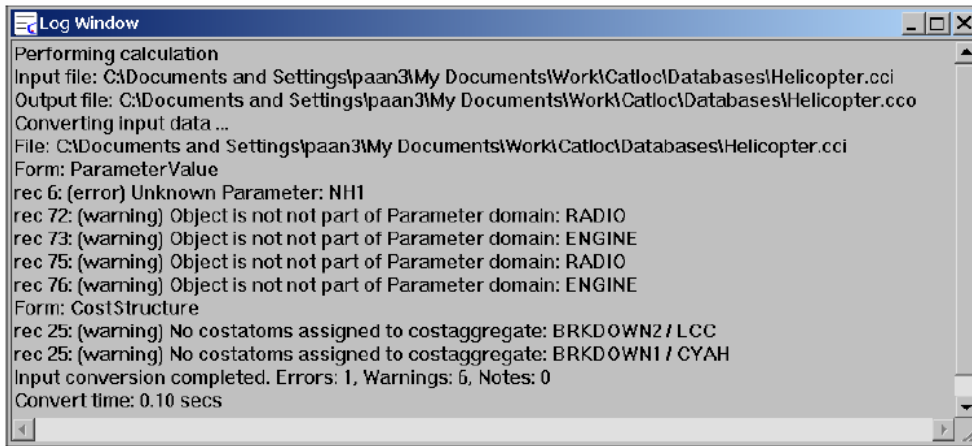


Figure F - The log window displaying error messages and warnings

There are many ways to easily transfer CATLOC input data to or from other applications. In order to perform multi-table data transfers, text file and relational database alternatives are available (e.g. it is possible to import data from OPUS10). The method used to import data consists in merging imported data into the CATLOC input document i.e. the software checks if a record with the same key already exists and if so, the existing record is updated with the values from the database. If a field in the imported record is empty, the existing value in the CATLOC table will not be erased. Furthermore, if no matching key is found, a new record is appended.

Besides being a grid view tailored for displaying and editing parameter values, the value view tool also provides extra information about the way the value for the parameter has been provided by colouring the cells, as we can see in Figure G.
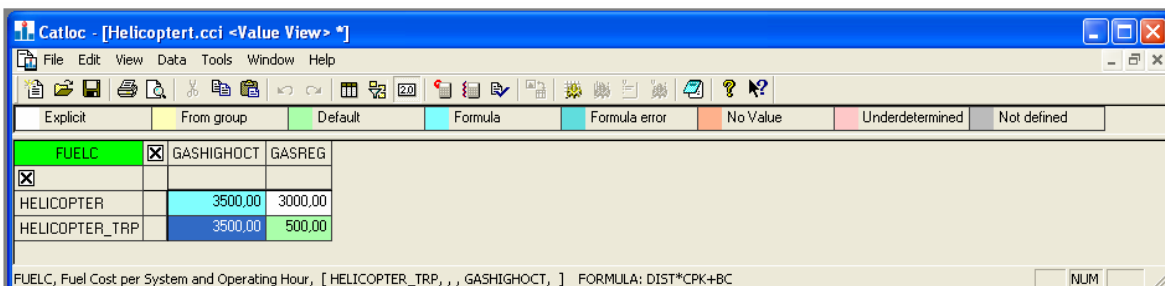


Figure G - Example of the Value View showing the colour coding

Each parameter cell is coloured in one of seven different colours: white, yellow, green, turquoise, dark turquoise and grey, depending how the value was provided to CATLOC. As we can see in Figure G, the

information about the selected cell can be seen at the bottom of the window. Colouring is also used to identify the different types of nodes (top level–red; intermediate levels–yellow; lower levels–green) and to differentiate the type of columns (key columns–orange; mandatory and essentials columns–yellow).

# D-LCC (ALD, Deutsche Bahn AG)

As described in the manual, D-LCC (Decision by Life Cycle Cost) is an interactive software package for Total Cost of Ownership calculation and Life Cycle Cost analysis developed by Advanced Logistics Developments Ltd and it is currently the tool used by Deutsche Bahn AG.

It is designed for systems analysts and engineers responsible for studying cost behaviour over time. Its flexibility allows the user to easily build a model that meets all requirements of any particular project. Additionally, this software ensures that each LCC analysis is structured, organised and "presentation ready".

In a few words, D-LCC provides the user bottom-up cost estimating, supports detailed examination of the costs and parameters affecting LCC including sensitivity analysis, and performs Net Present Cost analysis where discount and escalation rates can be defined for each project.

Each D-LCC project is composed by: a LCC Model (a CBS); a PBS / WBS (Product tree hierarchy and parameters) and Libraries (for storing of the life cycle parameters: alternatives, periods, global variables, tables and attributes).

All D-LCC project stages and components can be identified by the name in the Project Window where a Project Button Bar is presented on the left side. As we can see in Figure H, this feature covers all stages and components of the D-LCC project building and above all has an intuitive user interface for navigation through the project.
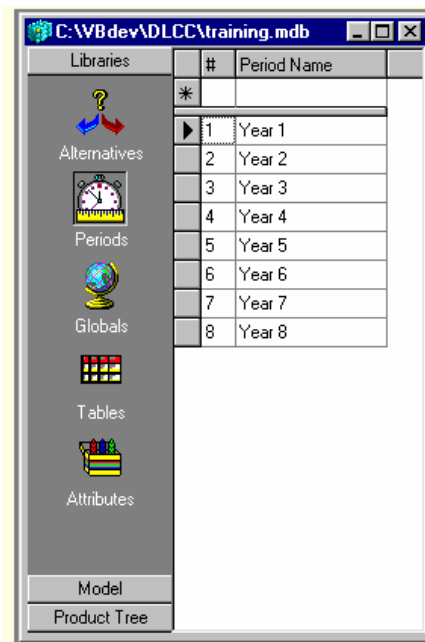


Figure H - Example of the Project Button Bar

Another interesting feature is the ability to calculate life cycle using variables with different weights, for example, the user is able to define a global variable (a variable available to all cost breakdown structure items) called "Discount Rate" that has weights increasing from 0.0 to 1.0 over the planning horizon.

Additionally, with this software is also possible to compute i.e. to gather elements life cycle costs using different operators, besides the addition operator. By looking at the Figure I this might become clearer.



| Operator | Operation | Example |
|----------|-----------|---------|
| + | Addition | P=A+B+C |
| - | Subtraction | P=A-B |
| * | Multiplication | P=A*B*C |
| / | Division | P=A/B |
| ln | Natural Logarithm | P=ln(A+B+C) |
| log | Logarithm base 10 | P=log(A+B+C) |
| ^ | Exponentiation | $P=X^{(A+B+C)}$ |
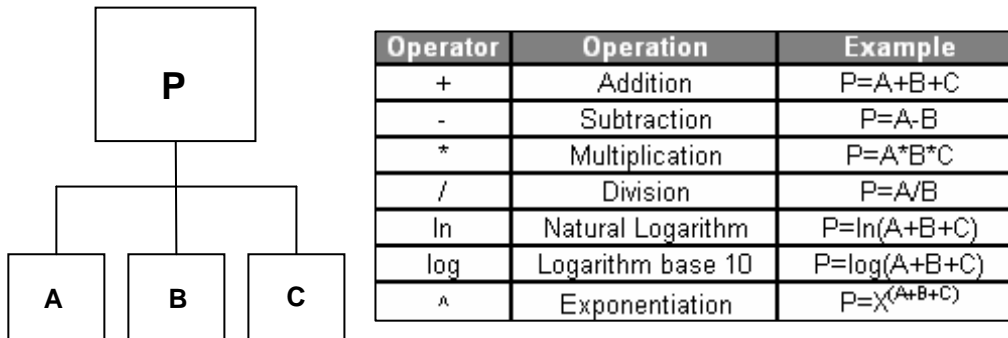
Figure I - Example of the available operators and their impact on the life cycle computation

Additionally, it is also possible to limit the computation time by checking the Fast Calculation where the minimum number of operations required is the product of the number of tree elements, periods and alternatives.

