LIFE CYCLE COSTING IN HIGH COMPLEX INDUSTRIES – DEVELOPING AND APPLYING A LIFE CYCLE COSTING APPROACH IN THE RAILWAY INDUSTRY

Christian Hoffart, Philipp Stüer

Research Institute for Operations Management at RWTH Aachen University (FIR), Pontdriesch 14/16, 52062 Aachen, Germany

In terms of sustainable thinking, life cycle costing attracts major notice among railway industries all over Europe. Europe's railway companies reconsider several reasons for the special need of life cycle costing investigations within the railway infrastructure. Ultimately, the railway companies address the question "how can life cycle costs of a signalling system be measured, considering the special circumstances in the railway industry".
Due to the reason that railway industries are bound to various regulatory rules and because of the high complexity of a signalling system, life cycle costs cannot be evaluated by simple cost measurement approaches.
To analyse life cycle costs among European railway industries and to gain cost reductions by deriving consolidated findings from a cost comparison among industries of different countries, a special methodology to analyze life cycle costs has been applied within the European funded research project INESS (Integrated European Signalling System).
Both life cycle phases, the product structure of interlocking systems itself and most important cost categories have been considered. Therefore, the whole life cycle of signalling systems has been analyzed with a special view on railway operators.
This paper describes an approach how life cycle costs have been evaluated based on the European norm DIN EN 60300-3-3 and how other industries can learn from this application.

1. INTRODUCTION

Companies continuously have to make important decisions about future investment projects and options. Especially, in the manufacturing and plant engineering industry a major part of the total costs is caused by investment costs. Investment decisions are mainly based on 1st cost, 2nd quality and 3rd reliability- aspects. In many cases more than 50% of the total costs are not regarded due to the fact, that only purchasing costs are considered (Asiedu & Gu 1998, p. 890; Geißdörfer 2008, p. 1-3).

In order to avoid this deficiency, Life Cycle Costing is one option. It provides a complete overview of the total cost structure of a product in each phase of its individual lifetime. Thus, the original investment decision will be optimized due to the fact that all follow-up costs are considered. In a long term perspective the holistic investment proposal is more sustainable and eventually also more favourable than an initial investment decision, mainly based on purchasing costs (Barringer 2003, p. 2, Zimmermann 2005, p. 2).

European railway operators have recognized the special need of Life Cycle Costing in their industry. Railway industries have to operate and maintain assets with a lifespan of more than 50 years, particularly signalling systems. As a consequence, life cycle costs are of major importance due to the fact that approximately 60-70% of the total costs occur after the actual investment (Internal Analysis within the INESS project). So far, the only barrier taking life cycle costs into account, has been a lack of knowledge and experience concerning approaches in high complex industries in this business to business market. Apart from former analyses that have been taken place in the automotive industry, there is an extraordinary lack of validated practical cases.

As part of its research and in cooperation with experts of the European railway industry, the Research Institute for Operations Management at RWTH Aachen University (FIR) has developed a model to measure Life Cycle Costs in high complex industries. For this purpose, DIN EN 60300-3-3 was taken as a methodological basis. Finally, the established approach was validated in practice through measuring LCC of signalling systems at six railway companies with the objective of identifying cost drivers within the life cycle. Continuative objectives in the INESS research project are references for a future business model within the European market for signalling systems. Outcome of the project will be a common business model, associated business cases and cooperation models to support intelligent migration strategies towards the advanced technology (ERTMS).

2. METHODOLOGY

This paper is structured according to the methodology of the INESS project. At first a generic LCC model will be described on basis of the framework DIN EN 60300-3-3. For the description the latest publications concerning methodologies about life cycle costing in practice have been considered. The description of the generic model is part of chapter 3.

Within the second part of the paper the generic model has been tailored to the specific challenges of European railways signalling technology. Chapter 4 describes three stages for the specification of an industry specific LCC model. Further on the implementation of the data collection and approaches for the data analysis are explained. The 6 companies being involved in the INESS railway data collection and data analysis are listed in Table 1.

Derived from the experiences gained during the LCC measurement within the INESS project success factors have been identified. Chapter 5 describes 6 steps by which a successful measurement can be conducted. Thereby risks and uncertainties are also identified.

Table 1
Railway Participants in LCC-Data Collection

Company	**Country**
ADIF	Spain
Banverket	Sweden
DB Netz AG	Germany
NetworkRail	Great Britain
ProRail	Netherlands
RFI	Italy

3. FRAMEWORK: THE LIFE CYCLE COSTING APPROACH “DIN EN 60300-3-3”

There are six phases of a general product life cycle (PLC), which form the basis for life cycle phases according to DIN EN 60300-3-3 (c.f. Figure 1).

