LIFE CYCLE COSTING AS A STRATEGY - SUSTAINABLE OPERATIONS OF SIGNALLING SYSTEMS IN THE RAILWAY INFRASTRUCTURE

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In terms of sustainable thinking, life cycle costing attracts major notice among railway industries allover 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 life cycle costs of a signalling system can 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, the special methodology to analyze life cycle costs has been applied within a European funded research project.

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 suppliers and customers of 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. CHALLENGES OF EUROPEAN RAILWAYS

Companies have to make important decisions about future investment projects and options all the time. Especially in the manufacturing and plant engineering industry a major part of the total costs is caused by investment and equipment costs. Investment decisions are mainly based on quality-, reliability- and especially on (investment) cost- aspects. In many cases more than 50% of the total costs are not regarded due to the fact, that only purchasing costs are considered (GEIßDÖRFER 2008, p. 1-3).

In order to avoid this deficient calculation of investment options the Life Cycle Cost measurement approach can be applied. The LCC approach provides a complete overview about 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 the initial investment decision (BARRINGER 2003, p. 2, ZIMMERMANN 2005, p. 2).

Privatisations in the railway sector lead to a breakup of Railway Infrastructure and Railway Transportation Companies in the 1990s. Most of these Railway Infrastructure companies are now facing the challenge to compete with other modes of transport like air, road or ship transport while necessary renewals of the often over aged infrastructure are anticipated by the public as well as its owners.

This article describes the challenges DB Netz as a German Railway Infrastructure company is facing especially in the field of Signalling Systems, how they can be evaluated and why Life Cycle Costing is an important investment criterion.

2. KEY FACTORS FOR THE INVESTMENT STRATEGY OF SIGNALLING SYSTEMS

Key characteristics of the railway infrastructure

Railway infrastructure is characterized by long-living investments of up to 100 years (i. e. for tunnels). In fast changing markets these characteristics need to be aligned with the rapidly changing demands of transport companies especially in the field of freight transport. On certain corridors current forecasts expect growth rates of 65 % especially on those lines which are already used almost to capacity today. Not only the number of trains is expected to grow but also the length of the routes will increase. Nowadays it is more cost effective for ocean carrier to supply the (Central) European market mostly from a number of big harbours i. e. in Belgium, The Netherlands and Germany.

Furthermore the extension of the infrastructure is characterised and to a certain extent limited by long approval procedures and construction times. To limit the impairment of nature or landscape and to respond to the dynamic markets as fast as possible DB is focusing on enhancing the capacity of the existing network by intelligent (re-) investment strategies for signalling and train control systems. Therefore the annual investments of approximately 4 Billion Euro need to be allocated following sophisticated strategies.

To operate the German rail network of 34,000 km length, currently 4,500 interlockings are in operation to control 69,000 points and 160,000 signals. Those interlocking systems are of different types like mechanical, electromechanical, relay-based or electronic. Each of these system categories consists of a great range of different implementation variants (see Figure 1).

The Figure also shows that some types of these in total 1,800 systems only exist in a very low quantity. Maintaining these systems where spare parts are often no longer available by the OEM is difficult. Keeping the knowledge of the systems and training of maintenance staff do – in the mid and long term – not allow cost efficient operation. Hence the investment strategy must work towards a replacement of these systems.

A second cluster is formed by those interlockings where a medium quantity is still in use (20 – 60 systems). Here it sometimes is advantageous to extend the life time of the systems by cannibalisation strategies, meaning the replacement of a limited number and the re-use of components to maintain the others.

Apart from these two clusters there are some systems (like SpDrS60, SpDrL60) where the quantity of systems in operation is still high enough to allow spare part supply by the OEM. By replacement of parts of the system the life time can be extended by at least 20 years without loss in availability or reliability. The large number of systems also allows special trainings for maintenance staff in order to keep the knowledge until the expected time of decommissioning.

