LAPPEENRANTA UNIVERSITY OF TECHNOLOGY

Department of Industrial Engineering and Management

Global Management of Innovation and Technology

GENERIC LIFE CYCLE COST MODEL AND COST-EFFECTIVE SOLUTIONS

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ABSTRACT

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Life cycle costing (LCC) practices are spreading from military and construction sectors to wider area of industries. Suppliers as well as customers are demanding comprehensive cost knowledge that includes all relevant cost elements through the life cycle of products. The problem of total cost visibility is being acknowledged and the performance of suppliers is evaluated not just by low acquisition costs of their products, but by total value provided through the life time of their offerings.

The main purpose of this thesis is to provide better understanding of product cost structure to the case company. Moreover, comprehensive theoretical body serves as a guideline or methodology for further LCC process. Research includes the constructive analysis of LCC related concepts and features as well as overview of life cycle support services in manufacturing industry.

The case study aims to review the existing LCC practices within the case company and provide suggestions for improvements. It includes identification of most relevant life cycle cost elements, development of cost breakdown structure and generic cost model for data collection. Moreover, certain cost-effective suggestions are provided as well. This research should support decision making processes, assessment of economic viability of products, financial planning, sales and other processes within the case company.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

ABBREVIATIONS

PLM	Product Lifecycle Management
PDM	Product Data Management
PLC	Product Lifecycle
BOL	Beginning of Life
MOL	Middle of Life
EOL	End of Life
LCC	Life Cycle Cost/Life Cycle Costing
LCA	Life Cycle Assessment
TCO	Total Cost of Ownership
WLC	Whole Life Costing
LCCA	Life Cycle Cost Analysis/ Life Cycle Cost Assessment
ICT	Information and Communication Technologies
RFID	Radio Frequency Identification
PEID	Product Embedded Information Devises
IoT	Internet-of-Things
CBS	Cost Breakdown Structure
GCBS	Generic Cost Breakdown Structure
RAM	Reliability-Availability-Maintainability
ABC	Activity Based Costing
CER	Cost Estimation Relationship
NPV	Net Present Value
OPEX	Operation Expenditures
COPEX	Capital Expenditures
TPM	Total Productive Maintenance
RCM	Reliability Centered Maintenance

1 INTRODUCTION

Manufacturing industry is constantly transforming and adapting to more service oriented environment. Such factors as globalization and increased competition require stronger supplier-customer relationship and provision of expanded solutions. Tangible product itself becomes a part of the total offering, which aims to fulfil wide spectrum of customer needs. From these trends it becomes clear that costs of the product through its life cycle comprises many different elements and not only the costs associated with acquisition. Customer is often requiring various cost data prior to the purchase in order to understand the total cost of the product through its life cycle. Such costs as operational costs, maintenance costs, logistic costs and other play important role in the highly competitive markets. Consequently, suppliers increasingly using the cost analysis that comprises all the elements, which appear though the whole life cycle of the product. Such cost data provides competitive advantage for the supplier, which can emphasise on the provision of the best lifetime value and not just low purchase price.

Life cycle cost (LCC) analysis, mainly used in military and construction industries, is now being widely applied in increasing spectrum of fields. The process itself can include many other concepts and types of analysis, such as reliability-availability-maintainability analysis, risk analysis, economic analysis, etc. In any case, the main objective of LCC is to assess the total cost of the product through the whole life cycle. The prediction of LCC can be used in decision making processes, design optimization, maintenance scheduling and for other purposes.

The case company needs to get more information and visibility of the total cost of its products. Such information is especially needed from the sales point of view, in order to provide total cost of ownership data for the customer. LCC analysis provides bases for cost element identification, which can be later used in the assessment of total cost.

1.1 Background of the study

The thesis work was done for and in the cooperation with Finnish company “Normet Oy” (further Normet). Company has around 50 years of experience and specializes in the development, production and sales of equipment and vehicles for underground mining and tunnel construction. Company has a wide range of services and products offered through the whole life cycle of the machine: training, audit, maintenance, service contracts, documentation, spare parts, rebuilding, etc. For this reason it is very important to have a deep understanding about the products and services from the life cycle point of view.

In order to successfully operate in the increasingly competitive global markets, company has to pay much attention to various occurring costs as well as the quality of their offerings. For that reason, the main purpose of the thesis was to make deeper analysis of all the factors and issues that influence the life cycle costs associated with products. Moreover, provide better understanding of the whole life cycle model of the machines and especially what factors have an influence to profitability of Normet’s products and services.

1.2 Research objectives and limitations

The main problems to be solved in the research are connected to the provision of better understanding about cost structure and cost model, which could serve as a framework for further data collection. While Normet does not have a clearly defined model and methodology of cost evaluation and analysis, this research work could help to improve the assessment of economic viability of products, long term financial planning and identification of cost drivers as well as cost-effective improvements. The main research questions are:

- What are the cost elements and cost structure through the whole life cycle of the machines from different perspectives?
- What could be the cost model for further data collection?
- What could be the cost-effective improvements?

The limitations in this thesis could be described as follows:

- Limited amount of concepts will be applied and not all the aspects of life cycle costing will be taken into consideration (e.g. life cycle assessment, which aims to measure environmental impact of the products, will be not used).
- The emphasis of analysis will be in after-sales stages of product life cycle.

- The cost structure will be analyzed from different perspectives. However, the analyses will be done in the collaboration with one actor: Normet.
- Life cycle cost modeling process will be limited in this research and the cost estimations will be excluded. Limited amount of process steps will be utilized as the main goal of the research is to provide a generic cost structure and model, which can be used for further data collection and life cycle cost analysis.

1.3 Research methodology

A theoretical base is essential for this thesis as it provides the understanding of the main concepts as well as certain methodology for the development of life cycle cost model. For that reason, extensive literature review, including academic research papers, books, journal articles, costing manuals, various standards and other sources, in the constructive manner will be applied. Developed methodology will be used in a qualitative - single case study. The developed methodology will be limited to three main steps of LCC process: 1) problem definition, 2) identification of cost elements and development of generic cost breakdown structure (GCBS) and 3) development of generic cost system model. Case study was made in cooperation with Normet and especially product life cycle manager Matti Juntunen, including meetings and discussions.

1.4 Structure of the thesis

This thesis could be divided into two main parts. The theoretical body includes second, third, fourth and fifth chapters, which build the main methodology for LCC analysis. The introductory second chapter describes the main concepts and trends related with product lifecycle management that are important in order to provide the view of business from life cycle point. The third and main chapter of theoretical body describes all the features and aspects related to life cycle costing, including definitions, applications, benefits, processes, IT tools, standards, etc. It is important to mention that literature analysis was aimed to provide wide overview and serve as general supporting methodology for the whole LCC process. However, the application of theoretical aspects was limited in the case study. The forth chapter describes the customer LCC concept, which also often referred as total cost of ownership (TCO), including very important description of TCO elements. The last chapter in theoretical part of the thesis includes the overview of after-sales support services. This part was created in order to provide better explanation of the cost element origin and try to define various cost-effective solutions.

The case study part, where the theoretical body with certain limitations was applied, include chapter six and seven. The main purpose of the case study was to identify the main costs elements that appear in the life cycle of the products and construct generic cost breakdown structure. The chapter six includes description of case company as well as general LCC process. Moreover, the generic cost breakdown structure with cost element description, generic life cycle cost model, use cases and suggestions for further cost modeling are presented in chapter six as well. In chapter seven concluding suggestions for cost-effective improvements are described. In the end of the thesis discussion and conclusion part will be provided.

2 PRODUCT LIFE CYCLE MANAGEMENT AND RELATED CONCEPTS

In this part of the thesis short overview of various concepts related to Product Lifecycle Management (PLM) and Product Data Management (PDM) will pre presented. It is important part in order to provide a better understanding of life cycle costing issues as well as topics related to life cycle support services. Moreover, presentation of modern life cycle management approaches will help to establish proper basis for life cycle cost model analysis and possible cost-effective improvements.

2.1 Life cycle of the product

Product life cycle (PLC) is a concept that differs quite extensively depending on the products and perspective of analysis. Every product has limited life cycle and it can be divided in separate stages depending on the context. Since 1960s PLC concept was used in different areas such as product management, marketing mix, linking production processes and pricing, etc. V. Ohri (2006) presents product life cycle from different perspectives, which are summarized in table 1:

Table 1. Product life cycle concept in different contexts (adapted from V. Ohri, 2006)

Context	**PLC concept**
Development of Sales	Introduction, growth, maturity and decline phases. Analyzes sales volume and earnings in different life stages. Useful for marketing and product strategy decisions.
Diffusion of innovation	Can be seen in parallel to PLC and defines phases in the spread of innovation: innovators, early adopters, majority and laggards.
Linking manufacturing process	Defines the stages in the view of production process in product-process matrix. The life cycle of product-process starts with inception, maturity standardization and becomes automated in the end. Flexibility and cost efficiency can be seen as too conflicting indicators. Helps to optimize production process and to recognize its competitive advantages.
International PLC	PLC is oriented towards internalization and emphasizes on relation between stage of production innovation and geographical location of manufacturing facilities. It is defined from the perspective of international trade and economies of scale.
Five element product wave	Five stages of activities through product life cycle: design

	engineering, process engineering, product marketing, production and end of life.
Life cycle assessment (LCA)	LCA concentrates on product life cycle analysis on environmental impacts concerning products and services. The main idea is that companies should take into consideration environmental aspects of their products and services from the beginning till the end of their life cycles, which could, for example, consist of raw materials used in products, production and distribution, use, recycling or re-use and disposal.
Life cycle cost (LCC)	LCC perspective on product life cycle focuses on various costs that occur not just in the beginning of product life cycle but also in all later stages. The main target is to define cost elements not just from supplier but from the customer point of view as well.