First, there is the **concept & definition,** which is followed by **draft & development, manufacturing**, **installation**, **operation & maintenance** and ends with the phase of **disposal.**

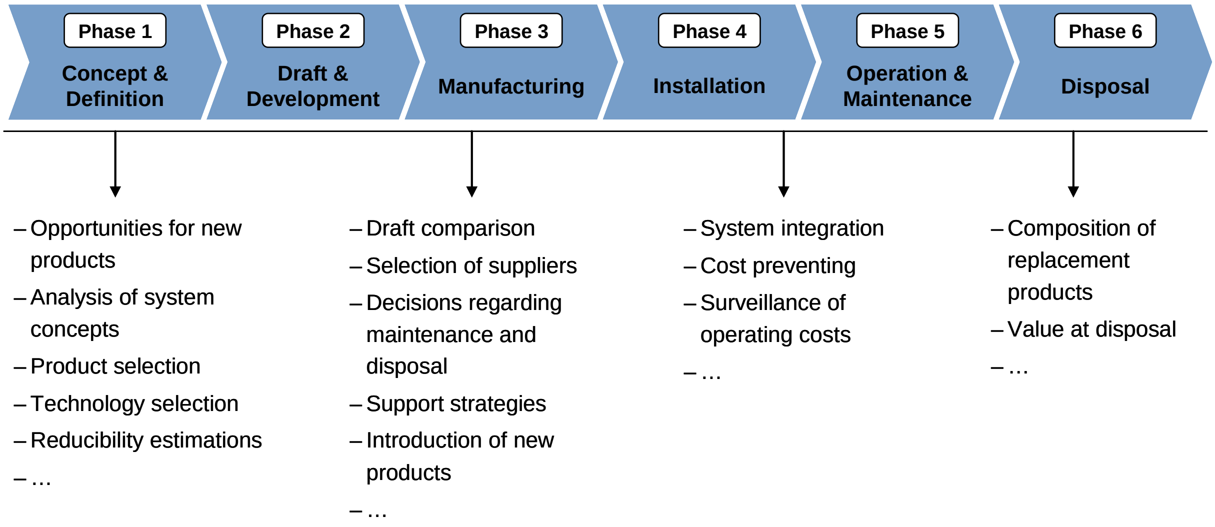

Figure 1 - Example for LCC application

The first phase of the PLC mainly describes the efforts for defining the actual project and developing a concept. During this phase the foundation and the actual framework is set. The second phase comprises the development of a draft and a more detailed plan about the project. After setting this basis manufacturing (Phase 3) and installation (Phase 4) follow. These two phases include continuous observation for improvement opportunities like for example improved support services. In terms of time, operation and maintenance (Phase 5) generally show the longest duration. A product needs to be operated, maintained, fixed, supplemented, updated, etc. and therefore a huge part of the total follow-up costs does emerge. In Phase 6, after a product is obsolete, it needs to be disposed. In many cases all mentioned phases (in terms of emerging costs) are regarded, but the disposal of a product is not included in the LCC calculation. Depending on the product, the operator has to pay for its disposal or might be able to sell the ‘old’ product for a much lower price than invested in the beginning of the life cycle (DIN EN 2004, p. 7f, Fischer 2001, p. 1-11).

It is essential to identify and analyse the main cost drivers in each phase and to look for alternatives (i.e. analysing different concepts of disposal, estimation of profitability of different projects/products, long-term financial planning, etc.) in order to analyse life cycle costs. Generally, it is important to calculate the LCC at the very beginning of a new project, because in many cases more than half of the total LCC is specified after the first phase “concept & definition” has been finished.

Eventually, the total costs can be divided into acquisition costs, costs of ownership and disposal costs (Ellis 2007, p. 2).

$$LCC = Costs_{\,Acquisition} + Costs_{\,Ownership} + Costs_{\,Disposal} \tag{1}$$

Acquisition costs: This category of costs is generally visible ahead of the actual purchase. In some cases the installation costs are already included.

Costs of Ownership: Costs of Ownership are often the main cost drivers in a whole product life cycle. They are not directly visible and difficult to anticipate.

Disposal costs: Even the costs of disposal can be a major part of a project. Depending on the respective legislation additional activities may be required for the disposal of certain products (Asiedu & Gu 1998, p. 889; DIN 2004, p. 8).

The function of the life cycle model is to give a survey of different costs in a very detailed way. It is important that the model comprises a description of all product attributes, including the utilization surrounding, maintenance concepts and all general limitations. Moreover, it should be holistic enough to include all essential factors. In order to make it easy to understand and practicable in terms of helping with the investment decision process, the model should be structured as simple as possible (DIN EN 2004, p. 11ff.; Ellram 1994, p. 171ff.).

In order to assure consistency of the LCC model six different steps have to be undertaken: First, all relevant costs that emerge in each phase of the product life cycle have to be detected and specified. Second, each task of every single phase needs to be broken down to its usage of resources. This includes usage of materials and services as well as the collection of all relevant data that is essential to define the task. The third step comprises the selection of all kinds of costs to avoid any double counting. Fourth, the various cost elements of the total Life Cycle Costs have to be identified. A cost element is the connection between the type of cost and the product/work breakdown structure. This crucial connection is most often achieved by a three dimensional matrix consisting of the ordinates "Product structure" (x), "Life cycle phases (y)" and "Cost categories (z)". Furthermore, each single cost element consists of recurring and non-recurring costs. The sum of both defines the total LCC of each cost element (Barringer 2003, p. 6, Ellis 2007, p. 3-4).