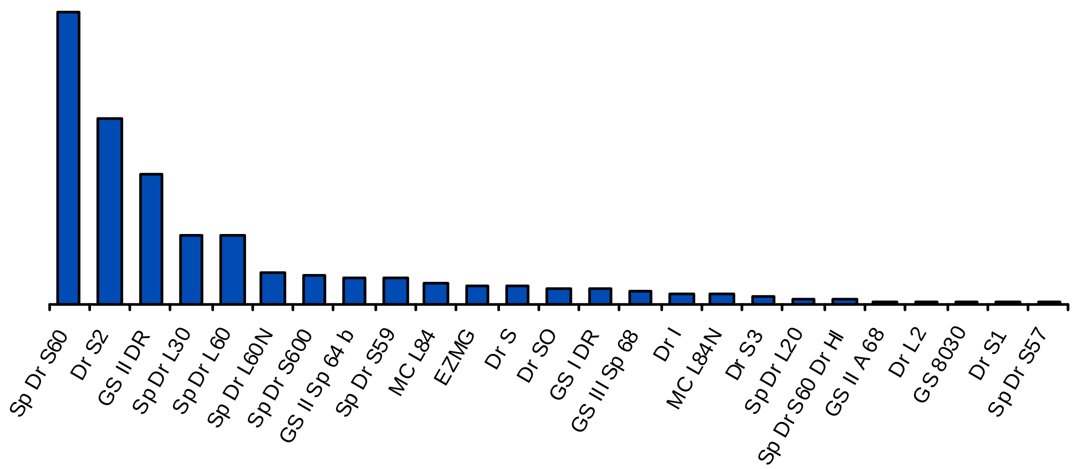

Figure 1: Relay type interlocking systems in operation

In contrast to older technologies like mechanical (80 years), electro mechanical (60 years) or relay (50 years) based interlockings modern computer based systems are afflicted by the short innovation cycles of electronic components. Therefore certain components are hardly available after 10 years of use requiring costly replacement of entire systems or at least great parts of it.

Consideration of Life Cycle Costs during the investment phase

Taking into account the shorter lifetime and the necessary reinvestments replacing old mechanical interlocking by electronic systems does not seem to be a good choice for the railways. This might be true for the investment, but over the whole life cycle of the asset modern systems allow high cost saving during the operation phase (see Figure 2) of the system. First analysis shows that more than 50 % of total life cycle costs are spend during the operation and maintenance phase. This incorporates labour costs for signaller and maintainer as well as those for spare parts, updates or energy consumption of the system.

Nevertheless it was found that today's prices for new systems will not allow the perpetuation of the network quality. Detailed knowledge about the lifetime of the systems helped to identify the required renewals. Based on these figures and implying that public funding will not significantly change during the next years a target price per SEU (Signal Equivalent Unit) could be defined.

Although this target price is defined for investments only DB currently implements additional criteria in the contracts with its suppliers to evaluate the life cycle costs of the offered system. Therefore all relevant cost drivers (i. e. costs of alterations, spare parts, updates, reinvestments or energy consumption) need to be considered. This ensures calculability of future costs at the time of first investment.

Cooperation on national and international level

While the above mentioned solutions could be done within the national market DB believes that international cooperation between infrastructure managers and supply industry can help reducing costs through economies of scale by standardisation of system interfaces and designs.

The challenges of all standardisation efforts are differences in national legislation as well as railway specific requirements. Research cooperation with independent institutes is expected to help identifying possible fields of improvement and to evaluate the feasibility of short or medium term implementation. Transparency of cost drivers on both sides – railway and supply industry – is vital to deduct the appropriate activities.

As an example the influence of railway specific requirements can be seen. It is expected that a harmonisation of these requirements will lead to reduced efforts for bringing products from one market to another. However up to now it was not possible to quantify the costs for market specific adaptation as data is not available to the infrastructure managers (it is indirectly part of the investment costs). Research cooperation with independent institutes and industry can close this gap by assuring the confidentiality of provided data through the researchers.

An European cooperation will also support the exchange of experiences. In the past the operation of railway infrastructure was a national business. The opening of markets is expected to accelerate standardisation with the objective of lifecycle cost reduction for signalling systems. This is an indispensable precondition to increasing the modal share of railways amongst Europe.

3. A LIFE CYCLE COSTING APPROACH - DIN EN 60300-3-3

The six phase model of a product life

In the following, the six phase's model of a general product life cycle, which is the basis of the LCC measurement approach in the DIN norm, will be explained.

The model starts with the phase of **(1) concept & definition**, which is followed by **(2) draft & development**, **(3) manufacturing**, **(4) installation**, **(5) operation & maintenance** and ends with the phase of **(6) disposal.**