Saaksvuori and Immonen (2005) state that PLM is based on product life cycle model, which represents different views of the product structure depending on the stage of life cycle. They define such stages: definition, design, sales, manufacturing and service.

However, as the analysis in this thesis will concentrate on the perspective of LCC and after-sales life cycle stages, the most suitable life cycle model could be divided into three main phases, which are: beginning of life (BOL), middle of life (MOL) and end of life (EOL). S. Terzi et al. (2010) presents a structural life cycle model, which you can see in figure 1. This type of life cycle structure is most suitable for the analysis in this thesis.

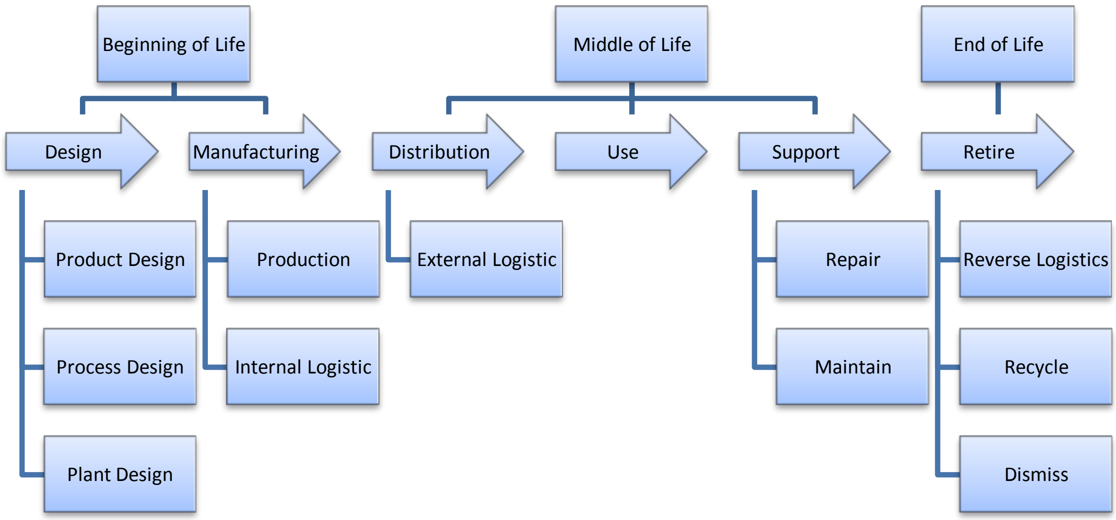


Figure 1. Product life cycle structure (adapted from S.Terzi et al. 2010, 365)

- Beginning of life (BOL) includes design and manufacturing. Main target is to conceptualize and physically realize the product.
- Middle of life (MOL) includes distribution, use and support services. Phase, where product is delivered and used by the final costumer. Support services and field data becomes an essential part.
- End of life (EOL). The stage starts when product does not anymore satisfy users and reverse logistics is implemented in order to recycle, re-use or dispose the product. (S. Terzi et al. 2010, 364)

2.2 Concepts of PLM and PDM

The concept of PLM just like PLC can been seen from many different perspectives and it is defined in different ways by researches and companies. According to Saaksvuori and Immonen (2005), who analyze the concept robustly from ICT perspective, product data management (PDM) can be seen as a subset of PLM and is needed to be integrated in order to have the right information at the right time and place. While PDM could be the system that allows companies to capture and manage product related data, PLM gains much wider and strategic meaning in business environment. Authors also define PDM as a systematic method to manage and develop industrially manufactured product and state that the term PDM could be seen as a predecessor of PLM.

According to J. Stark (2005, 16): "PLM is a holistic business activity addressing many components such as products, organizational structure, working methods, processes, people, information structures and information systems". "CIMdata" defines PLM as a strategic business approach that supports collaborative creation, management and use of product definition information supporting extended enterprise and integrating processes, people, business systems and information through the whole life cycle of the products.

S. Terzi et al. (2010) summarizes different approaches and defines PLM as a product centric ICT supported and life cycle-orientated business model, in which data is shared between different actors and processes in the different phases of the product life cycle in order to achieve required performance and sustainability for the product and related services. Moreover, they define methodologies, ICT and processes as three fundamental parts of PLM, which can be seen in figure 2.

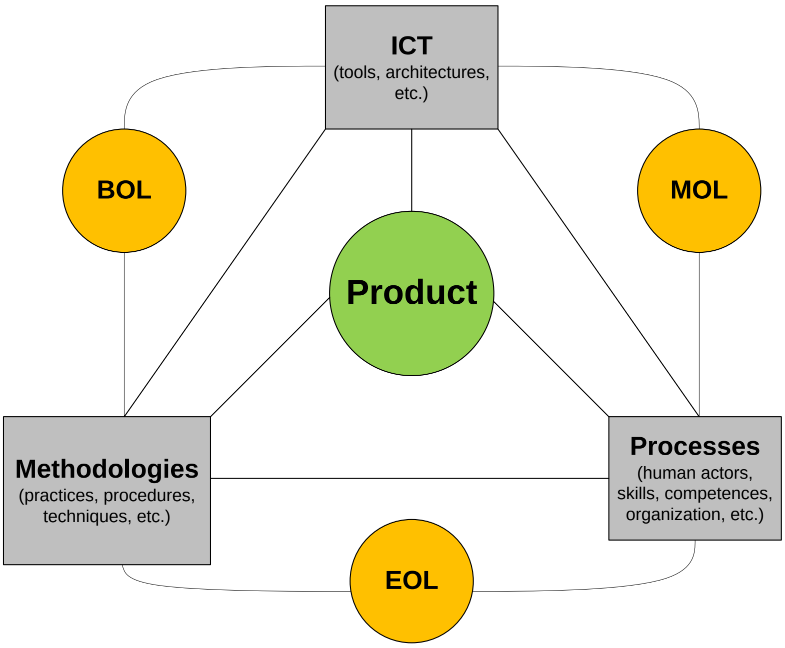


Figure 2. Elements of PLM (adapted from S.Terzi et al. 2010, 367)

PLM concept will be more analyzed in following sections, which describe PLM's role today and in the future.

2.3 PLM role today

Product lifecycle management is becoming an essential part and significant tool for many organizations worldwide. Especially in manufacturing industries, where increasing competition is pushing enterprises into closer collaboration and information sharing with partners, customers and even competitors in different stages of product life cycle. Dramatically increasing amount of dispersed product data and knowledge creates even more market challenges. This requires certain management practices and tools for successful capture, utilization and re-use of internal and external product related information and knowledge. Moreover, these trends often require technological and organizational changes, which are enabling strong service orientation and full range solutions for the customer. Nevertheless, product life cycle management should be viewed not just from provider, but from the customer point of view as well. While manufacturer's goal is to optimize the revenues and profits through the whole life cycle of the product, customers often want to know total costs and value of ownership and use of the product till the end of its lifetime. (V. Ohri, 2006; W.M. Cheung et al. 2011; R. Fornasiero, A. Zangiacomi 2009).

The concept of PLM is being researched and used in expanding manner constantly. Companies are using PLM to increase efficiency and consistency through whole life cycle of the product. Product related information, data and knowledge management and sharing could be pointed as basis of PLM (M.G. Marchetta et al. 2011, S. Terzi et al. 2010). According to J. Stark (2005) PLM concept brings together products, services, structures, activities, processes, people, skills, ICT applications, practices, data, knowledge, procedures, standards, techniques and other activities as well as resources. In figure 3 you can see the extended value chain of the enterprise, which shows the current challenge for the companies to unite and utilize different actors, processes and information through life cycle of the products.

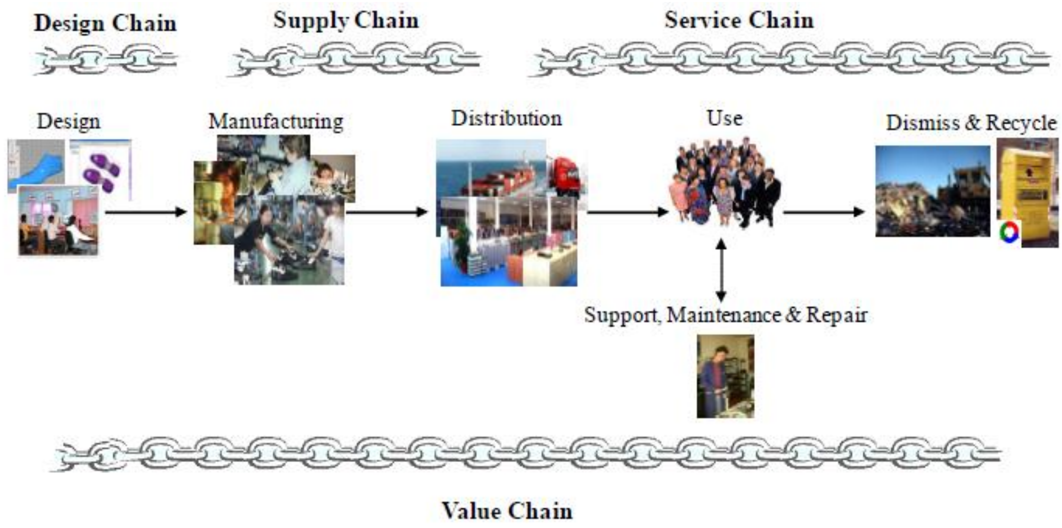


Figure 3. Extended value chain of 21st century organization (S. Terzi et al. 2010, 363)

S. Terzi et al. (2010) analyze current PLM perspective and utilization in different life cycle stages of the product, which as mentioned earlier are divided in three main categories: beginning of life, middle of life and end of life. In the BOL phase PLM usually serves as a design support system, which helps to create, capture, manage and distribute various product design data at the right time and context. PLM concept is often formed from various ICT systems (CPD, SCM, ERM, etc.) and is referred as a “system of systems”. However, widely excepted commercial PLM tool that would satisfy all different users and extensively cover and support all stages of BOL is not yet established and probably will not be in the near future. During MOL and EOL phases PLM acts as a service support system, where data is extensively gathered from field and used for managing and improving product performance as well as enhancing support services. However, authors also claim that information sharing is still very limited after product is delivered to the customer.