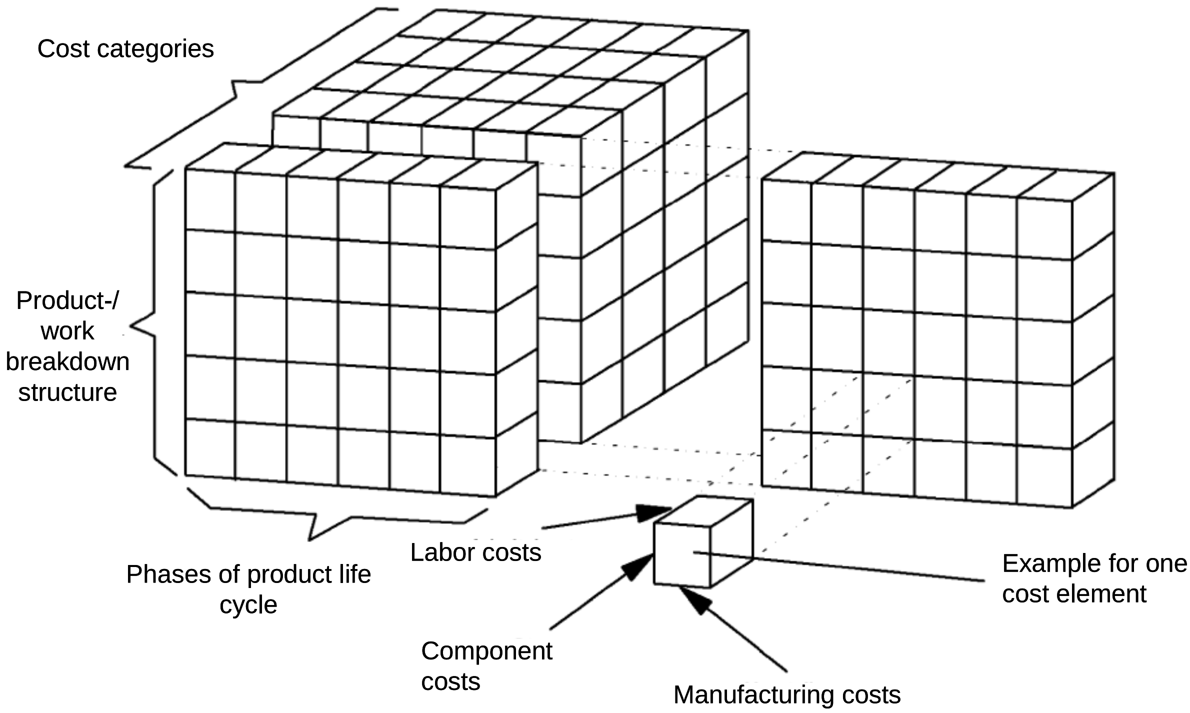

Figure 2 - Concept of cost elements

Figure 2 shows an abstraction of the cost elements that form the basis of the LCC model in question. After the specific cost elements have been identified and the cost structure has been determined the fifth task is to estimate all elements of costs. This estimation is done by means of the DIN EN 60300-3-3. The norm provides three different approaches how costs can be estimated. It is possible to use one or more of these methods for one project. Furthermore, it is helpful to give chances for further adjustments and the possibility of applying a sensitivity analysis. The sensitivity analysis is used for the identification of total LCC effects if single factors like hourly wages, materials etc. change. In order to analyse these effects the data input of different parameters is varied and by the help of the right tool, these long-term effects can be seen.

Possible cost estimation methods are the following:

i. Engineering cost method – Standard estimations of cost attributes are the basis of this calculation method.

ii. Analogue cost method – Basis of this method are estimations of costs which are based on experiences with other similar products or technologies.

iii. Parametric cost method – Parameters and variables are used for the development of cost estimating relationships.

Finally the sixth step is to develop a concept how to visualize and present the results of the LCC model. It is crucial to find a suitable visualization which assures that even though the project might be quite complex a clear and straightforward overview is guaranteed.

4. PRACTICAL APPLICATION OF THE LCC MODEL

Supported by FIR the practical application of the generic Life Cycle Costing model was conducted with focus on railway signalling systems. Within the European research project INESS LCC was applied on high complex industries like signalling systems for the first time. The application of the model was split into the following three stages:

- Stage 1: Development of an industry-specific LCC model
- Stage 2: Implementation of a LCC Data Collection
- Stage 3: LCC Data Analysis

The first stage of the practical application contained the customization of all three LCC dimensions explained in chapter 3 to the application field of railway signalling systems. Main objective was to provide the opportunity for merging all existing LCC data from INESS railway partners into one LCC-database. The second stage was the LCC data collection process. This stage had two main objectives. On the one hand an extraction of LCC data from the local accounting department of every project partner and on the other hand a detailed description of all framework conditions related to the local signalling system project. Stage three was the analysis of all collected datasets.

4.1 Stage 1: Development of an industry-specific LCC Model

For the development of the industry-specific LCC Model, workshops with all experts in the field of signalling systems from national railways have been conducted. To provide the basis for data input from six railway partners with projects in several European countries, the three dimensions of the LCC model had to be conditioned for data with varying quality and quantity. To achieve an appropriate degree of comparability between several LCC observed objects in high complex industries it is essential to clearly define the scope of the LCC-object with all its borders. First the dimensions had to be adjusted to the architecture of the industrial object – meaning the signalling system in INESS context. After that all three dimensions had to be scaled fitting to the size of datasets provided by the railway and industry companies. The higher the level of detail of the data within the three dimensions of the specific model the more options for possible analyses can be chosen in stage 3 of the application. Thus all three dimensions had to be divided into sub-units with a higher level of detail for the specific model.