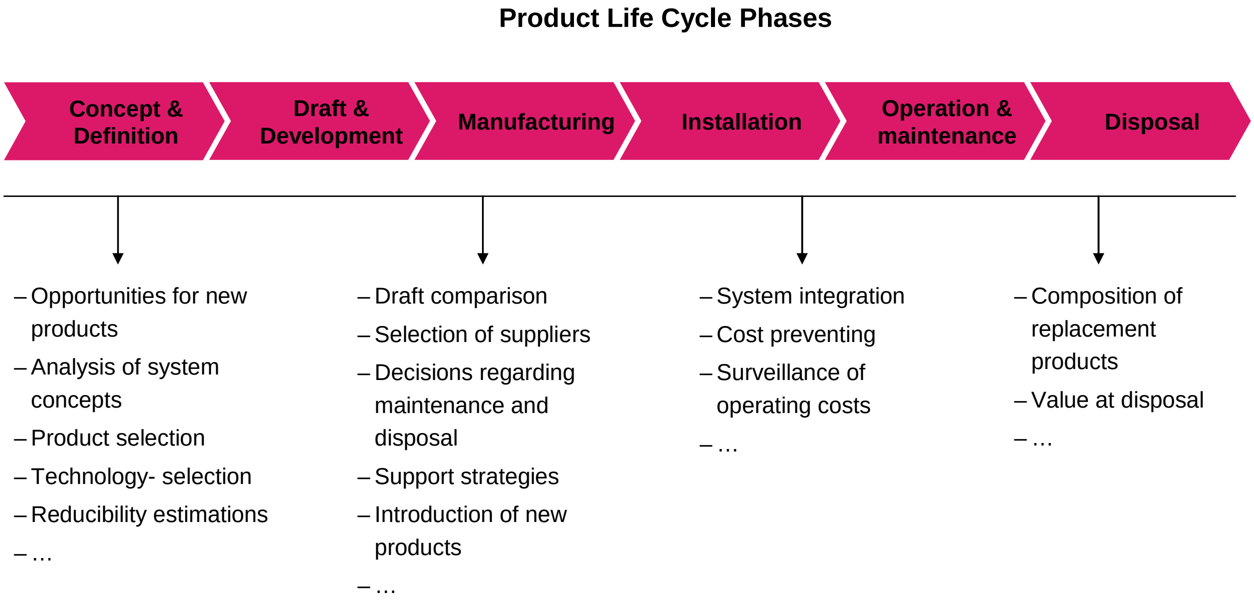

Figure 2 - Example for LCC application

The first phase of the PLC (Product Life Cycle) 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 the basis the production (3) and the installation (4) phase follows. These two phases include continuous checking of room for improvement regarding possibilities of improved support services. In terms of time, the fifth phase is generally the one with the longest duration. A product needs to be maintained, fixed, supplemented, updated, etc. during the operation time and therefore a huge part of all follow-up costs does emerge during this fifth phase. Eventually, 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 it costs at the beginning (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-dated financial planning, etc.) in order to analyse the LCC. Generally, it is important to analyse the LCC at the very beginning of a new project, because in many cases more than half of the total LCC are fixed after the first phase of **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).

$$LCC = Costs_{\text{Acquisition}} + Costs_{\text{Ownership}} + Costs_{\text{Disposal}}$$

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 law additional activities can be required for the disposal of certain products (DIN 2004, p. 8).

Like all other models the model of life cycle costs is an abstraction of reality and has the function 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 and 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 simply as possible.

Figure 3 shows the actual content of the LCC model. The mentioned aspects/steps should be included in the modelling of LCC.

#	Content of the LCC model	Short explanation
1	Cost breakdown structure	Illustration of the costs that emerge in all single phases
2	Product/work breakdown structure	Detailed illustration of the costs that emerge for the used materials and manpower
3	Selection of different kind of costs	It has to be decided which kind of costs are analysed
4	Selection of cost elements	It has to be decided which elements are defined and analysed
5	Estimation of costs	The occuring costs have to be estimated
6	Visualisation of results	The results have to be visualized
If aplicable the following aspects are added:		
Environmental- and security aspects		
Uncertainty- and risk aspects		
Sensitivity analysis in order to identifly the cost drivers		

Figure 3 - Important aspects of the LCC measurement

1. **Cost breakdown structure** – All important costs that emerge in each phase of the product life cycle are depicted in this first step.

2. **Product/work breakdown structure** – This step consists of a detailed analysis of the used materials, services and data which define the essential tasks.

3. **Selection and definition of different kind of costs** – It is important that all elements are clearly defined so as to avoid double counting.

4. **Selection and definition of cost elements** – The total life cycle costs consist of various cost elements that have to be identified. A cost element is the connection between the type of cost and the product/work breakdown structure. The most frequently used approach to determine the single cost elements is the three dimensional Matrix approach. In this approach it is important to define three dimensions regarding:

- **Product structure** (i.e. product/work breakdown structure)
- **Life cycle phases**
- **Cost categories** (i.e. labour costs, material costs, energy costs, etc.)

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 4 shows an abstraction of the Cost Element Cube.