Another interesting D-LCC utility is the Delete Global Dialog that is displayed when the user is trying to delete a global variable. As we can see in Figure J, the Details button (pressed by default) provides a list of CBS components and corresponding formulas where the global variable, that the user is about to delete, is included. This message will allow the user to complete the process of deleting of the global variable after being convinced that this will not influence the cost calculation.
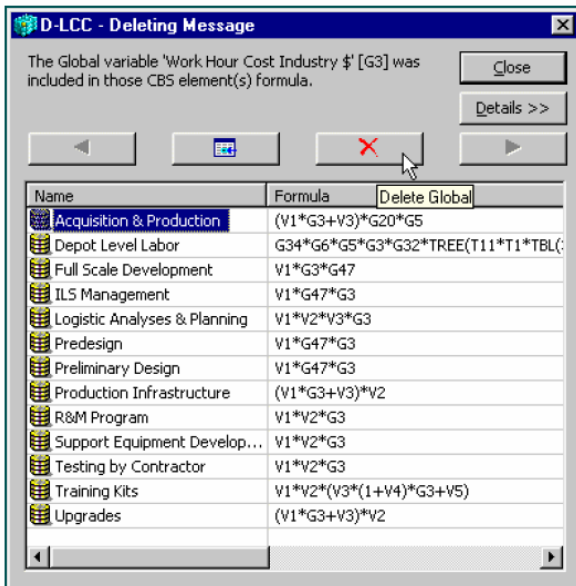


Figure J - Example of the Delete Global Dialog

In fact, as we can see in Figure J, this utility allows the user to trace the path of each parameter in the CBS and additionally, to modify the CBS formulas containing the global variable that is about to be deleted.

In D-LCC is only possible to check the validity of the CBS when the user runs the Cost Calculation. In such case, a message will appear to notify the user if the calculation is performed successfully or not. If the calculation failed, a list of the errors is displayed showing the CBS element causing the error.

Disabled in D-LCC 7.1, it is planned for the next version the possibility to calculate the cost and effectiveness of various levels of repair alternatives by using the Optimal Repair Level Analysis (ORLA) module.

## LCCWare (Isograph)

LCCWare is a software application developed by Isograph which calculates the life cycle cost of a system. Its flexibility allows the user to build the tree interactively and create a CBS suitable to each project needs, varying from a building, a ship, a weapon system to a power station.

This application enables the user to easily assign the cost functions to the nodes on the cost tree in order to calculate the individual cost values. These cost functions can range from simple equations to more complex calculations based on Visual Basic compatible coding. Cost functions can be defined in more than one set of time points with the purpose of allowing the user to investigate the effects of variations in the time point dates and the values of variables at those times.

Additionally, the latest version of LCCWare also includes a utility named part trees that provide the user with a convenient method of assigning the costs associated with a frequently used piece of equipment (and its constituent parts) to a cost function. Furthermore, a code palette is provided to simplify the task of creating the cost equations as we can see in the Figure K.
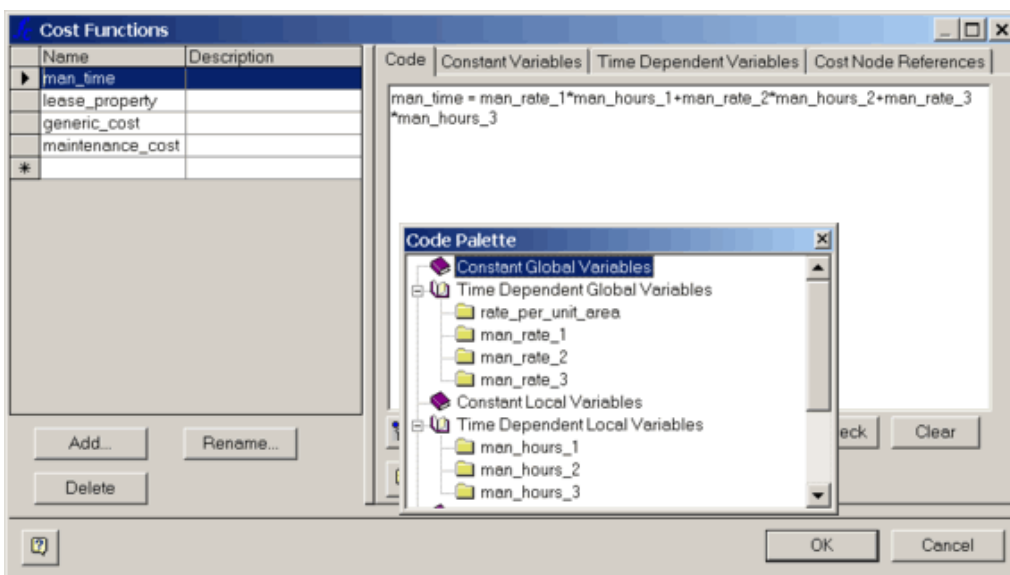


Figure K - Example of the Cost Functions dialog with a typical cost equation displayed

As in the majority of the LCC models studied, at the end the elements of cost will then be added together to give the total cost for each item and a grand total for the system through its full life i.e. it is not possible to compute element's life cycle costs using different operators (besides the addition operator).

An interesting feature available in this software is a debug facility that allows the user to insert breakpoints, step through cost function code and examine variable values. This utility is very useful in complex cost models to trace the progress of the calculation through coding. As we can see in Figure L, the debug process is controlled using the Debug menu options or the equivalent buttons on the toolbar. The Consistency Check Dialog can detect the following errors: cost nodes without cost functions; cost functions not referenced on the cost tree and cost node reference errors.

Figure L - Example of the consistency check dialog

LCCWare is able to perform a standard sensitivity analysis to the LCC parameters on constant and time dependent global variables, and constant and time dependent local variables, in order to allow the user to pinpoint variables which have the most influence on system cost. The sensitivity variation can be specified as a percentage of, or as an offset to, the normal value as well as an absolute value for constant global variables.

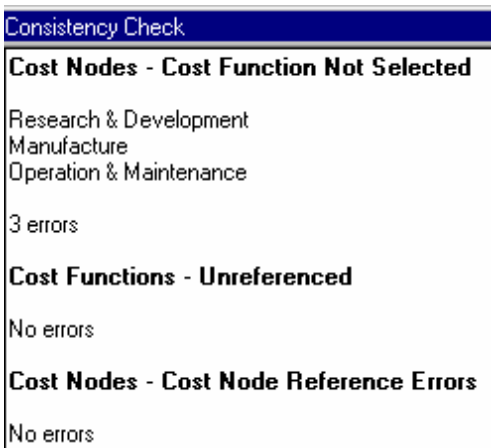One of the most useful and interesting utility available in the LCCWare is the Perform Analysis at First Time Point radio buttons to specify whether or not the analysis will be carried out at the first time point. This feature helps the user when is not necessary to calculate results at the first time point but instead to start at the second time point. In such cases, time dependent variable values will be grayed out for the first time point and no results will appear for this time point.