As a first dimension of the specific LCC model the “Product Structure” was specified to the technical architecture of a signalling system. Based on the expert knowledge of INESS railway partners all cost relevant items of the product structure have been listed. After that the product structure has been clustered into two levels of detail (c.f. Figure 3). The detailed 2nd level consists of 22 components. For each of the components the related cost data can be filled into the template. The rough 1st level, consisting of only five elements, has provided the opportunity for an accumulation of datasets, if data cannot be provided by the partners in a high level of detail. Input for the design of the product structure can be the product- or work-breakdown-structure. The product breakdown structure is often used for cost calculation in industrial sales or accounting departments.

Level	Total Traffic Control	Total Core System	Total Field Elements	Connection to Field Elements	RBC
1st Level	Total Traffic Control	Total Core System	Total Field Elements	Connection to Field Elements	RBC
2nd Level	Traffic Control System Data Preparation System	Diagnostic System Juridical Recorder Control Module Interlocking Kernel Power Supply incl. UPS OC-LX OC (Balise) OC (Point) OC (Track Segment) OC (Signal) OC (ATP)	Balise (LEU) Point Track Segment Signal ATP RBC (Interface)	Civil Works Cabling	RBC

Figure 3 - Dimension “Product Structure”, example for two levels of detail

Focussing on the LC Phases FIR undertook a distinction into clusters with three levels of detail (c.f. Figure 4). In cooperation with experts from several project partners the five first level LC phases were subdivided into 14 clusters of the second level and 62 sub phases on the third level of detail. For products within high complex industries typically the first phases of the LC “System Design” and “System Implementation & Transfer to Operation” are very cost intensive. This is one reason, why these phases of the life cycle should be split into very short phases. The resulting challenge is to allocate sources for cost data-sets related to such short phases of the LC.

1st Level	2nd Level	3rd Level
System Implementation & Integration and Transfer to Operation	Contracting	Interlocking contract Bid Contract Construction contract Engineering contract
	Project Specific Planning	Scheme Plan Planning Planning Assessment System Requirement Specification System Architecture Prepare Basic Plans Prepare documentation for Test, Installation, Commissioning
	System Configuration	Product adaption System Configuration Configure indoor equipment Configure outdoor equipment Configure data for system
	Installation & Construction	Transfer System to destination Installation Construction
	Testing & Approval	Data integration test Provide Infrastructure for Tests Prepare Process Simulation Factory Acceptance Tests Commissioning & Tests Validation Assessment and Approval Site acceptance Integration test/commissioning
	Documentation	Archiving of documents Deliverables
	Additional	Handover Provide warranty phase Provide spare parts Remove failures

Figure 4 - Dimension "LC Phases", example for three levels of detail

For defining the last dimension of the specific LCC model, all relevant cost categories for signalling systems had to be identified. According to the experts LC costs of a signalling system can be distinguished between the following six categories: “Material-“, “Equipment-“, “Labour-“, “Energy-“, “Capital-“ and “Service-Disruption”-costs. Any expenses for raw material like steel, copper or concrete can be related to the cost category “Material”. Examples for the cost category “Equipment” are components already named in the product structure, i.e. signals or point machines. Expenses for maintenance or engineering working time belong to the category “Labour” costs. Costs for financing, i.e. bank loan interests or charges/fees belong to the cost category “Capital”. From the expert’s point of view the last relevant category are costs for delays due to interruptions of interlocking components. The related costs are allocated to the category “Service Disruption”.

For the on-site data collection the specific LCC model was transferred into an LCC Template with one worksheet for each of the six cost categories (c.f. Figure 5). Realizing the definition of the LCC Template, the LCC data collection and the analysis of the LCC data the software Excel provides all necessary functionalities.