Extensive networking requires information base that could be used by different actors in different life cycle stages in order to maintain overall operational efficiency. For that reason PLM supports the management of product design, manufacturing, service knowledge creation as well as sales, customer services, product disposal and other activities. (E. Subrahmanian et al. 2005)

2.4 Future PLM trends

Product lifecycle management will be utilized much more extensively in the future and support growing number of enterprise activities. Moreover, increasing service focus will shift PLM to have much stronger customer orientation. In figure 4 it is showed how the value creation is increasing dramatically and shifting towards design and later stages of product life cycle. Environmental issues, risk management, life cycle cost and service quality will play much more important role in future as well. Emergence of product-service systems creates new challenges and requirements for PLM based business approaches.

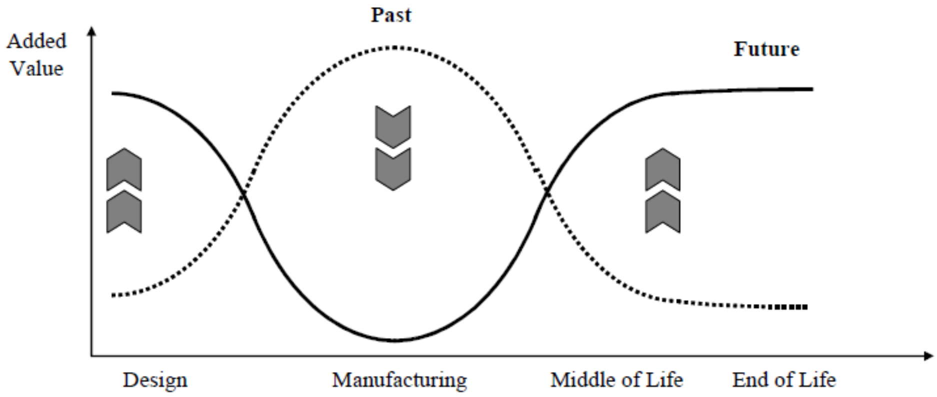


Figure 4. Changing perspectives in the company value creation (S. Terzi et al. 2010, 383)

S. Terzi et al. (2010) emphasizes on the importance of closing the information gaps, which are most commonly created between BOL and MOL-EOL phases. This creates many problems that are triggered form lack of data, feedback and knowledge, which negatively effects support service quality and supplier-customer relationship.

According to D. Kiritsis et al. (2008) closing such information loops will provide complete data to producers about modes of use and retirement as well as disposal condition of the products. Moreover, it will help service, maintenance and recycling experts to have up-to-date data about the product condition and real time-assistance as well as provide other valuable information and knowledge to designers and recyclers/re-users of the products.

Technology and software will also definitely play very important role in closed-loop life cycle management and real-time data sharing, such as radio frequency identification (RFID), product embedded information devises (PEID), internet-of-things (IoT) technologies and other. In general S. Terzi et al. (2010) summarizes that PLM is expected to strongly influence value creation in the society through various areas:

- Technical. Covering user's needs (formulated and latent) by providing optimal functionality products and utilizing life cycle field data.
- Economical. Value creation for producer, service provider and user.
- Social. Providing such features as safety, comfort, security and satisfaction.
- Environmental. Minimizing negative environmental impact by applying optimal life cycle planning.

2.5 Benefits of PLM

Manufacturing industry is constantly changing and evolving into more complex structures and business models. Globalization, increased product complexity, environmental regulations and large amounts of data, information and knowledge are requiring new management tools and approaches. Companies worldwide are acknowledging PLM as a robust supporting strategic tool, which create wide range of benefits for the producers as well as end-users.

Saaksvuori and Immonen (2005) define PLM benefits, which can be summarized as: time savings, improvement in quality and reduction of tied-up capital. S. Terzi et al. (2010) states that PLM is able to develop less resource demanding society and more competitive industry with:

- Improved product traceability
- Expanded knowledge-based services integrated into products
- Improvement in material recycling by effective knowledge integration
- Improved knowledge-intensive optimal use of resources.

In general, according to D. Kiritsis et al. (2008) the most important PLM feature is that it allows company to control and maximize the value of its products and product portfolios through their life cycle. Moreover, it helps to reduce product-related costs and improve product development process. Four main beneficial areas can be determined:

- Financial performance- reduced product-related costs and increased revenues.
- Time reduction – reduced project times, engineering change times, etc.
- Quality improvement – reduced defects, product returns, customer complaints, etc.
- Business improvement – increased innovation, expanded product-service portfolio, increased product traceability, etc.

2.6 Customer orientation

One of the targets of analysis in this thesis is after-sales support services or middle of life phase of a product. In that case it is important to take a closer look how PLM at present and future shifts towards stronger customer orientation and expansion of middle of life stage. These topics will be analyzed more extensively in later chapters of the thesis as well.

Manufacturing industry is changing into more service-oriented businesses, where the tangible product itself is becoming just a part of the whole offering. Life cycle strategic perspective provides companies with opportunities to have innovative solutions and dramatically expand their lifetime care services, which have high potential in possible revenues. Customers are no longer requiring just simple provision of products and e.g. spare parts, but much wider range of supportive services, such as training, maintenance, audit, commissioning, rebuild, recycle etc. In general, customer role in the whole life cycle of the product, from “cradle to grave”, is becoming more important and essential for manufacturers worldwide. Attention and support from manufacturers in EOL phases is increasing as well due to many international regulations. In conclusion, support services are shifting middle and end of product life cycle stages to become essential for producers and users.

V. Ohri (2006) defines new concept “Customer Oriented – Product Life cycle Management (CO-PLM)”, which refers that PLM cannot be longer seen only as ICT tool that supports design and manufacturing of the products. Instead, PLM concept should be extensively spread through whole product life cycle and manufacturers should analyze customer's value chains and product-related activities in order to provide best solutions and gain competitive advantage. In that case PLM system has to manage information from the customer standpoint related to after-sales support and brand. In table 2 you can see how V. Ohri (2006) envisions enhancements in CO-PLM in comparison to traditional PLM.

Table 2. Comparison of traditional and customer oriented PLM (adapted from V. Ohri 2006)

Life cycle phase	Traditional PLM	Enhancements in customer oriented PLM
Requirement specification	Requirement management Technical specifications Regulations Quality needs	Discovering latent needs of customer Competitive Product intelligence Environmental and safety concerns Brand & target segment specific information Industry / emerging standards
Engineering	Digital product definition and validation - CAD/CAE/CAM Lean Manufacturing support	Augmented Product definition Feature and function prioritization for new product Product – Brand alignment
Manufacturing	Project and Program management Bill of Material Bill of Process Visualization	Product platform management Integrated PLM for component products Flexibility management – Ability to communicate /change configuration late as actual assembly
Launch and sale	Maintaining As-Built BOM Visualization Product configurator for sales team	Linking sales and product configurator Enriching pre-sales experience, product configurator and virtual reality support Product specifications Managing sub-brands to enable cross selling of products related to brand
After-sales support	Visualization	After-sales product support Customer As-Maintained BOM On-line service manuals Services on consumables New product information Customer feedback results Performance monitoring Product operator behavior
Product decision		Product prioritization and platform planning Product line comparison & evaluation

3 LIFE CYCLE COSTING

In one of the main chapters of the thesis, life cycle costing (LCC) will be analyzed in order to develop profound theoretical basis for building and analyzing cost model of Normet products. More detailed look will be taken into life cycle cost definitions and related concepts. Having in mind that the generic cost model will take a shape mainly as a cost breakdown structure (CBS), various CBS models and development techniques will be reviewed as well. Moreover, it is important to overview various cost estimation approaches and IT tools support, even if it is not in the center of analysis in this thesis. Life cycle costing analysis will be viewed from both: supplier and customer perspectives with a particular interest in after-sales phases cost modeling. However, the overview of cost structure from the customer point of view, which can be defined as Total Cost of Ownership (TCO), will be presented in more detail in the next chapter of the thesis.

3.1 LCC related concepts

Life cycle costing is gaining more attention from companies worldwide as a result of expanding product-service portfolios and growing emphasis on product lifecycle management itself. Life cycle costing or whole-life costing techniques are already used extensively in construction industry. However, other industries are still trying to adapt, optimize and utilize similar costing practices. There are many concepts used in practice and literature that generally describe similar features, such as: life cycle costing or life cycle cost (LCC), life cycle cost analysis (LCCA), whole-life costing (WLC), total cost of ownership (TCO) or total ownership cost (TOC) and other. In this sub-chapter short overview of the definitions and similarities behind these concepts will be presented.

In figure 5 you can see the graphical presentation of LCC, WLC and TOC definitions presented in NATO Research and Technology Organization technical report (2003) about cost structure and life cycle costs for military systems. The life cycle costs are described mainly from the user point of view and procurement processes. Life cycle costs of a system are defined as all costs made by the owner in order to acquire, exploit and dispose the system.