# Relex LCC (Relex)

Life cycle cost by Relex is a LCC analysis module integrated in the software named Relex Reliability Studio. Each analysis module can function as a complete package on its own, or it can be used in conjunction with other modules to offer a custom solution.

In addition to the flexible format, this software application is told to have a rich user interface coupled with innovative features such as the task list for quick access to commonly used tasks and data filtering for ultimate user control of data views.

Relex LCC allows the user to define variables as constants, or changing over time, over design alternatives, or over both and also be linked to data from your other Relex Architect modules for expanded analysis capabilities. For example, the user can factor in failure and repair rates from Relex Reliability Prediction and Relex RBD (Reliability Block Diagram) to obtain more accurate accounting of system failure and repair costs in total product lifetime cost.

According to Relex, this LCC module is a full life cycle cost analysis package which supports parametric, analogy, bottom-up, and direct cost analysis types. LCC Relex is able to compute the cost of a system over its entire life span by first defining the cost breakdown structure (CBS) of the costs incurred over its life in order to assign an equation representing the cost calculation to each CBS item. The equations available in the Equation Editor tab are completely user-customisable as we can see in the Figure M.
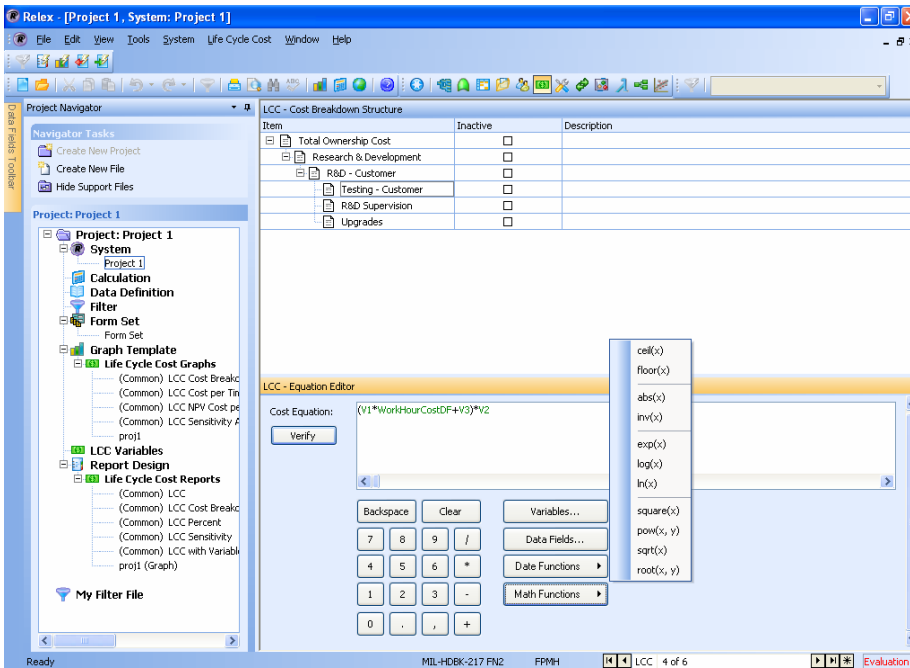
Figure M - Example of the LCC Equation Editor

LCC Relex has a utility named Calculation File that is created when the Project is created i.e. there can be only one occurrence of a Calculation file in the Project. This feature enables the user to create subroutines for specialised calculations, by storing custom calculations for the Relex FMEA (Failure Mode Effects Analysis), Relex FRACAS (Failure Reporting Analysis, Corrective Action System), Maintainability Prediction, and Reliability Prediction modules.

In order to validate cost equations by verifying its input data, the user can click in the Verify button and if the calculation is invalid, information about the error appears in a dialog box. Invalid equations can result from: including unrelated data fields; syntax errors and mismatched parentheses or square brackets (see Figure M). However, validation of a calculation will not catch a divide by zero problem. Nevertheless, in those situations, an error message will appear after the calculation is performed.

Computing life cycle costs for a project can be computationally intensive, however this software module allows the user to limit the number of items to be included in the calculations by selecting (active) or not (inactive) the item from the CBS. Additionally, there is a feature named Filters that allows the user to define criteria to limit data for viewing, calculating, reporting, or graphing as we can see in Figure 15. Filters can also be applied to limit the items included when importing/exporting data, but also can be used with fields attached to dependent lists and to group and sort selected items. Furthermore, filters can be used to perform comparisons between its inputs/outputs and historical data or reference values, with the aim of obtaining a more calibrated model and preventing, for example, incorrect application of the regulation or errors due to incorrect data introduction (see Figure N).
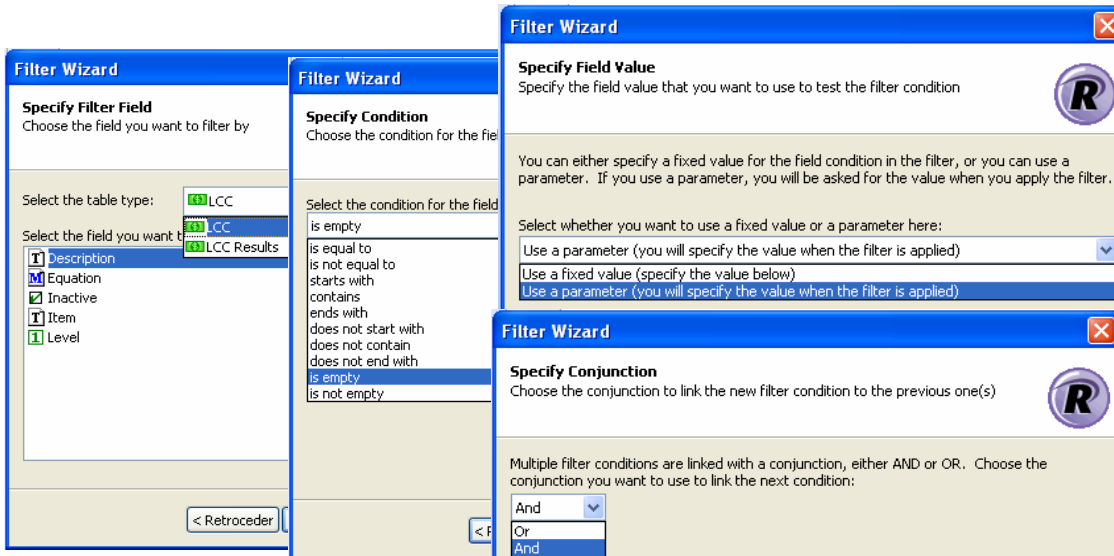
Figure N - Examples of the Filter wizard

One requirement that helps the user to rely on the LCC outputs, bearing in mind the level of uncertainty of some inputs, is the ability of the software to perform a sensitivity analysis to the LCC parameters. Performing a sensitivity analysis enables the user to view how the cost varies with the changes to the underlying variable i.e. how much of an effect a particular variable has on overall system cost.

Relex LCC also performs Net Present Value (NPV) or cost based on today's currency, with the goal of determining if a specific cost would be better incurred this now or postpone to some future point in time. Rather than assuming a constant interest rate across all time intervals, to make more realistic cost computations, this software allows the user to calculate the NPV for each interval, by specifying an interest (or inflation) rate for each interval inserted.

An interesting and useful program included is the RelImEx.exe, a program for importing and exporting data automatically using the Windows Scheduled Task Wizard. Additionally, if the user selects the Add New Records option in check box that becomes available, when no matches to existing items can be found, new records will be added during update. Nevertheless, settings for an import or export have to be saved first in an Import/Export Template file i.e. data must be inserted manually one time in the file, in order to allow it to be updated later.