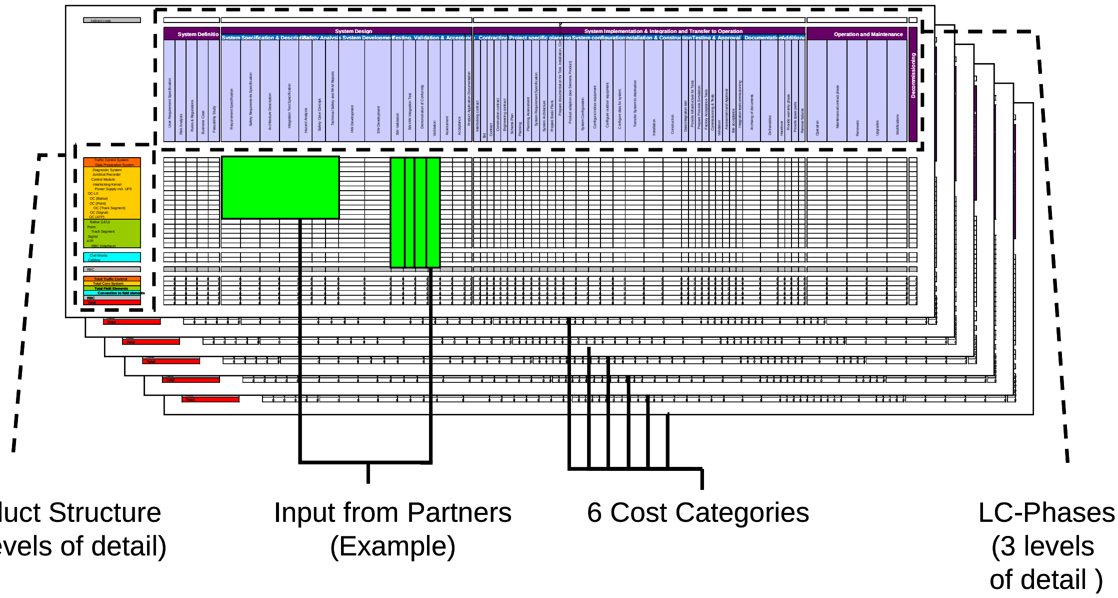

Figure 5 - Life Cycle Costing Template (Excel based)

4.2 Stage 2: Implementation of a LCC Data Collection

The LCC data collection was conducted within short onsite visits at the INESS railway partners. For an efficient and accurate collection every partner has prepared two documents in advance to the visit. The LCC Template has been filled with cost data in the highest available level of detail and a description of further project specific circumstances was provided by the companies. During the visit the delivered data was inspected concerning comparability and - if necessary - adjusted by the railway project partner.

Objective of the INESS LCC data collection was the identification of cost drivers within the European market for signalling systems. That is why other qualitative aspects, besides the collection of high quality and quantity cost data, had to be taken into account. For not drawing incorrect conclusions from the data-comparison some aspects of the project circumstances had to be considered during the selection of projects. Other aspects were captured within the LCC data collection in addition to the cost data. Every partner was asked further questions for the evaluation of project specific circumstances with impact on the collected cost data. Relevant general specifications in the INESS context were project size, project duration, architecture (centralized/decentralized), greenfield or brownfield character of the project and the location of the project (urban centre or rural). Also contractual items can be relevant in terms of LCC. Sharing of risks, intellectual property rights, responsibilities for reliability/availability and penalties in case of deviations are some exemplary contractual items.

4.3 Stage 3: LCC Data Analysis

After the data collection all input from INESS railway partners had to be consolidated and analysed. The character of the data analysis had to be adjusted to the objectives of the LCC data collection. Potential objectives – connected with related analyses of the LCC data collection – are exemplary introduced in Figure 6.

1. LCC objective is the identification of cost drivers

➢ Classification of cost items oriented towards product structure, cost categories or LC phases and visualisation in a Pareto Chart.

---

2. The objective of LCC is transparency over the distribution of costs within the life cycle.

➢ Collection of cost items in a high level of detail and visualization of results related to the highest possible level of detail in LC phases.

---

3. LCC objective is measuring the relation between Acquisition Costs and the sum of Costs of Ownership and Disposal costs.

➢ Calculation of Costs $_{\text{Acquisition}}$ + Costs $_{\text{Ownership}}$ + Costs $_{\text{Disposal}}$

Figure 6 - Overview about objectives of LCC and related analyses

If the objective is the identification of cost drivers, as it is within the INESS project, cost items have to be clustered to the dimensions of the LCC model. Clustering should be made towards the different phases and sub-phases of the life cycle or towards the product structure. For the identification of cost drivers a visualisation of the data-clusters in form of a pie chart is very transparent (c.f. Figure 7). Depending on the size of the data-sets contained in the LCC this kind of analysis can be made for first, second or third level of detail. A second possible objective for the analysis of LC data conduces to visualization of the cost distribution over the life cycle of the cost object. For this analysis data-sets need to have a high level of detail regarding the phases of the life cycle. The costs are displayed with a graph over the time. This kind of analysis is for example used to layout maintenance strategies for high complex industry facilities. LCC is also applied with the objective of comparing several investment scenarios. For this analysis a classification of cost data into the three categories Acquisition Costs, Costs of Ownership and Costs for disposal leads to a suitable result. For instance this analysis can be used for the illustration of the relation between investment costs, operation and maintenance costs as well as other costs.

Some exemplary results of the INESS data analysis are pictured in the following. Due to confidential project information, only a small amount of information can be presented here. Figure 7 shows the average proportion of total life cycle costs among Europe's railway operators.