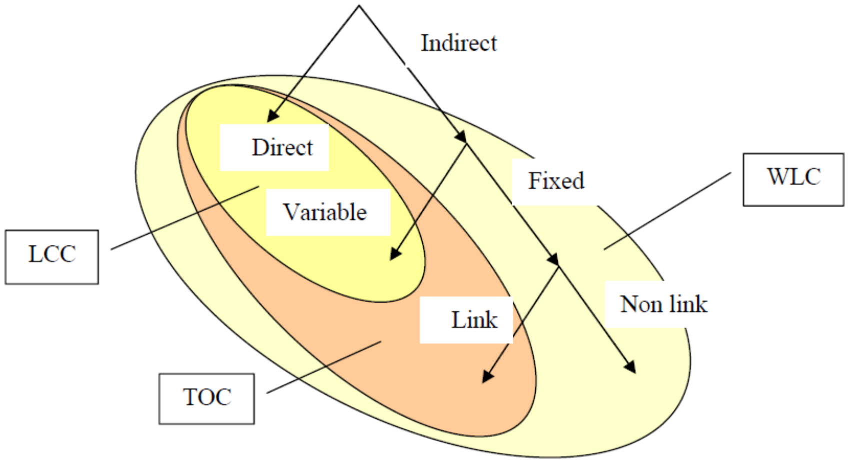


Figure 5. Graphical presentation of LCC, TOC and WLC (RTO technical report TR-058, 2003, 11-1)

From the figure 5 it is visible that LCC consists of all direct costs plus indirect-variable costs occurred within procurement, operation & support and disposal of the system. Indirect linked costs can be such as additional administrative personnel or additional support equipment, while non-linked will be the costs, which cannot be easily associated with system, such as new recruiters to recruit additional personnel. In this LCC definition all indirect costs that are not affected by introduction of new system are not taken into consideration.

TOC consists of all LCC elements plus indirect-fixed-linked-costs, which can be such as common facilities, common support equipment, personnel required for administration, supervision, operations planning, etc. In general it includes all costs associated with the ownership of the products, except non-linked fixed costs, which are connected to the running of the organization.

Whole Life Costing (WLC) has all TOC elements plus indirect-fixed-non-linked costs, which can be such as medical services, basic training, headquarters and staff, etc. All expenses that are made by organization are attributed to the products it produces and included in WLC.

Further, closer look to LCC and other related concepts will be presented.

3.1.1 Life cycle cost emergence and definition

Life cycle cost includes R&D, installation and operation through the whole system life. The concept of life cycle cost was first utilized by US Department of Defense in 1960s, which used it for evaluation of new weapons systems. It was also noted that operation and support costs for weapon system could account for 75% or more of the total cost over the life span. Other industries also applied this concept, which was first developed mainly for procurement purposes, however, complex systems are difficult to track trough the whole life span and some cost elements might not be easily indentified. (N. U. Ahmed, 1995; Y. Asiedu, P.Gu 1998, 884)

In the period of 1970s and beginning of 1980s LCC was mainly applied in military systems and later spread to other industries, such as electrical power plants, aircraft, oil and chemical and railways. In the power, oil and chemical industries LCC is more linked to reliability-availability-maintainability (RAM) analysis, where production regularity is essential concern. (Y. Kawauchi M. Rausand 1999, 5-7)

Fabrycky and Blanchard (1991, 122) states that the emphasis on life cycle costs was influenced primarily by a combination of inflation and cost growth factors, which were formulated by such factors as poor quality of products in use, engineering changes during design and development, unforeseen events and problems, estimating and forecasting inaccuracies and other.

Total system cost invisibility is also identified as one of the main economic problems (figure 6) that creates an “iceberg effect”, where all the costs of ownership are not visible for organization. Furthermore, problems can be associated with faulty accounting procedures, inflexible budgeting practices, incorrect application of individual cost factors, etc.

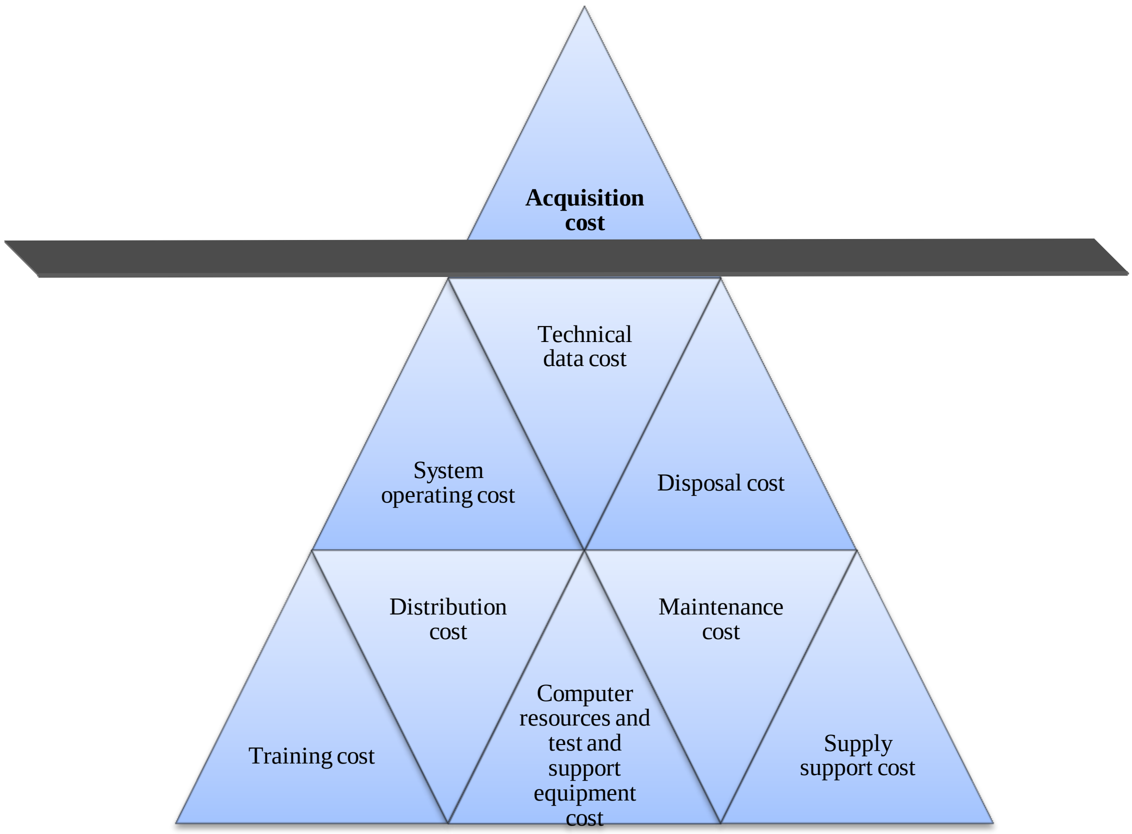


Figure 6. Total cost visibility (adapted from Fabrycky and Blanchard 1991, 124)

Moreover, it can be said that LCC, together with other factors, is very important for successful launch of the product and helps to design more cost-efficient products and services. Nevertheless, wrong estimation of LCC may lead to financial loss of the company. (H. Liu et al. 2008)

Life cycle cost is determined by identification of applicable functions in each phase of life cycle, costing of these functions, applying the function-specific costs and accumulating them over the entire life cycle. Moreover, not just producers but customers costs should be included as well. (Fabrycky and Blanchard 1991, 124)

According to Graham Mott (1997, 116-117), who defines LCC from investment perspective, life cycle costing aims to optimize cost of physical assets over their whole life cycle and represents the whole costs of ownership of an asset. It is also mentioned that life cycle costs can be very important for the customer and serve as a main criteria for choosing between different assets or investment options. It is important, that companies would put costs, such as acquisition, operating, maintenance and disposal in one set and would not look at them as separate units.

SAE International LCC definition is presented in VIVACE project (2004), which unites aerospace engine manufactures: “LCC is the sum total of the direct, indirect, recurring, non-recurring, and other related costs expended, or estimated to be expended in the design, research and development (R&D), investment, operation, maintenance, and support of a product over its life cycle, i.e., anticipated useful life span. It is the total cost of the R&D, investment, operating & support and, where applicable, disposal phases of the life cycle. All relevant costs should be included regardless of funding source or management control. LCC is defined as the sum of all monies expended, attributed directly and indirectly to a defined system from its inception to its dissolution: encompassing the acquisition, ownership and disposal phases of a program.”

In general it can be said that life cycle cost is the sum of all costs that can be associated with each stage of product life cycle, such as cost of failure, cost of maintenance, cost of components, etc. In other words LCC can be used as a management tool that comprises all the product related costs from the inception to disposal or so called “from cradle to grave”. Moreover, LCC should be viewed from manufacturer, customer, and sometimes even society point of view.

3.1.2 Life cycle cost analysis

In general life cycle cost analysis (LCCA) can be defined as a technique, which utilizes life cycle cost in order to evaluate different investment alternatives or introduce cost effective improvements. LCC analysis develops a framework for specifying the total incremental costs for developing, producing, using and retiring the particular product. The US Department of Defense used the analysis to increase effectiveness of government procurement and was mainly concentrated on design-to-cost targets and competitive source selection. (Y. Asiedu, P. Gu 1998)

Nowadays, LCCA can be described as a process that aims to evaluate the total economic cost of an asset by analyzing initial and discounted future expenditures, such as maintenance, repair and renewal as well as producer, user and social costs over the life of the asset. (S. Rahman, D. J, Vanier, 2004, 1-2)

Fabrycky and Blanchard (1991) define life cycle cost analysis (LCCA) as an application of life cycle costing methods in system design and development stages. It can be described as systematic analytical process to evaluate various designs or courses of action, which aims to define the best way to utilize scarce resources. There can be one clearly defined goal of analysis (e.g. design to minimum life cycle cost) or a number of sub-goals, which address the issue of the analysis. Very important step of analysis is setting the proper boundaries or limitations, which can be technical characteristics of the product, operational requirements, maintenance concept, etc.