Besides providing easy and flexible methods for importing data into and exporting data from Relex, the Import Wizard and Export Wizard presents the following benefits: eliminates repetitive data entry; decreases data entry time; reduces the possibility of data entry errors.

# Annex II: Assessment Criteria Table

## Assessment Criteria Table about LCC commercial tools

This table has been prepared to conduct an assessment about LCC features and it was sent to both INNOTRACK participants and the first LCC software suppliers identified. Since no answers to the questionnaires were provided by the first providers identified, it was decided that ADIF would be responsible for filling the questionnaire for all tools, evaluating the different aspects of each LCC program. It should be noted that this table was fulfil given the information available by the suppliers.

| **LCC software - General features** | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | What LCC program do you use? | | **Relex LCC** | **LCCWare** | **D-LCC** | **CATLOC** | **UNIFE-UNILIFE** |
| 2 | If the program is available for the public in general what are the licenses costs and its duration? | | Yes | Yes | Yes | Yes | Yes |
| 3 | 3.1 | Does it have a manual? How detailed is it? | Manual not available. | Yes (around 200 pp). | Yes (around 100 pp). | Yes (around 200 pp). | Yes (around 50 pp). |
| | 3.2 | Does it include support actions (e.g. Workshops, on-line/telephone support, training courses, etc)? | Yes | Yes | Yes | Yes | No. The software has been created with little or no support envisioned. A user's guide is included with the software. If direct contact with the software developers is required, contact UNIFE for their details. |

| | | LCC software - General features | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|---|---|
| 4 | 4.1 | User friendly interface? Or do you have to be an expert to introduce inputs and view outputs? | Yes. It has a friendly interface. | Yes. It has a friendly interface. | Yes. It has a friendly interface. | Yes. It has a friendly interface. | Yes. It has a friendly interface. |
| | 4.2 | Runs on known software or has similar interface? | Microsoft office products. | Microsoft office products. | Microsoft office products. | Microsoft office products (especially excel). | Excel. |
| | 4.3 | Allows copy/past functions? | Yes | Yes | Yes | Yes | Yes |
| | 4.4 | Allows copy/past from one project to other? | Yes | Yes | No | Yes | Yes |
| | 4.5 | Allows undo/redo functions? Multiple undo? | Yes | Yes | No | Yes. However, a deleted value is permanent and cannot be undone yet; the deleted value is not saved to disk until the user selects FILE -SAVE or FILE -SAVE AS. | Yes |
| | 4.6 | Is it necessary to have a training course to use the tool? | No. However, a training course would be very useful in order to take advantage of all features. | No. However, a training course would be very useful in order to take advantage of all features. | No. However, a training course would be very useful in order to take advantage of all features. | Yes, fundamental to be able to built a first template. | No |
| | 4.7 | Please refer any other factor related to the "ease of use" of the tool. | A rich user interface is coupled with innovative features such as the task list for quick access to commonly used tasks and data filtering for ultimate user control of data views. | The Browse dialog now displays all variables, functions, part trees, parts and part tree variables in a tree structure. Selecting an item in this tree displays the function or cost node that references the item in a list. Selecting a referenced item from the list allows the user to edit the item directly or, in the case of cost nodes, display the item. | Project Window with the Project Button Bar on the left side covers all stages and components of the D-LCC project building. The Project Button Bar is an intuitive user interface for navigation through the project. | An explorer which enables easy navigation inside and between cases. | Navigation between work areas are made by buttons on Navigation worksheet. |
| 5 | | Can manage different projects at the same time? | No | No | No | Yes (*) | No |

| 6 | Can you compare different alternatives within one single project? | -- | -- | Yes (*) | No (*) | -- |

| LCC software - Main structures (CBS/PBS) | | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|---|
| 7 | Is your program spreadsheet-like, flexible and easy to modify cost models for each CBS element i. e. can it be easily tailored to meet all needs of any particular project? | Yes | Yes | Yes (*) | Yes (*) | No. As UNLIFE/UNIDATA is basically an EXCEL workbook, they can not be easily tailored to meet each project's needs. |
| 8 | Does it allow drag-and-drop and cut-paste for copying and editing of CBS/PBS elements? | Yes | Yes | Yes | Yes | Yes |
| 9 | Does it allow graphical representation of CBS providing convenient and fast data input and search? | Yes | Yes. The Edit, Find Cost Node menu option has been included in LCCWare. You should type the unique name of the required cost node into the Name dialog and then the tree will be moved, if necessary, so that the node will appear selected in the viewing area. | Yes. (*) If the item you specified is found, its icon and path appear in the grid and can be changed | Yes. (*) It is possible to search the current column for a match of a specified string. If one is found the active cell is moved to this cell. | No. UNLIFE/UNIDATA workbooks do not have a basic PBS/CBS tree representation not allowing the user to easily visualise input data position. |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |

| LCC software - Main structures (CBS/PBS) | | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|---|
| **10** | Is able to perform comparisons with pre-existing LCC models to recognise the elementary cost elements? | No | No | No | No | No |
| **11** | Is it possible to create user subroutines for specialised calculations? | Yes. The Calculation file is a Singular Support file that is created when the Project is created. This means that there can be only one occurrence of a Calculation file in the Project. The Calculation file is used to store custom calculations for the Relex FMEA, FRACAS, Maintainability Prediction, and Reliability Prediction modules. | Yes. On the one hand, there are the Global functions (Visual Basic like functions) that can be used to carry out certain operations or calculate values. On the other hand, there are the User functions (Visual Basic like functions) that can be assigned to cost nodes to carry out various ancillary calculations. Furthermore, the latest version of LCCWare also includes part trees, a utility that provides the user with a convenient method of assigning the costs associated with a frequently used piece of equipment (and its constituent parts) to a cost function. | No (*) | Yes. (*) Even though the values of parameters are typically given in the ParameterValue table, it is also possible to define aggregated parameters by specifying a mathematical function, defined by the FUNC field, in terms of other parameters, constants and arithmetic operators. | Yes. There is the possibility to create a MACRO. |

| LCC software - Main structures (CBS/PBS) | | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|---|
| 12 | Is it possible to introduce functions to define LCC cost elements? If yes, which? | The built-in equation editing allows the user to create cost equations using common math functions - abs; exp; int; ln; log10; pow; sqrt; root and other functions such like ceil (x) - returns the smallest integer >= x; floor(x) - returns the largest integer <= x; inv(x) - returns the inverse (1/x) of x and today - returns today's date (number of days since 12/30/1899). In addition to the math functions described previously, Relex supports many other math functions that you can enter directly in the equation – max; min; sum; mod; mean; fac (factorial); sin; cos; tan; asin; acos; atan; sinh; cosh; tanh; coth; sech; cosech; arsinh; arcosh; artanh; arcoth and std. | Cost functions are written in a Visual Basic compatible language. | Standard functions (abs, exp, int, ln, log10, pow10, sqrt). Other functions such like the table function (e.g. tbl (1,4) – table#1 is checked for the result it contains for the value of 4) and the tree function to incorporate the PBS parameters (e.g. MTBF, operating hours, etc.) into the CBS calculation. | Yes, basic mathematical and some excel operators like ">" - greater than; "<" - less than; "=" - equality; "( ... )" - and; are available. Note: All the boolean operators (=,<,> ) return 1 if the statement is true and 0 if the statement is false. Additionally, the following functions are also available: aggregate functions (SUM, PROD, MEAN, MIN, MAX, TOFFSET, TDIFF and TSUM); structural aggregate functions (INFSUM, SUPSUM, INFPROD and SUPPROD) and auxiliary functions (IF, FACT, MOD, CEIL, FLOOR, ZTO). | Yes, all excel functions. |
| 13 | Is it possible to import (global) variables | Yes | Yes | Yes (*) | Yes (*) | -- |