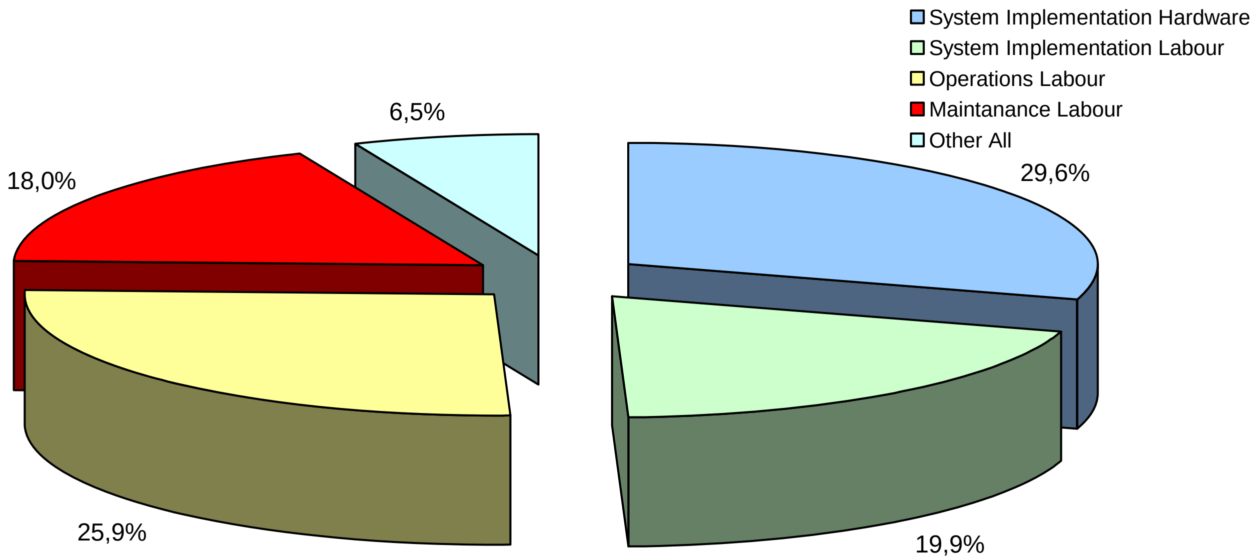

Figure 7: Proportion of total life cycle costs with a time span of 25 years

Total costs, which are made up of investment costs and costs for operations and maintenance show an approximate ratio of 50-55% for invest costs and 45-50% for operations and maintenance costs. A further breakdown shows that investment costs consist of approx. 60% hardware costs and 40% labour costs. A detailed analysis of operations and maintenance costs reveals that operations costs have a share of approx. 55% and maintenance costs of approx. 45%.

In a next step, a deeper look into the system implementation, operations and maintenance phase was undertaken to identify cost drivers of an interlocking system. Within this analysis averages of each product component were identified. The analysis of the costs by product structure and phases for a time span of 25 years shows the following results. System implementation, which was analysed for hardware and labour costs, respectively, shows a cost distribution for hardware costs of 1.2% for traffic control systems, 8.7% for core systems, 10.4% for field elements, 9.2% for connections to field elements (FE) and 0.3% for RBC. Labour costs consist of 1.9% for traffic control systems, 10.6% for core systems, 5.7% for field elements, 1.7% for connection to FE and 0.7% for RBC. The labour costs within the operations phase consist only of traffic control system costs and amount to 26.6%. The labour costs of maintenance comprise 1.9% for traffic control systems, 4.4% for core systems, 9.1% for field elements, 2.0% for connection to FE and 0.8% for RBC. All the other costs comprise 2.4% for traffic control systems, 3.6% for core systems and 0.5% for field elements.

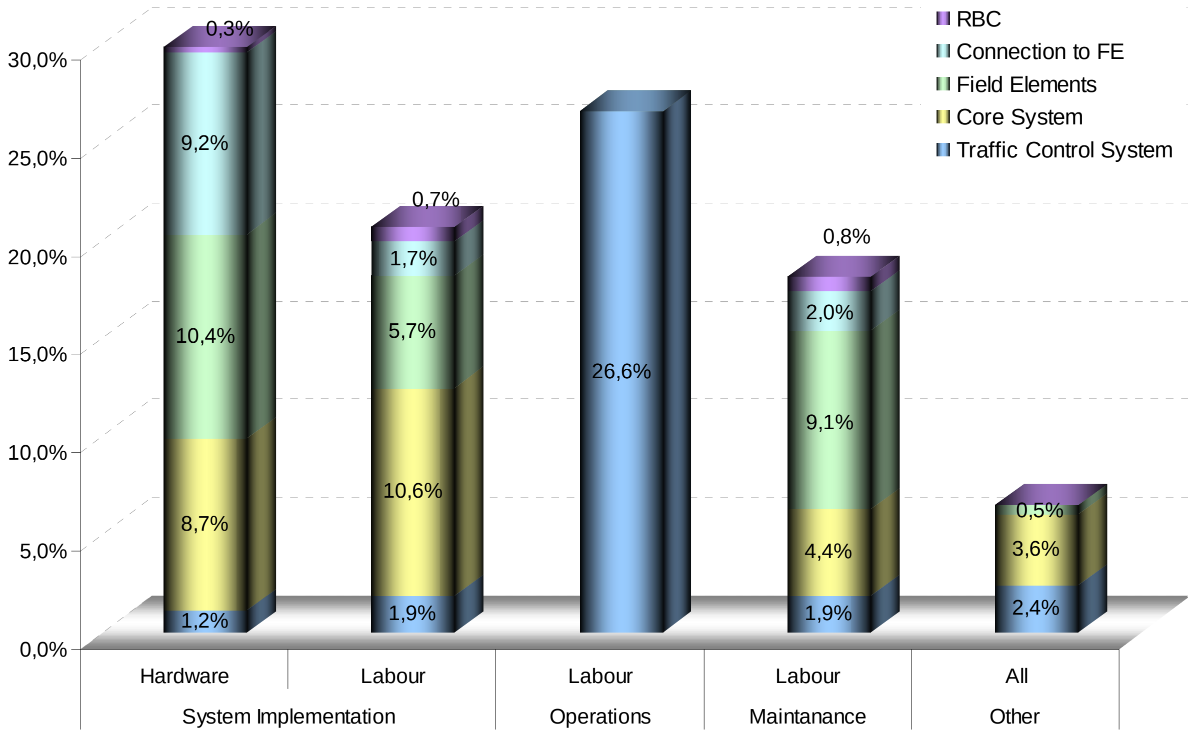

Figure 8: Costs by product structure and phases (Time span 25 years)