In LCC manual prepared for the U.S. Federal Energy Management Program (1996) the life cycle cost analysis is defined as an economic method for project evaluation, which is based on all costs occurring through the life cycle from owning, operating, maintaining and disposing. It is mentioned that LCCA is very useful especially in evaluating different building designs in order to achieve satisfying building performance. Nevertheless, LCCA can be applied to many capital investment decisions, because it provides much profound long-term cost information than other economic methods.

In the construction sector, ISO standard 15686, defines it as “tool and technique which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial capital costs and future operational and asset replacement costs, through to end of life, or end of interest in the asset – also taking into account any other non construction costs and income.” (Davis Langdon Management Consulting 2007, 2)

In summary, LCCA can be defined as term that unites many kinds of analysis, such as reliability-availability-maintainability (RAM), risk, economic and other. It helps organizations to monitor and analyze the costs that occur through creation, operation and disposal of the products. The main objective of LCCA includes the calculation of predicted life cycle cost of the products, which can be used for purchasing decision making, maintenance scheduling, design optimization, revamp planning, cost reductions during operation and maintenance, etc. Moreover, the important part of the analyses is that all relevant costs should be discounted to their equivalent present value. LCCA applications and purposes are discussed more in the separate sub-chapter. (Y. Kawauchi

M. Rausand 1999; K. Oeveren, M. Wilks 2009; E. Korpi, T. Ala-Risku 2008; D. Singh, R. L.K. Tiong 2005)

3.1.3 Whole life costing

Whole life costing (WLC) is very commonly used as a synonym for LCC in various publications and costing manuals. From the overview of many different academic articles it can be seen that whole life cycle costing concept is applied particularly in construction industry related publications, instructions and manuals, such as ISO 15686-5. Despite the fact that WLC is sometimes distinguished from LCC in such industries as construction or, as presented earlier, military systems, other academics and practitioners do not present clear boundaries and differences between these concepts.

In the final report for life cycle costs in construction prepared for European Commission (2003) by an expert group it is stated that LCC is a term, which describes the same process as whole life costing (WLC). Moreover, WLC is more commonly used in United Kingdom and particularly applied to describe life cycle of a building and material. **(**LCC in Construction 2003)

As an example, M.A. El-Haram, S. Marenjak and M.W. Horner (2002) describe WLC as a technique for examining and determining all direct and indirect costs of designing, building and facility management (operating, maintenance, support and replacement) of a building through its entire service life. It also defines WLC as economic and engineering evaluation tool for evaluating different design options by comparing life cycle costs in equivalent economic terms. Moreover, it aims to evaluate and optimize life cycle costs of a building while satisfying client and specification requirements.

3.1.4 Total Cost of Ownership

Total cost of ownership (TCO) usually describes the life cycle costs from the customer or user point of view. This concept comprises all product related costs that occur for the user of the product through its life cycle, such as acquisition, operational and disposal costs.

Having in mind that the target of analysis in this thesis is mainly after-sales costs that occur for supplier and user as well, total cost of ownership (TCO) is very important aspect and will be a major part of the generic cost breakdown structure. Moreover, this thesis aims to propose cost effective solutions by analyzing LCC model and the customer perspective is essential. For these reasons TCO and cost elements will be analyzed in more detail in the separate chapter.

3.2 Life cycle stages and costs

Different costs occur in different stages of product life cycle. It is very essential that organization is able to define all the cost elements, which can occur from the idea generation to the disposal or re-use of the products. Many cost elements can be hidden and not easily allocated. Moreover, while defining cost composition, it is important to consider not just producers', but customers' point of view as well. Moreover, when producer has cost knowledge from the costumer point of view, it can successfully introduce cost-effective services and solutions.

Many cost elements can be defined trough the product life cycle from different perspectives. More detailed analysis of life cycle cost elements will be presented in the section about cost breakdown structure (CBS). However, couple of models that show different costs in connection with different life cycle stages can be described. Life cycle costs are often viewed and analyzed from the single perspective of supplier, as it is visible in table 3:

Table 3. Life cycle stages and costs (adapted from H. Liu et al. 2008, 99)

Life cycle stages	Cost elements
Design stage	Specification cost Engineering design cost Drawing cost Computer processing cost Design modification cost Production preparation cost Management cost
Production stage	Material cost Facility cost Manufacturing cost

Marketing and after-sale stage	Marketing cost Distribution cost Maintenance costs Downtime costs
Disposal and recycling stage	Retrieval cost Disassembly cost Reprocessing cost landfill cost

However, many academic researches and practitioners recognize the importance of several perspectives while analyzing life cycle costs of the product: supplier, user and even society. Users and purchases are the ones that in fact have to pay the total cost of the product eventually. Consequently, total cost will have big impact on the marketability of the product. Moreover, society bears certain costs from the pollution, health issues, resource exploitation and other. In table 4 life cycle costs from different perspectives are presented:

Table 4. Life cycle costs (Adapted from Y. Asiedu, P. Gu 1998; H.S.C. Perera et al. 1999)

Life cycle stage	**Manufacturer**	**User**	**Society**
Design	Market recognition Product development		
Production	Materials Labour Energy Processing Facilities		Waste Health damages Pollution
Distribution	Transport Inventory Packaging Damages	Transport Packaging Damages	Packaging
Use	Storage Waste Warranty Service Breakage	Storage Energy Maintenance Breakdown Materials	Waste Health damages Pollution
Disposal/Recycling	Recycling/Disposal	Disposal/ Recycling dues	Waste Disposal Health damages Pollution

In the figure 7 the committed costs and actual expenditures as well as uncertainty in cost prediction are presented. Many researchers agree that first steps of the product development are essential as many costs, such as operational and disposal, are locked in already in the design stage. For that reason, LCC analyses performed in the early stages of product life cycle can significantly reduce the overall costs of the product. It is widely suggested that often around up to 80% percent of the overall life cycle costs are determined by decisions that are made in the first 20% of the project life. Nevertheless, the uncertainty of LCC prediction is also much higher in the first stages of the project, as showed in figure 7. Producers have to choose the most optimal time for LCC analysis in order to gain best results.

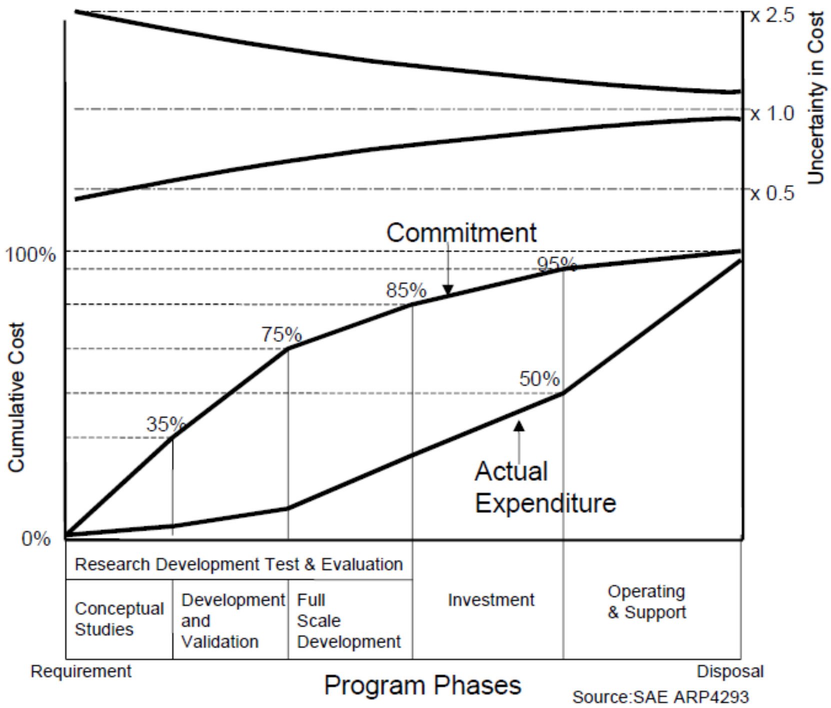


Figure 7. Life cycle stages and committed costs (Y. Kawauchi M. Rausand 1999, 9)

3.3 LCC applications, purposes and benefits

Wide range of different applications and goals of LCC practices can be established. Such targets often differ depending on the perspective, industry, product and other factors. However, as it was mentioned before, it is very important to evaluate required recourses and establish clear limitations and scope of the LCC analysis in order to reach required targets.

3.3.1 LCC applications and purposes

In table 5 you can see summarized LCC applications and purposes from different academic sources:

Table 5. LCC applications and purposes

LCC applications and purposes	
Mott (1997)	Pricing – It helps to set more appropriate selling price and provide expected return by taking into account direct costs and a share of indirect costs. Purchase decisions – LCC can provide more accurate cost information, than e.g. just looking at acquisition cost, needed to make purchasing decision. Manufacturers' designs – Knowledge of user's life cycle costs can be utilized in design phase in order to introduce cost-effective modifications. User modifications – Monitoring the actual life cycle costs in comparison to predicted life cycle costs can point to more effective modifications in service, like design out higher-than-expected maintenance costs or the costs of downtime. Replacement decisions – Keeping track of life cycle costs of number of identical physical assets can provide valuable and reliable information for replacement of assets decisions.
Y. Kawauchi M. Rausand (1999)	Evaluation and comparison of alternative designs; Analyzing economic viability of projects/products; Identification of cost drivers and cost effective improvements; Evaluation and comparison of different product use, operation, test, maintenance, etc. strategies; Evaluation and comparison of different practices for replacement, upgrade, rebuild or disposal of products; Optimization of available funds for product development/improvement processes; Long term financial planning; Assessment of product assurance criteria.
H.P. Barringer D.P. Weber (1996)	Affordability studies – measure the project's or system's LCC impact on budgets and operating results. Source selection studies – compare estimated LCC between competing suppliers. Design trade-offs – influencing design features of equipment and plants that have direct impact to LCC. Repair level analysis – analyze maintenance demands and costs. Warranty and repair – suppliers and end users should have knowledge about the cost of failures in equipment selection and use. Supplier's sales strategies – can define LCC from specific equipment grades, operating experience and failure rates. Such information can be used as a sales strategy for best lifetime benefits and not just low initial purchase cost.