| | (e.g. work hour cost, fuel cost, and discount rate) or they had to be inserted manually? | | | | | |
|---|---|---|---|---|---|---|
| **14** | Can (global) variables be stochastic? | No | No | No | No | No |

| LCC software - Main structures (CBS/PBS) | | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|---|
| **15** | Is able to perform direct interactions between cost elements? | No | No | No | No | Yes. Excel workbooks do not have that restriction. |
| **16** | Is it possible to define cost functions that changes over time (e.g. cost A enters in year 1 and then from year 5 up to year 8)? | No. However, it is possible to define variables that change over time. When the utility Varies Over Intervals is selected as the variable type, the Variable tab displays a two-column table for indicating the value to use for each time interval. The number of rows in this table depends on the number of time intervals that have been inserted on the Alternatives tab. | No. However, it is possible to define variables that change over time. | No. (*) However, it is possible to define variables that change over time. | Yes (*) | No. As the CBS does not incorporate the time scale (life cycle phases). |

| | | | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|---|---|
| 17 | | Is it possible to trace the path of each parameter in the cost breakdown structure? | Yes. If the parameter is a variable, there is a type of Report Design file supplied with Relex LCC which outputs the variable values for each CBS item. | No | Yes, if the parameter is a global variable and you are trying to delete it. In such cases, the Delete Global Dialog is displayed allowing the user to view and modify the CBS formulas containing the Global you are about to delete. | Yes, it is possible to trace which costs that are affected by scaling a particular parameter P. Those cost elements (bars) that are affected by parameter P are marked with a spring pattern. | No |
| **LCC software - Main structures (CBS/PBS)** | | | **Relex LCC** | **LCCWare** | **D-LCC** | **CATLOC** | **UNIFE-UNILIFE** |
| 18 | 18.1 | Is it possible to evaluate the parameter importance in the global framework by estimating its intervention degree in each cost element? | No | No | No (*) | Yes (*) | No |
| | 18.2 | If yes, can the results be reported at a project and/or element level? | | | | Element level. The resulting costs can be shown as graphs with spring patterns revealing which costs are affected by a specific parameter and its intervention degree. | |
| | 18.3 | Versatile user-definable graphs | | | | Yes | |
| | 18.4 | Versatile user-definable tables | | | | Yes | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **19** | Is your software able to perform comparisons between its inputs/outputs and historical data or reference values? How? | Yes. There is an utility named filters that can be applied to perform comparisons between its inputs/outputs and historical data or reference values, with the aim of obtaining a more calibrated model and preventing, for example, incorrect application of the regulation or errors due to incorrect data introduction. | No | No | Yes, if the user is trying to import data. In such cases, CATLOC checks if a record with the same key already exists. If so, the existing record is updated with the values from the database. Fields that are empty in the imported record do not erase an existing value in the CATLOC table. If no matching key is found, a new record is appended. | No |

| LCC software - Main structures (CBS/PBS) | | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|---|
| **20** | Is it possible to compute element's life cycle costs using different operators (besides the addition operator)? | No. The cost for a parent record is equal to the sum of the costs for all child records. | No | Yes. The operations available are: addition, subtraction, multiplication, division, natural logarithm, logarithm base 10 and exponentiation. | No | Yes |
| **21** | Is your program able to compute life cycle using variables with different weights? | No | No | Yes. A global variable can contain weights by periods and alternatives. D-LCC multiplies the value of the global variable to compute element's costs. | No | Yes |

| 22 | Is your program able to limit the computation time? | Yes. There is a feature named Filters that allows the user to define criteria to limit data for viewing, calculating, reporting, or graphing. Additionally, filters can be applied to limit the items included when importing and exporting data. Filters can also be used with fields attached to dependent lists and to group and sort selected items. | Yes, there is a possibility of the user to set the Perform Analysis at First Time Point radio buttons in order to specify whether or not the analysis will be carried out at the first time point. In some cases you will not want to calculate any results at the first time point but instead to start at the second time point. If you decide not to calculate results at the first time point then time dependent variable values will be grayed out for the first time point and no results will appear for this time point. | Yes. In order to diminish the calculation time, you can limit the computation by checking the Fast Calculation where the minimum number of operations required is the product of the number of tree elements, periods and alternatives. This does not include formulas used to compute CBS elements, additions, discounting and overhead transactions. | Yes. Calculations can be performed only for relevant combinations. Additionally, it is possible to break a calculation in progress. This done using the Tools::Break command (shortcut: CTRL+Break), if the editor window has input focus. If the log window is active, the corresponding command is found as Tools::Break Calculation. | No |
|----|----|----|----|----|----|----|

| LCC software- Data/Results interaction with other software | | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|----|----|----|----|----|----|----|
| 23 | Import data from other software, like EXCEL, ACCESS, and a RAMS program? | | | (*) | (*) | |
| 23.1 | Relex | Relex OpSim, Relex Reability Block Diagram, Relex Reliability Prediction | | | | |
| 23.2 | Reliasoft (Weibull ++, ALTA, etc) | | | | | |
| 23.3 | RAM Commander (A.L.D) | | | Yes | | |
| 23.4 | Math Office (IZP Dresden) | | | | | |

| | | | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|---|---|
| | 23.5 | MS Excel (Developed software) | Yes | Yes | Yes | Yes | Yes |
| | 23.6 | MS Access | Yes | Yes | Yes | Yes | Yes |
| | 23.7 | If you use any other software other than the above mentioned, please mention | Features such as support for Microsoft SQL Server, Oracle, Microsoft SQL Server Desktop Engine (MSDE) and Microsoft Jet Engine (Access compatible) databases, permission based security, user and group roles, front end web interfaces, Relex Dashboard for a high-level overview of system metrics, audit trails for tracking data modifications, and customisable data connectors insure that Relex meets the needs of full scale, enterprise-wide teams. | LCCWare can also act as an OLE automation client and receive data from other OLE enabled products. | | OPUS10 for logistics support and spares optimization;<br><br>SIMLOX for simulation of logistics support scenarios;<br><br>MADCAT for analysis and categorisation of maintenance data. | |
| **LCC software- Data/Results interaction with other software** | | | **Relex LCC** | **LCCWare** | **D-LCC** | **CATLOC** | **UNIFE-UNILIFE** |

| 23 | 23.8 | Is the imported data up-dated manually? Please explain. | Yes. Settings for an import or export have to be saved once i.e. data must be inserted manually at least once in an Import/Export Template file, in order to allow it to be updated later. Afterwards, the file created can be used to perform a scheduled import or export. The Import Wizard and Export Wizard provide easy and flexible methods for importing data into and exporting data from Relex. Being able to import and export data provides the following benefits: eliminates repetitive data entry; decreases data entry time; reduces the possibility of data entry errors. | Yes. LCCWare provides extensive import and export facilities allowing users to transfer project data to and from Microsoft Access compatible databases, Microsoft Excel worksheets and text files. | Yes. Import files should reflect the structure of either the PBS or Globals Library. Import is performed to the currently active project. Import of tables not possible. | Yes. The import from text files requires properly inserted headers and data delimiters that can be interpreted by CATLOC. There is also a built in database interface that enables import and export of data to and from relational databases that support ODBC, Open Database Connectivity. | Yes |
| --- | --- | --- | --- | --- | --- | --- | --- |