Field elements and the core system cause the major costs. Eventually, 25.7% of the costs are caused by field elements. Especially, hardware costs in the system implementation phase and labour costs for maintenance make up an essential part of the total field elements costs. With 27.3% of the total costs, costs for the core system make up another major part of the total costs. These costs especially occur during the system implementation. Both, hardware and labour generate this significant part of the total costs. Operations costs are also on a high level. For the operation of an interlocking, only workforce is a cost driver. Over 25 years operations costs make up more than a quarter (26.6%) of the total costs. Ultimately, all cost items that make up more than 5.0% of the total costs have been defined as cost drivers. An overview of these cost drivers is given in Figure 9.

- 26,6% = Labour costs during the Operation phase.
- 10,6% = Labour costs spent on the Core System during the System Implementation.
- 10,4% = Hardware costs for Field Elements during the System Implementation.
- 9,2% = Hardware costs for the Connection to Field Elements during the System Implementation.
- 9,1% = Labour costs to maintain the Field Elements.
- 8,7% = Hardware costs for the Core System during the System Implementation.
- 5,7% = Labour costs for Field Elements during the System Implementation.

Figure 9: Identified Cost Drivers

As mentioned above, a more detailed and deeper explanation of the identified results is not allowed due to confidential agreements.

5. SUCCESS FACTORS FOR LCC MEASUREMENT

5.1 Required tasks

Based on the development of a Life Cycle Costing approach and on the LCC measurement within the railway industry as well as former findings by other researchers, six major steps have been identified, that are necessarily needed to identify Life Cycle Costs within a high complex industry.

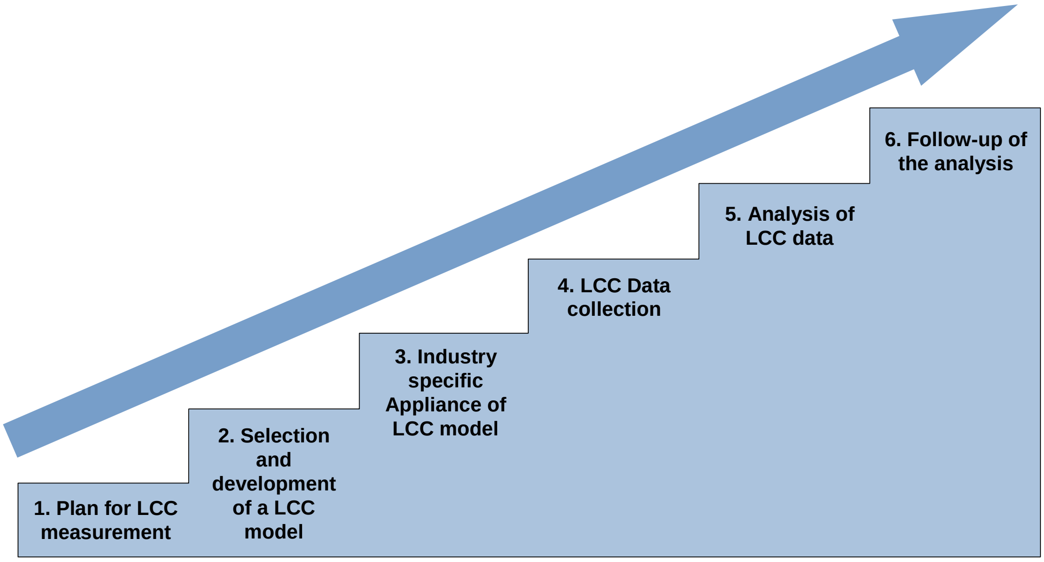

Figure 10 - Steps for successful LCC measurement

First of all, a plan for Life Cycle Cost measurement needs to be developed. It should include a **definition and targeting** of the requested goals and results. Furthermore, a definition of the extent of **analysis** and an **identification** of underlying conditions, assumptions, restrictions etc. is required. In order to keep the plan as flexible as possible further definitions of **potential action alternatives** are necessary. To get an overview about all **required resources** (time, costs, workforce etc.), resource estimations should be conducted. This basic plan for the following analysis should be well documented and adjusted to the requirements of the clients as well as the suppliers in order to ensure that all needs are regarded correctly.

Second, LCC models which fit to the actual plan have to be selected or developed. During that task it has to be proved and ensured, that the required data to be collected and analysed in later steps fits to the LCC model. Data also has to be available in a detailed way (Christensen et al. 2005, p. 252 ff.).

The third step deals with the actual appliance of the selected LCC model. The identification of Life Cycle Costs should be conducted in the following proceeding:

- **acquisition** of essential data for each cost element,
- **utilisation of LCC analysis** for the different operation scenarios,
- **reporting** about the analysis,
- the **in- and outflow** of the LCC model has to be scrutinized to detect the most influential cost elements,
- identification of major **differences between the analyzed options,**
- **classification** and summary of the results,
- utilisation of the **sensitivity analysis** to analyze the impacts of certain assumptions and uncertainties in the different cost elements on the final results,
- **verification of results** concerning the determination of desired results (plan for LCC measurement).