3.3.2 Benefits of LCC

Life cycle costing benefits can be easily identified by viewing previously stated goals and purposes. It is important for many companies to utilize LCC because simply it helps to provide the best value products and services with optimized costs. It helps to improve such processes as engineering, purchasing, project engineering, process engineering, maintenance, reliability engineering, costing, procurement, design and other. (H.P. Barringer and D.P. Weber 1996)

Moreover, it can provide more comprehensive cost knowledge to suppliers and users as it includes costs that occur during all stages of product life. This can be essential, as for instance, operating costs of a hospital consumes the equivalent of the capital costs every two-three years. Furthermore, it often helps to define the cost elements that have the major impact on total life cycle cost. (Life cycle costing guideline 2004; E. Korpi, T. Ala-Risku 2008)

In addition to already mentioned advantages, few other ones can me defined:

- Provide reasoning for “spend to save” decisions;
- Provide basis for comparison and evaluation of alternative systems/products/projects;
- Provides more solid information base for decision making;
- Evaluate different points of reliability and maintainability in order to enable potential trade-offs;
- Provides more effective monitoring of program processes;
- Improved forecasting processes;
- Can provide basis for competitive advantage;
- Increase the awareness of total costs;
- Helps to indentify most import cost drivers and introduce cost effective improvements.

  (DiscFlo 1998)

3.4 Life cycle cost estimation approaches

Despite that life cycle cost estimation does not fit into the scope of this thesis, it is important to describe main cost assessment approaches in order to provide the basis for further development of generic LCC model. Moreover, cost data collection and estimation are very important steps in the LCC modeling process.

Many different classifications of cost estimating techniques can be found in various literature sources. For instance, Terrence J. Sidey (1992) in his thesis names such approaches as: catalog method, specialist method (expert judgment), man-loading method, parametric, analogy, engineering/bottom up and hybrid methods. Fabrycky and Blanchard (1991) define three different cost estimating approaches: 1) estimation by engineering procedures 2) estimating by analogy and 3) parametric estimating. While Y. Asiedu and P. Gu (1998) divide cost estimating models in such three categories: 1) parametric 2) analogous 3) detailed. Some academic articles (P.P. Datta, R. Roy 2010; H. Liu et al. 2008) summarize various estimation approaches into categories as showed in figure 8.

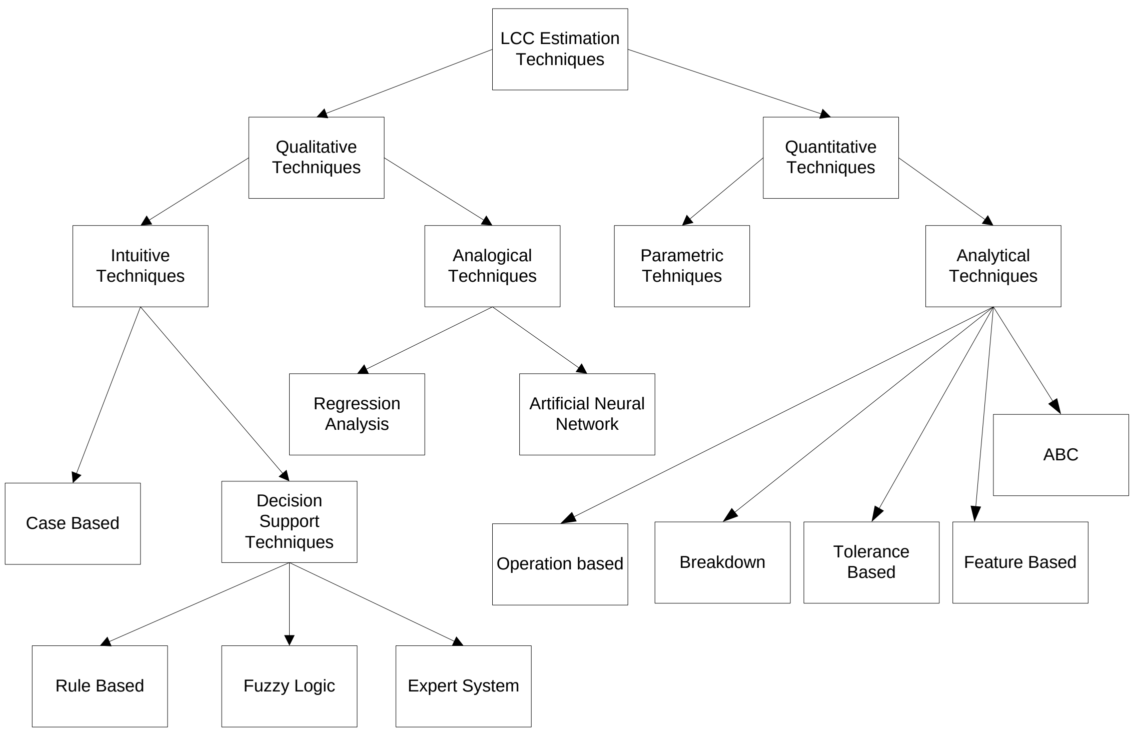


Figure 8. LCC estimation techniques (H. Liu et al. 2008, 100)

Qualitative techniques are mainly used in the early life cycle stages, such as design and are utilized as a decision support tool for designers and developers. Such techniques can be further divided into:

- Intuitive – estimations are mainly based on experience and expert opinions;
- Analogical – estimations are based on the definition and the calculated cost of the similar product.
  (P.P. Datta, R. Roy 2010; H. Liu et al. 2008)

Quantitative approaches provide more accurate results and are needed for estimation of profit margins. However, the utilization of such techniques is possible just in later stages of design or development as it requires wider range of data. These techniques are usually classified into:

- Parametric – estimations are based on analytical function of a unit of different product parameters. It can also be called top-down approaches.
- Analytical – estimations are based on detailed analysis of elementary tasks in manufacturing process. These techniques can be also called the bottom up approaches as they aim to collect data from the smallest component levels and add to the total product level. Activity-based costing (ABC) can be named as one of the example of this technique.
  (P.P. Datta, R. Roy 2010; H. Liu et al. 2008)

All mentioned techniques have some common disadvantages, such as lack of overall applicability and lack in accuracy. In table 6, you can see the comparison of mostly used product cost estimation approaches. In addition to already mentioned techniques, there can be defined some that are not widely adapted and relatively new, such as multiple regression, neural networks, fuzzy logic and feature-based costing. Most of these methods can be very effective in the high uncertainty early stages of product development. However, especially neural networks and fuzzy logic approaches are highly sophisticated and is not widely applied in practice. (Y. Asiedu, P. Gu 1998; P.P. Datta, R. Roy 2010, L. B. Newnes et al. 2008)

Table 6. Comparison of different cost estimation techniques (adapted from P.P. Datta, R. Roy 2010, 146)

Cost estimation approach	Strong sides	Limitations
Parametric	Rapid; Repeatable and objective; Less information required; Suitable for budget estimates and baseline assessments;	Some parameters that are not included can become important; Most useful in mixture with other methods; Cost estimation relationships (CER) are too simplistic ; Uncertainties are high as CER are not specific enough;
Analogy	Fast and based on actual data ; Requires few data; Origin of the estimate is known for the user; Full understanding of problem is not needed; Accurate if there is minor difference from analogous case; Good for rough estimates in lack of adequate data;	Might be subjective adjustments; Accuracy depends on similarity of items; Difficult to assess effect of design change; Cost drivers are not indentified; More challenging than parametric method; Not suitable for innovative solutions;
Analytical	More accurate than analogy and parametric methods; Detailed breakdown useful for negotiation; Suitable when all characteristics of product and production process are well known;	Slow execution; Detailed data is required; Not suitable at design stage; Inaccurate allocation of overheads;
Activity-based costing	Allocates costs accurately to where they are incurred ; Improved accuracy and relevance ; Details the causes of costs and points out potential profitability;	Time consuming and costly ; Difficult in using as the only costing method; Allocation of overhead is complicated;
Expert judgment	Fast and flexible ; Less time and costs needed; Can be as accurate as other more expensive methods;	Open to bias and error; Not clearly defined process; Nondeterministic as differs depending on the expert;

The mentioned cost estimation techniques are often used in mixed manner and depend on many factors, such as life cycle stage, goals of estimation, scope of analysis, available data, etc. (Korpi, T. Ala-Risku 2008). The suggested techniques in different life cycle stages are presented in figure 9.

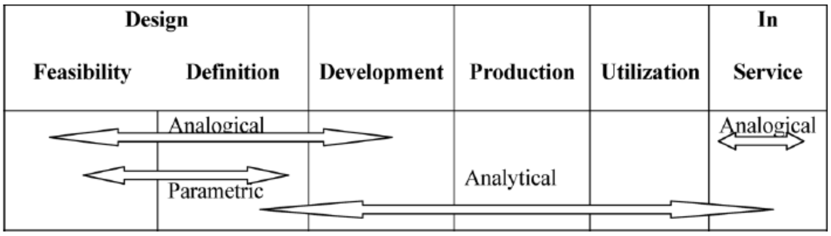


Figure 9. Different cost estimation techniques in different life cycle stages (L. B. Newnes et al. 2008, 104)

3.5 IT support and tools

Companies have already utilized various software tools in LCC prediction, calculation, monitoring and other functions. However, it is observed that extensive widely adapted IT tool is not yet developed and probably will not be in the near future. The main reason for that is the complexity and diversity of different cost structures in connection with detailed product structures. The comprehensive tool would require flexibility in combining complex cost and product structures. (R. Enparantza et al. 2006)

Y. Kawauchi and M. Rausand in the report about “Life cycle cost analysis in oil and chemical process industries” (1999) state that in general there are two main software packages for LCC analysis: effectiveness analysis tools (reliability-availability-maintainability (RAM)) and cost analysis tools, which are presented in figure 10.