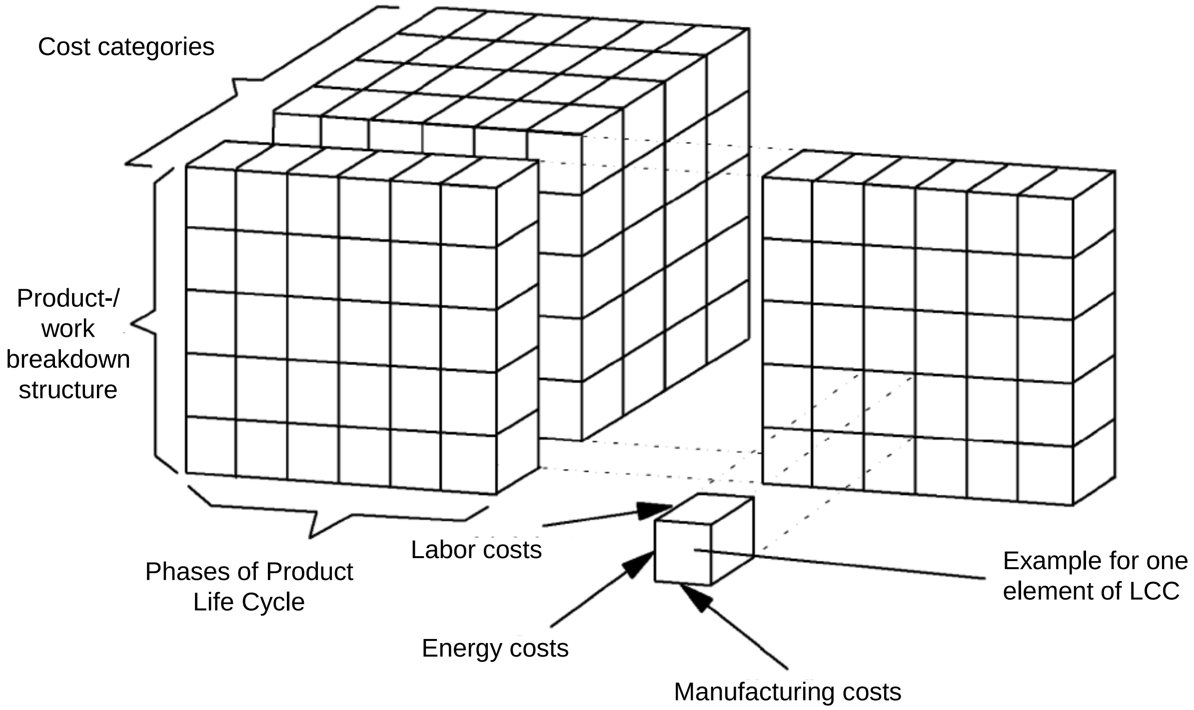

Figure 4 - Concepts for cost elements

5. **Estimation of costs** – Based on the DIN norm, there are 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 the **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.

Three possible cost estimation methods are the following:

- **Engineering cost method** – Standard estimations of cost attributes are the basis of this calculation method.
- **Analogue cost method** – Basis of this method are estimations of costs which are based on experiences with other similar products or technologies.
- **Parametric cost method** – Parameters and variables are used for the development of cost estimating relationships.

6. **Visualisation of results** – the last part of the LCC model is the final presentation and visualisation of the results. Depending on the complexity of the project it can be essential to find a good and clearly arranged way of visualisation (PARNELL, DRISCOLL & HENDERSON 2008, p. 126).

4. SUCCESS FACTORS FOR LCC MEASUREMENT

Required tasks

The following part deals with the approach of the practical process of LCC measurement. The LCC concept itself, which was explained above can be found in success factor three (see circled step in figure 4). Based on the EN norm this process should be structured in six different phases in order to make it reasonable and correct. The process itself is meant to be multidisciplinary. In practice this means that there should be at least one person participating that is familiar with a certain phase of the product life cycle. Furthermore, some of the phases can be conducted iteratively if certain parameters have changed (BARRINGER 2003, p. 3).