| LCC software- Data/Results interaction with other software | | | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|---|---|
| 23 | 23.9 | Can the imported data be up-dated automatically? What does it requires? | Yes. However, settings for an import or export have to be saved first in an Import/Export Template file i.e. data must be inserted manually one time in an Import/Export Template file, in order to allow it to be updated later. Afterwards, the file created can be used to perform a scheduled import or export. To schedule this task, the user will need to specify the necessary parameters on the pages displayed by the Windows Scheduled Task Wizard. Relex includes a program for importing and exporting data so that such tasks can be automatically run unattended by the Windows Scheduled Task Wizard at whatever interval you specify. This program, RelImEx.exe, uses the Import/Export Template files that are created when the settings for an import or export are saved. | No | No | No | No |

| LCC software- Data/Results interaction with other software | | | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|---|---|
| **24** | Export data to other software (data and results)? | | | | | | |
| | **24.1** | MS Excel (Developed software) | Yes | Yes | Yes (*) | No (*) | Yes |
| | **24.2** | MS Access | Yes | Yes | Yes (*) | No (*) | Yes |
| **LCC software - Data/Results accuracy** | | | **Relex LCC** | **LCCWare** | **D-LCC** | **CATLOC** | **UNIFE-UNILIFE** |
| **25** | Is your program able to perform a standard sensitivity analysis to the LCC parameters? | | Yes. All variables in the LCC Variables file for the Project as well as all data fields used in the LCC equations are available for selection. | Yes. Any number of sensitivity studies may be carried out on constant and time dependent global variables, and constant and time dependent local variables. | Yes. (*) Only the fluctuation of the element as a function of a global variable can be analysed. | Yes. (*) The Sensitivity analysis in CATLOC is done by scaling parameter values. | No |

| LCC software - Data/Results accuracy | | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|---|
| 26 | Is your program able to perform a risk analysis i.e. a probabilistic sensitivity analysis using, for example, the Monte Carlo simulation technique to LCC parameters? If yes, which? | No. However, there is a diagram module in Relex Reliability Studio software named Relex RBD (Reliability Block Diagrams) that allows you to quickly evaluate the reliability, availability, and MTBF of complex redundant systems. This fully featured graphical RBD evaluator enables you to draw system elements and then connect them to perform fast and accurate reliability calculations using the built-in Monte Carlo simulation engine for complex diagrams. | No | No. (*) However, there is compatible software designed by A.L.D. named RAM Commander. This software has a module entitled Reliability Block Diagram (RBD) that allows performing the functional Reliability and Availability analysis of systems with variety of reliability distributions, and types of redundancy and repair factors. RBD performs either analytical calculation or Monte Carlo simulation depending on the type of a reliability configuration of the system. | No (*) | No |

| LCC software - Data/Results accuracy | | | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|---|---|
| 27 | Is your program able to notify the user if the alternatives in study have or have not the same level of detail and boundary conditions? How? | | No | No | No (*) However, it is possible to identify visually from the result report table. | No (*) | No |
| 28 | Is your program able to identify the cost drivers with conclusively reports with different modes of presentation? | | Yes | Yes | Yes | Yes | No |
| | 28.1 | Versatile user-definable graphs | Yes. Available graph types: Area, Bar, Line, Pareto, Pie, Scatter, Stacking bar. | Yes | Yes (*) | Yes (*) | |
| | 28.2 | Versatile user-definable tables | Yes | Yes | Yes (*) | Yes (*) | |
| | 28.3 | Others (please mention) | Three-dimensional pie chart. | | | | |
| 29 | Does it provide reports for both total and detailed costs for any combination of Product Tree items and CBS elements? | | Yes | Yes | Yes (*) | Yes (*) | No |

| LCC software - Data/Results accuracy | | Relex LCC | LCCWare | D-LCC | CATLOC | UNIFE-UNILIFE |
|---|---|---|---|---|---|---|
| 30 | Is your program able to track errors in input data? | Yes. There is a feature named Filters that allows the user to define criteria to limit the items included when importing and exporting data preventing, for example, incorrect application of the regulation or errors due to incorrect data introduction. | No | No | No, but before the calculation takes place, CATLOC performs a test of blank fields in input data. | Yes. There is an error checking facility to identify errors in the data fields, to verify if any rule for entering data has been broken. |
| **LCC software - Data/Results accuracy** | | **Relex LCC** | **LCCWare** | **D-LCC** | **CATLOC** | **UNIFE-UNILIFE** |
| 31 | Is your program able to track errors in CBS equations? | Yes | Yes | Yes | Yes | No |

| | LCC software - Accounting features | | | | | |
|---|---|---|---|---|---|---|
| 32 | Does the tool allow target costing? How? | No | No | No | No | No |
| 33 | Does the tool allow a linkage to accounting software? Which? How? | Yes, but only if there is a package in place which can export to Text Files, Microsoft Excel Workbooks and Microsoft Access Databases formats then Relex can bring the data in. Currently there is no direct link to any accounting software. | Yes, but only if the exported files from the accounting software are in compatible formats such as Excel Workbooks or Access Databases. Currently there is no direct link to any accounting software. | Yes, but only if the exported files from the accounting software are Text Files, Microsoft Excel Workbooks and Microsoft Access Databases formats. At the moment, there is no specific link to an accounting software application. | Yes, but only if the export files from the accounting software are in compatible formats such as Excel Workbooks or Access Databases. Currently there is no direct link to any accounting software. | Yes, but only if the export files from the accounting software are in compatible formats such as Excel Workbooks or Access Databases. Currently there is no direct link to any accounting software. |

(*) – Answers were confirmed while testing in detail both CATLOC and D-LCC.

# Annex III: Analysis of LCC tools/models in the rail sector

**T-SPA (SERCO, Network Rail)**

The Track Strategic Planning Application (T-SPA) is the software developed by Serco and used by Network Rail to support the submission of a network investment strategy to the rail regulators.

According to Serco, the concept underpinning the T-SPA approach is one of establishing linkages between decisions that lie within the control of Network Rail and its principal stakeholders and the consequences of those decisions on the future state of the railway infrastructure. The ability to specify alternative renewal scenarios and link the work volumes to outputs is at the core of the T-SPA functionality.

Long-term forecasting of track renewal volumes and the assessment of alternative output scenarios are based on experience from service lives of track components and degradation models. Both perspectives are used in order to provide complementary points of view on the necessary levels of renewal.

T-SPA calculations forecast the life of rail by predicting the incidence of rail defects and the rate at which these will result in rail breaks, and applying an intervention threshold on the predicted rate of breaks per mile per year.