RAM tools can be described as the ones that are utilized in order to model a system and predict its performance, such as maintainability or reliability. Such predictions as maintenance frequency or production rate, are crucial for LCC calculations. These software packages are further divided in two types: simulation and analysis tools. Simulation approach can also be categorized as numeric-stochastic and also called Monte Carlo simulation. On the other hand, cost analysis tools are aimed to calculate LCC on already predefined cost breakdown structure (CBS). Such tools add up all costs elements, such as maintenance cost, equipment cost, etc. taking into account the impact of inflation and develop cost profile as well as calculate net present value (NPV).

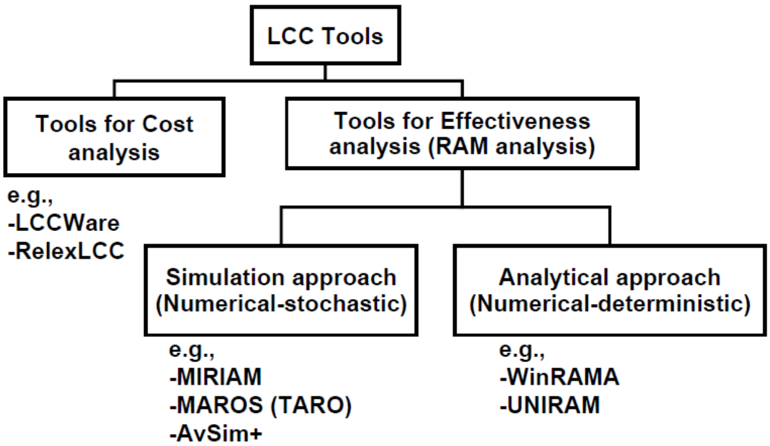


Figure 10. Classification of IT tools for LCC analysis (Y. Kawauchi, M. Rausand 1999, 44)

LCCWare developed by Isograph is aimed to build costing model by defining the cost tree structure. Objects in the bottom level of the tree show the cost functions created with local or global variables. Similarly RelexLCC (current Windchill LCC) enables user to define cost breakdown structure (CBS), net present value (NPV) calculation, inflation factor, sensitivity analysis, etc. (Y. Kawauchi, M. Rausand 1999, R. Enparantza et al. 2006)

L. B. Newnes and others (2008) analyze various software packages, such COSYSMO, Relex LCC, SEER-H, Vanguard Studio and PRICE-H, for low-volume, long-life products. The analysis is made with an emphasis on user requirement fulfillment and defines whether systems focus on certain domains or industries, modeling methods, etc. Main user requirements were identified as ability to use databases, utilize a mix of parametric and bottom-up design, use sensitivity and risk analysis, have domain-specific software packages, utilize whole-life costing for purchase decision making, perform analysis of reliability, etc. Summarized comparison of mentioned software packages based on indentified user requirements is presented in table 7.

Table 7. Comparison of different commercial systems for LCC analysis (adapted from L. B. Newnes et al. 2008, 109)

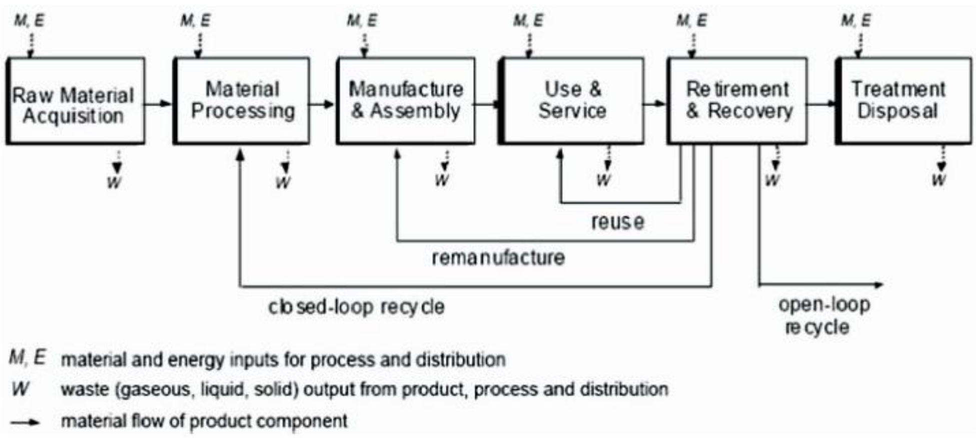
	Software package				
User Requirements:	**SEER-H**	**Relex LCC**	**Vanguard Studio**	**PRICE-H**	**COSYSMO**
Specific domain:					
Aerospace					
Automotive					
Construction					
Defense					
Electrical					
Electronics					
Mechanical					
Naval					
Life cycle coverage:					
Concept					
Development					
Production					
Utilization					
In-service					
Retirement					
Modular modeling and modular libraries					
Parametric model availability					
Detailed modeling					
Mix and match of parametric and detailed models					
Expressive model communication to user					
Statistical analysis:					
Regression					
Learning curve Risk analysis					
Uncertainty					
Sensitivity					
Trade-off					
Monte Carlo					
Knowledge-based support					
Historical database					
Web-based interface					
Open architecture					

3.6 Life cycle assessment and life cycle costing

Nevertheless that life cycle assessment (LCA) is not in the scope of this thesis, it is important to describe life cycle assessment in connection with life cycle costing in order to show increasing involvement of environmental aspects in costing processes. In general life cycle assessment (LCA) is not aimed for life cycle cost analysis, for that reason concept of life cycle cost assessment (LCCA) is often used in order to describe the costing aspects of LCA. (P. Gluch, H. Baumann 2004)

LCA itself is aimed to systematically evaluate environmental impacts of a product or activity across its entire life cycle. Moreover, it is used as an instrument for environmental decision support. Many companies have adapted ISO standard 14040 series, which define LCA guidelines. Such factors like solid wastes, atmospheric emissions, energy and raw material consumption, waterborne emissions and other are mapped over the life cycle of process, product, etc. as it showed in figure 11 and the impact from these factors is evaluated. (J-J. Chanaron 2007)

Figure 11. LCA through product life cycle (J-J. Chanaron 2007, 292, orginal: ISO)



LCA is comprised by three dimensions: life cycle stages, analysis of multiple environmental and resource problems, and assessment of the analysis results, which can result in various changes in the processes of organization. LCA can also be defined as a tool uniting inventory, impact and improvements analysis, which generally aims to reduce the environmental burdens, such as energy, material use and waste emissions. However, LCA concept is often extended in order to include cost factors occurring from environmental burdens. (S.K. Durairaj et al. 2002)

Economics and especially cost assessment possibility in LCA is becoming an essential task as companies need to evaluate different products and projects from the environmental cost point of view and promote sustainability. Moreover, environmentally optimized product designs can be only accepted by wide range of producers if such designs are also cost beneficial. (P. S. Castella et al. 2009)

In the figure 12 you can see the proposed model for LCA-type LCC with an emphasis on sustainability evaluation. It unites typical LCA and LCC procedure into one methodology. Very important step is the establishment of life cycle inventory, which defines all inputs and outputs, such as waste, energy and material flows. The inventory data is used as a basis for following LCC process. (E. M. Schau et al. 2011)

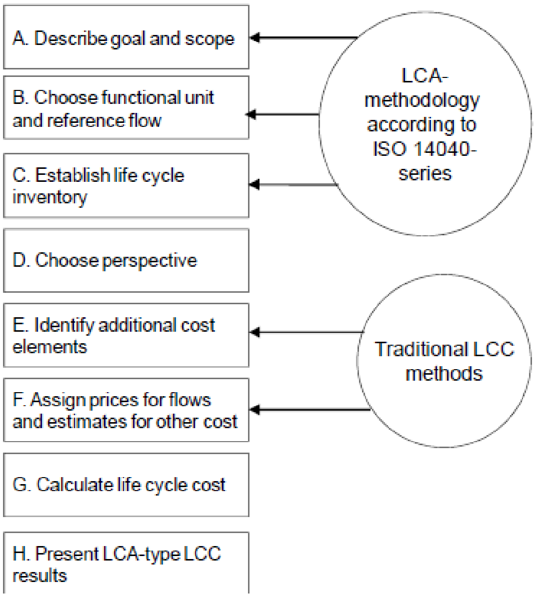


Figure 12. LCA type LCC procedure (E. M. Schau et al. 2011, 2272)

3.7 Life cycle cost modeling

Wide variety of standards, manuals, instructions, reports and academic sources can be found for LCC. However, widely accepted standard that would define LCC modeling process does not yet exist. Various manuals and standards often are sector-specific and proposed by various international organizations. In this part of the thesis the short overview of proposed LCC models and processes will be presented.