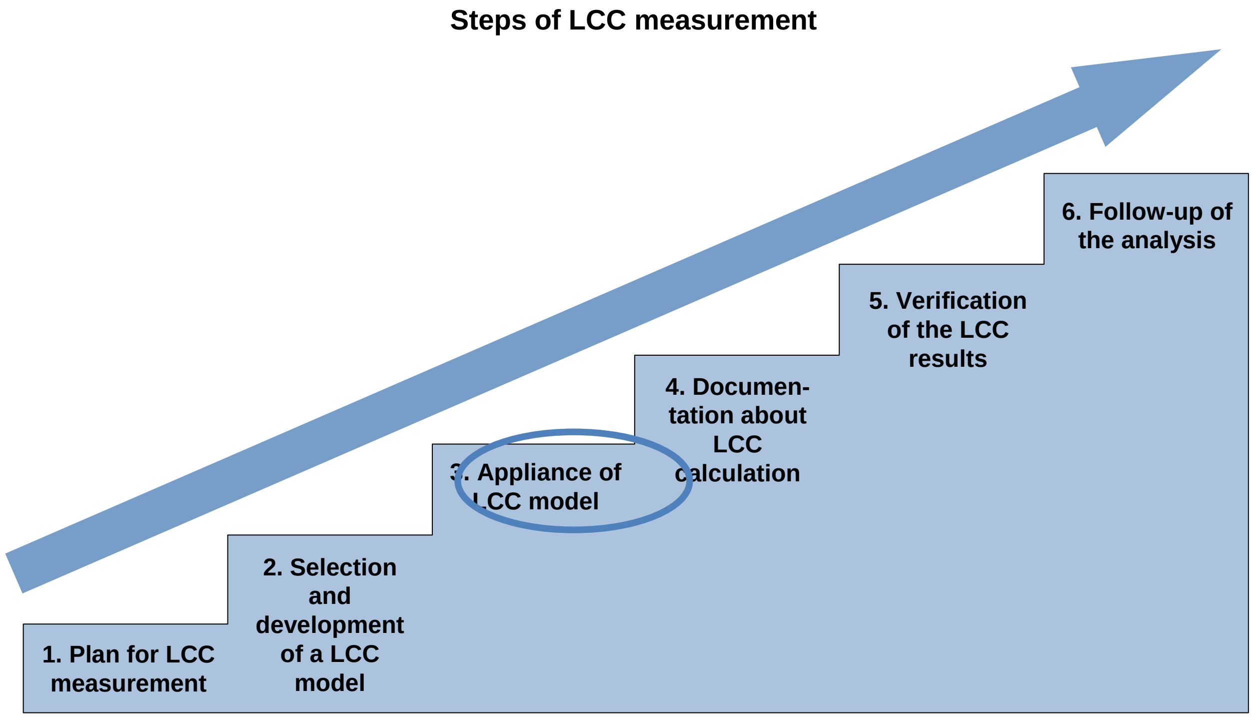

Figure 5 - Steps of LCC measurement

First of all, a plan for life cycle cost measurement needs to be developed. It should include a **definition and targeting** of the requested aims and results. Furthermore, a definition of the **analysis extend** 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 correctly regarded.

In the next step LCC models which fit to the previous plan have to be **selected** or **developed**. It has to be ensured that the required data is available and detailed enough.

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 steps:

- **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 process of **documentation** about the LCC measurement begins. The documentation should contain a short **summary of** aims, 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 to understand how the LCC application process was conducted. 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 extend 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 aims** and the extend of the analysis, the **review of the LCC model itself** (including definition, cost elements and assumptions), the **review of the application** to assure that the input data was measured correctly and finally 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 real data to make the model as accurate as possible (DHILLON 1989, p. 35 – 39).

<u>Uncertainty and risks</u>

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-analysis. By the help of this tool a range of variation can be demonstrated to the policy-makers.

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

5. LESSONS LEARNED

Especially for investments with a long lifetime considering the whole life cycle of products and services is necessary to make reasonable investment decisions. The appliance of the LCC concept within a European research project 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 are available.

Time and effort for the development of the overall approach as well as the data evaluation should not be under estimated; especially in case of an application of the methodology in a complex and big company. Often the right allocation of data sets takes much more time than the data sourcing itself.

6. ABBREVIATIONS

DB	Deutsche Bahn AG
DIN	Deutsches Institut für Normung
EN	European norm
LCC	Life Cycle Cost (ing)
OEM	Original Equipment Manufacturer
SEU	Signal Equivalent Unit

7. REFERENCES

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

2. DHILLON, B. S. (1989): Life Cycle Costing. Amsterdam.

3. 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

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

5. FISCHER, M. (2001): Produktlebenszyklus und Wettbewerbsdynamik. Mannheim.

6. GEIßDÖRFER, K. (2008): Total Costs of Ownership (TCO) und Life Cycle Costing (LCC). Berlin.

7. PARNELL, G. S.; DRISCOLL, P. J. & HENDERSON, D. L. (2008): Decision Making in Systems Engineering and Management. Hoboken.

8. ZIMMERMANN, M. (2005): Life Cycle Costing. Norderstedt.