Constructed to be as flexibly as possible, T-SPA allows a renewal to be specified when almost any calculated parameter reaches a predefined limit. For example sleepers may be renewed when they reach the end of their nominal service life, ballast may be renewed when the calculated deterioration rate reaches an unacceptable level, and rail may be renewed when the number of predicted defects and/or the rail wear reach specified values. An example can be seen in the Figure O, where a scenario in which the rail, sleepers and ballast are renewed at the end of their service lives.
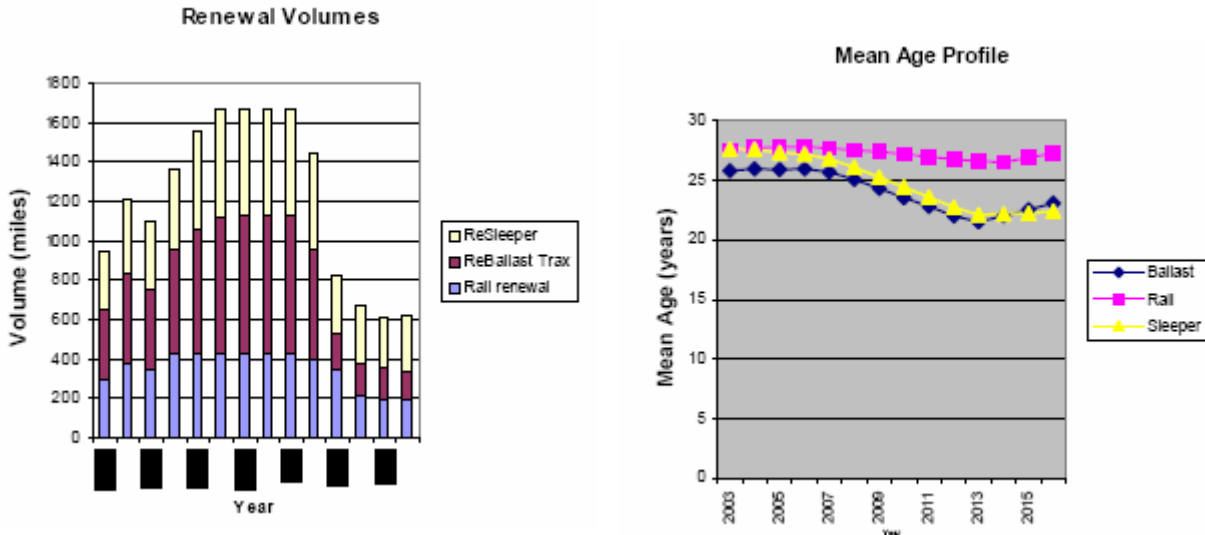


Figure O - Example of outputs over a fourteen-year period commencing 2003

In addition, for the first three years of the calculation, the volumes are constrained to represent specific workbanks identified in regional plans, and smoothing of the volumes over the next seven years has been applied to provide a consistent input to the delivery of the work.

T-SPA calculations generate a significant volume of outputs, which can be viewed at the individual segment level (sections of the order 100m) or, more commonly, at higher levels of aggregation such as the whole

railway infrastructure comprising almost 20,000 track miles. Depending on the segment aggregation level, calculations can take a few minutes (for a route) or hours (for the entire network).

One requirement that helps the user to rely on the LCC outputs, bearing in mind the level of uncertainty of some inputs, is the ability of the software to perform a sensitivity analysis to the LCC parameters. T-SPA does not have that feature consequently, engineers have to carry out their own sensitivity tests and derive probability distributions.

One of the most useful and interesting utility available in T-SPA, considered by many a key requirement for practical asset planning, is the possibility to apply volume and/or budgetary constraints, according to each project requirements.

Another interesting feature is the T-SPA Pre-Processor that checks for errors in the input data, ensuring that the input data has been prepared correctly.

**LCM (ProRail)**

Life Cycle management (LCM) is a LCC calculation tool developed by ProRail and it is used to find out what is the cost effectiveness of construction or maintenance action of different alternatives.

The LCM methodology helps to make choices of options by comparing investment and maintenance costs, and valuing planned and unplanned interruptions (see Figure P). All decisions on new building alternatives and maintenance versus renewal are taken on the basis of demonstrably lowest life cycle costs.
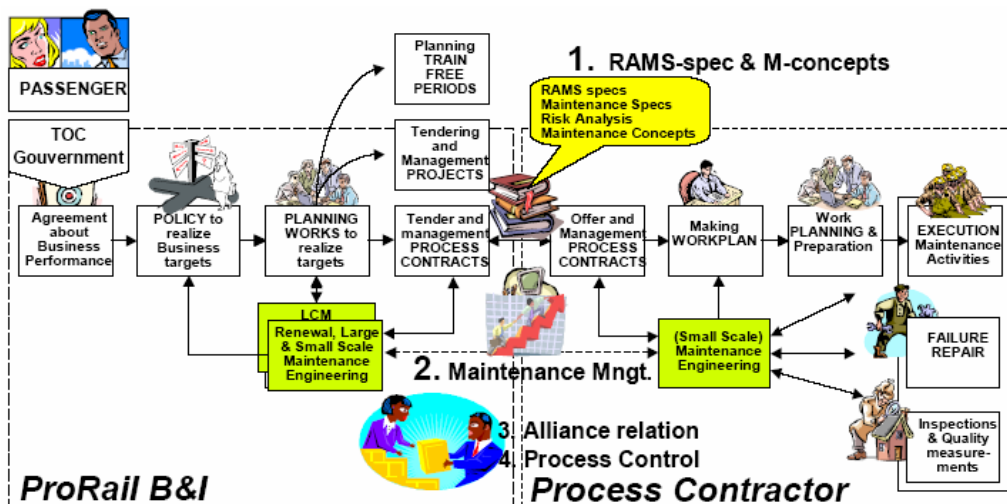


Figure P – Improved branch maintenance process

In order to use LCM as a calculation tool it is necessary to perform the following steps (see Figure Q):

1. Define the project's characteristics (time frame, boundaries, delimitations, etc.);

2. Identify different alternatives (information on different alternatives are gathered by experts groups doing the brain storming);

3. Describe the project;

4. Insert the different maintenance activities, costs, failure rates etc. into the tool, bearing in mind that this software application does not provide a scope of calculating failure rate from the failure data and consequently, it has to be calculated manually and entered into the tool afterwards;

5. The tool provides a cost for different alternatives broken down to different cost categories and finds out the most cost effective alternative;

6. The tool also represents the costs graphically and a sensitivity analysis can be carried out;

7. To finish, description of why the alternative is chosen is entered into the tool.
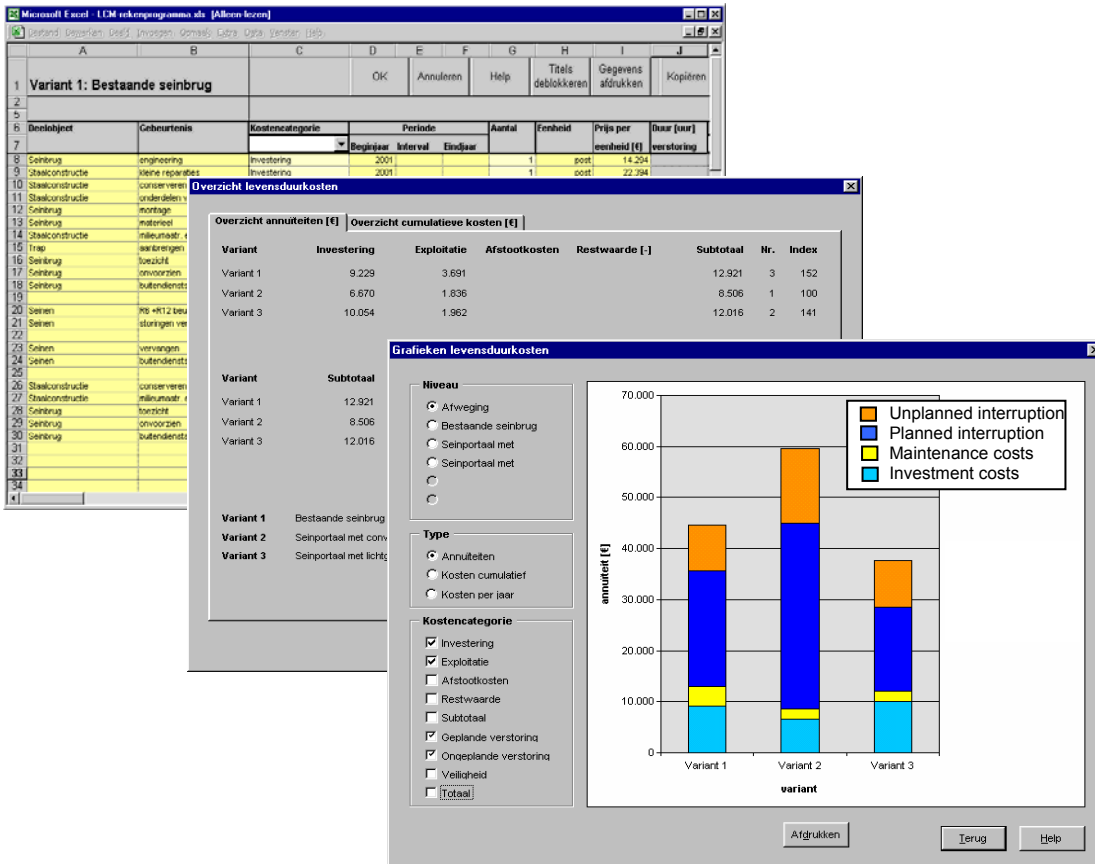