After the actual LCC model is applied, the actual data collection and analysis starts. During the collection a sophisticated documentation is mandatory to guarantee a successful LCC measurement. The documentation should contain a short **summary** of goals, results and conclusions. Furthermore, all **objectives** and the **application range** of the analysis as well as a **description and summary of the LCC model** (including the relevant assumptions and an explanation of all major cost elements) should follow. Besides that, the documentation of the **description of the application process** of the LCC model including all essential cost drivers and the results of the sensitivity analysis help the reader understanding the LCC application process. After the description of the process is done, a **detailed discussion and interpretation** of the results including all related uncertainties and a **conclusion and recommendation** of all objectives, results, recommendations related to future decisions should be the last part of the documentation (Barringer 2003, p. 9).

In order to assure a sufficient extent of accuracy, all results of the LCC analysis have to be reviewed and audited. If possible this review should be conducted by an external assessor and a special focus should be set on the **review of goals** and of the analysis extent. Furthermore aspects like the **review of the LCC model itself** (including definition, cost elements and assumptions) and the **review of the application** to assure that the input data was measured correctly have to be regarded carefully. Finally the focus should be set on the **review of all basic assumptions** in order to guarantee that they are reasonable and sufficiently documented (Zimmermann 2005, p. 8-11).

Ultimately, the whole process of LCC measurement is a continuous process and all data (especially the estimated data) has to be updated continuously. As soon as new data is available the basic assumptions have to be updated with actual data to make the model as accurate as possible (Dhillon 1989, p. 35 – 39).

5.2 Uncertainties and risks

The measurement approach of life cycle costs is mainly based on estimations, extrapolations and especially dependent on the reliability of information. It has to be emphasized that various factors, like new technologies, changing inflation rate, changing economic and political situations, exchange rates, human behaviour, usage of out-dated data, unpredictable results etc. are not steady and therefore difficult to predict.

In order to reduce potential risks it can be useful to conduct sensitivity-analyses. By the help of this tool a range of variation can be demonstrated to the decision-makers.

Ultimately, it became obvious that errors or wrong estimations are inevitable. Therefore, it is essential to conduct an uncertainty- and risk-analysis in addition to the sensitivity-analysis (Backlund & Hannu 2002, p. 78; DIN EN 2004, p. 20).

6. CONCLUSION

Life cycle costing is one beneficial option for a more sustainable way within the investment decision process. Taking life cycle costs into account enables a better understanding of the total costs of ownership. All following costs apart from the actual investments costs can be captured and forecasted more efficient, which leads to cost economies and thus to superior investments decisions.

The analysis within the railway industry has shown that life cycle costing also works in high complex industries. It could be also shown that especially these industries require a well structured methodology. The appliance of the LCC concept within the European research project INESS leads to the conclusion that EN 60300-3-3 delivers a suitable methodology to develop a life cycle model for high complex industries. It also provides the flexibility to gain adaption to special market needs.

It became obvious that the involvement of experts and a clearly structured appliance of the LCC approach are mandatory. Also, it has to be assured that all required data is available in detail. The more detailed the data is, the more detailed and informative the results of the analysis will be. Time and effort for the development of the overall approach as well as the data evaluation should not be underestimated; especially in case of an application of the methodology in a complex and large company. Often the right allocation of data sets takes much more time than the data sourcing itself.

7. REFERENCES

1 Asiedu, Y. and Gu, P.(1998) 'Product life cycle cost analysis: state of the art review', International Journal of Production Research, 36: 4, 883 — 908.

2 Backlund, F. & Hannu J. (2002) Can we make maintenance decisions on risk analysis results? Journal of Quality in Maintenance Engineering, Vol. 8, No. 1, 77-91.

3 Barringer, P. H. (2003): A Life Cycle Cost Summary. Perth. <http://www.barringer1.com/pdf/LifeCycleCostSummary.pdf >

4 Christensen, P. N., Sparks, G. A. & Kostuk, K. J. (2005) A method-based survey of life cycle costing literature pertinent to infrastructure design and renewal. Can J. Civ. Eng. 32: 250-259.

5 Dhillon, B. S. (1989) Life Cycle Costing. Amsterdam.

6 DIN EN 60300-3-3 Dependability management – Part 3-3: Application guide – Life cycle costing (IEC 60300-3-3:2004);
German version EN 60300-3-3:2004

7 Ellis, B. A. (2007) Life Cycle Cost. *International Conference of Maintenance Societies* < http://www.jethroproject.com/Life%20Cycle%20Cost1.pdf >

8 Ellram, L. (1994): A Taxonomy of Total Costs of Ownership Models. Journal of Business Logistics, Vol. 15, No. 1, 171-191.

9 Fischer, M. (2001): Produktlebenszyklus und Wettbewerbsdynamik. Mannheim.

10 Geißdörfer, K. (2008) Total Costs of Ownership (TCO) und Life Cycle Costing (LCC). Berlin.

11 Parnell, G. S.; Driscoll, P. J. & Henderson, D. L. (2008) Decision Making in Systems Engineering and Management.
Hoboken.

12 Zimmermann, M. (2005) Life Cycle Costing. Norderstedt.