Figure Q – Examples of the LCM program

To sum-up, the LCM method is a calculation tool that allows the user to:

- Assess alternatives;

- Determine each item economic life;

- Create a multiyear replacement plan (20 years);

- Make a production plan (5 years) and a priority matrix;

- Find cost ratios for maintenance and renewal (RCB);

- Take into account rejection standards: RAMS – specifications and Maintenance concepts.

**PriFo (JBV, Norway)**

Prifo is the Life Cycle Cost (LCC) analytical model for prioritisation of maintenance and renewal projects developed by JBV - Jernbaneverket (Norwegian Railway Administration). The following dimensions are included in this LCC model:

- safety costs;

- punctuality costs;

- maintenance & operational costs;

- cost due to increased residual life length;

- project costs.

Taking into account this model performance, Vatn (2002) has pointed out the following major advantages:

- As all maintenance and projects are evaluated in the same way;

- In situations with budget constraints, it is possible to have a sound basis for choosing the "best" projects;

- Project LCC results can be used in discussion with all the stakeholders.

In this LCC model, the description of each maintenance or renewal project is stored in an MS ACCESS database and the basic inputs are:

- Qualitative information – measurements and analysis of track quality, trends, among others;

- Safety related information – states and values related to various RIF (Risk Influencing Factors) as it relates both to the accident frequency, for example number of cracks in the rails, but also to the accident consequences like speed, terrain description, amongst others. The program calculates the actual risk using different functional forms (e.g. linear, exponential etc.);

- Punctuality information – ordinary speed of the line and any speed reductions due to the degradations the project is intended to fight against. Cascading effects can be entered as well as trend information;

- Maintenance and operating costs – extra runs of the measurement car, extra line inspections, amongst others;

- Residual life length;

- Project costs - entered for each year in the project period;

- Cost parameters (2002?) – common for all projects: interest rate r= 4%; cost per minute kiloton freight delay =160€; cost per passenger minute delay = 0.4€ and Monetary values for safety consequence classes as given in Table A:

| Safety consequence | | Monetary value |
|---|---|---|
| C1 | Minor injury | 2.000 € |
| C2 | Medical treatment | 33.000 € |

| C3 | Serious injury | 330.000 € |
| C4 | 1 fatality | 1.700.000 € |
| C5 | 2-10 fatalities | 11.000.000 € |
| C6 | > 10 fatalities | 175.000.000 € |

Table A – Monetary values for each safety consequence class. Source: Vatn (2002?)

# Annex IV: Preparation of next steps within WP6.2

## Summary of information available on existing practices (based on Questionnaires I and II and WP6.1 reports)

With the intention of preparing questions to be addressed on personal interviews to Infrastructure Managers on the LCC existing practices, a summary, based on the LCC information available in the Questionnaires I and II, follows:

- IMs use LCC analysis to have feedback for technical improvement, to evaluate maintenance strategies and also, investment alternatives;

- All IMs consider in their LCC calculation both the operation and maintenance phase. Regarding the research and development phase, only OBB and Prorail take into account it in their LCC analysis. Concerning the investment phase, apart from NR, all IM's consider it for the LCC analysis. Finally, the disposal phase is only integrated by DB and OBB in LCC calculations;

- IMs calculate the following maintenance categories separately: corrective maintenance, preventive maintenance, condition based maintenance and renewal;

- The heavier maintenance actions done on track that all IMs consider in the LCC model are: inspection for safety, inspection for maintenances, rail grinding, track tamping, failure replacement (of rail, sleeper, fastening etc), rail renewal and ballast renewal. Two-thirds of the IMs consider the following maintenance actions as important as the ones mentioned above: track adjustment, ballast cleaning and compacting;

- From the IMs' experience the factors that have major effects on LCC values, especially in the maintenance costs, are: traffic volume, axle load and type of rail;

- According to IMS, from the heavier maintenance actions mentioned, the major cost drivers in the LCC calculation are: tamping and rail grinding (result of workshop SP1).

- To validate LCC calculations IMs use: experts estimation, simulation, experience and analysis of existing systems. For example, in Network Rail, LCC calculations on track have been validated in the past by detailed investigations on small samples of the network using external contractors;

- By performing LCC analysis, IMs found out that the major benefits produced are the long term forecasting of rail renewals/enhancements. This information provides to IMs and stakeholders (including regulators) transparency on how the age, configuration, capability and condition of the track network will evolve for different levels of investment. Therefore, LCC analysis can be useful in reaching agreement with regulators and funding bodies (including governments) on the investment requirements of the network as it helps validating the decision-making procedure;

- IMs define reliability target for their systems and the reliability analysis is mostly done by expert estimation not by the tools;

- 50% IMs define availability targets. Availability analysis is also done mostly by expert estimation;

- Maintainability targets are considered by only very few participants. Analysis is mostly done by experts;

- Only OBB has a safety target for their systems and only NR has multiple hazard logs to deal with a wide variety of circumstances. For example, Network Rail's Hazard Reporting Index combine events on track (e.g. broken rails, track buckles, track twist, broken fishplates, track out of gauge etc.) with local factors such as line speed, number of trains or layout complexity, to provide an overall hazard rating;

- All participants consider traffic disruption cost and cost due to un-availability/ downtime in their LCC calculations. Only DB and NR take into account penalty costs (failing to meet schedule, specification etc) imposed by traffic operator;

- 50% IMs reported service life time as economical life time and DB considered service life as technical life time. Prorail did not answer to this question;

- DB fixed the discount rate in 8% to every project, while OBB uses internal rate of return (IRR). Other IMs confirmed having an establish discount rate, however did not specify the rate selected;

- To DB, environmental costs like noise are incorporated in the LCC model as investment and maintenance costs due to the components such as cost noise barrier or pads. OBB only takes into account such costs in big new investments such as "Koralmtunnel". Currently, the other IMs do not include them;

- Risk analysis is not considered by any IM while modelling LCC;

- There are several problems that make more difficult achieving LCC targets: unavailability of quality data, non-existence of funds to maintenance/renewal, non-aggregation of costs by component (e.g. labour costs obtained from an accounting software) and the difficulty to make links between inputs and outputs (e.g. degradation relationships and links to train performance).