3.7.1 International standards and manuals

As it was mentioned, there is large number of LCC standards and manuals issued by various international organizations, governments, military, companies, etc. The comprehensive list of LCC specific and related standards can be found in appendix 1. The short list of main organizations and their standards can be presented as follows:

- Society of Automotive Engineers (SAE) provided standards specifically for LCC, including “SAE-ARP4293: Life cycle cost- techniques and applications” and “SAE M-110 Standard”
- International Electrotechnical Comission (IEC) provide commercial standard for more general use: “IEC-60300-3-3: Life cycle costing”.
- The International Organization for Standardization (ISO) provides some standards, which are sector-specific: “ISO 15663 Petroleum and natural gas industries – Life cycle costing” and “ISO 15686-5 Buildings and constructed assets – service life planning – Life-cycle costing”.
- Verein Deutscher Ingenieure (VDI) provides a standard: “VDI 2884 – Purchase, operating, and maintenance of production equipment using Life Cycle Costing (LCC)”.
- Norsk Sokkels Konkuranseposisjon (NORSOK), which refers to the competitive standing of the Norwegian offshore sector, provide standards that are developed by the Norwegian offshore oil and gas industry: “NORSOK O-CR-001, Life cycle cost for systems and equipment” and “NORSOK O-CR-002, Life cycle cost for production facility”
- The Australian and New Zealand standard “AS/NZS 4536 Life Cycle Costing - An application Guide” can be named as an example of governmental LCC standards.
- Construction industry has many manuals and standards, including the ones provided by American Society for Testing Materials “ASTM”, which provides a standard “E 917-02 Standard Practice for measuring Life-Cycle Costs of Buildings and Building Systems”.

- Military organizations have various LCC manuals, including the technical reports, such as "TR-058 - Cost Structure and Life Cycle Costs for Military Systems" prepared by NATO Research and Technology Organization.

3.7.2 General LCC process and models

The variety of different life cycle cost analysis processes is as wide as for LCC related standards. It depends on many factors, such as: sector/industry, analysis goals, required data, etc. However, having in mind the large number of available LCC processes and models, the selected ones that are most applicable to this thesis will be shortly reviewed and summarized into one general LCC process. The LCCA, which aims to compare different building design alternatives, could, for example, follow such process (Federal Highway Administration 2002):

1. Establish design alternatives
2. Determine activity timing
3. Estimate costs (agency and user)
4. Compute life-cycle costs
5. Analyze the results

Considering the high complexity of the systems and products that LCCA has to be applied, N. U. Ahmed (1995) suggests that it is essential to achieve cost goals by proper planning and management activities, which are directed towards design-to-cost philosophy. In figure 13 you can see the suggested planning framework, which can help to utilize successful life cycle costing practices. The life cycle of the product is divided into two main phases: acquisition and operation, which have certain management tasks. (N. U. Ahmed, 1995)

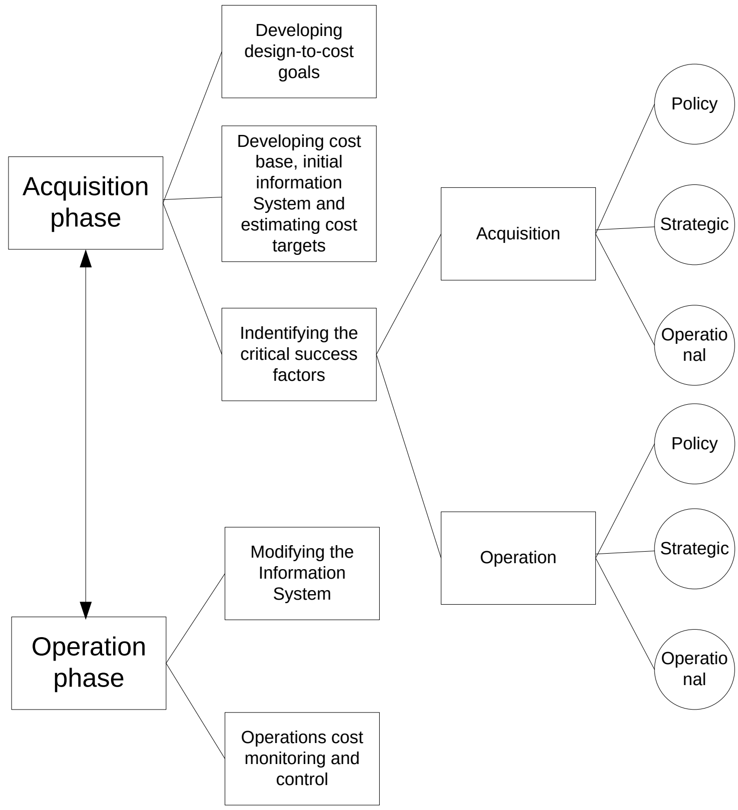


Figure 13. Design-to-Cost planning framework (adapted from N. U. Ahmed 1995, 262)

One of the most cited (e.g. H. P. Barringer, 2003, 4; S.K. Durairaj et al. 2002) and used life cycle cost modeling processes (figure 14) is the one developed by Fabrycky and Blanchard (1991). It aims to support the detailed and comprehensive cost analysis for the life cycle of the product. The essential step of the process lays in development of detailed cost breakdown structure (CBS), which is one of the main goals of this thesis as well. This model is applicable in all stages of product life cycle and addresses wide variety of goals. The iterative process itself has to be tailored to different applications and products.

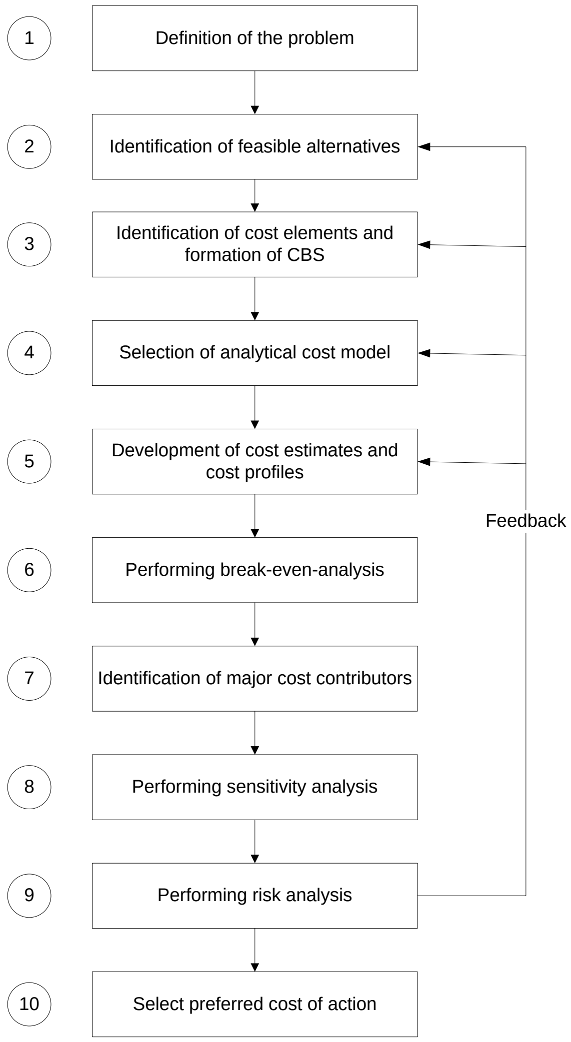


Figure 14 LCC process (adapted from H. P. Barringer, 2003, 4; S.K. Durairaj et al. 2002, 34)

In figure 14 the typical LCC process is presented: 1) Identification of analysis targets, financial criteria and time period for project life study 2) Identification of alternatives by technical features and economic consequences 3) Identification of all relevant product life cycle costs and development of CBS 4) Selecting most appropriate cost model depending on project complexity 5) Gathering cost details and assembling cost profiles 6) Performing break-even-analysis for key issues comprising time and money 7) Indentify essential cost contributors by Pareto distribution 8) Testing alternatives by performing sensitivity analysis 9) Analyzing uncertainty and risk for high cost items and providing iterative feedback for LCC studies and 10) Selecting most suitable course of action. (H. P. Barringer, 2003, 4-5)

However, the LCC process (figure 15) in this thesis will follow more general and essential steps, which are suitable for a development of generic life cycle cost model. The process is based on the LCC analysis steps provided Y. Kawauchi and M. Rausand (1999), which summarizes the essential steps common in various academic sources, standards and manuals.

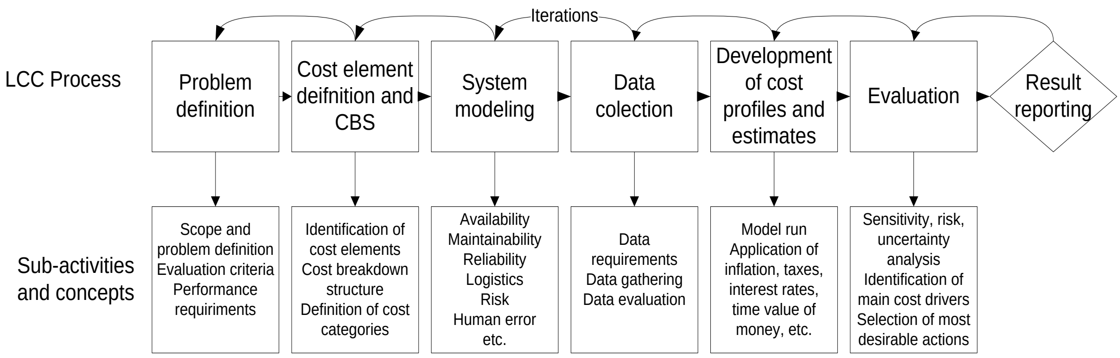


Figure 15. LCC process and concepts (adapted from Y. Kawauchi and M. Rausand 1999)

1. The first and very important step is to define the goals and limitations of LCC analysis. The scope can be defined by selection of product life cycle phases, products, activities, etc. to be modeled. Another important feature is to define evaluation criteria, which are based on cost effectiveness and system performance characteristics.
2. Essential step is the identification of all relevant cost elements, which are comprised into a common cost breakdown structure. This step is explained and described thoroughly in the following section.
3. System modeling aims to define relations between input parameters and cost elements in order to quantify them. Such models as availability and maintainability are most significant in this analysis, because they impact wide range of cost elements, especially in operation and support stages.
4. Accurate and reliable data is crucial in order to have correct LCC prediction. However, such data is usually very disperse and hard to gather, because it might come from the sources that are outside organization, such as operational data.

5. Cost profiles are defined by running cost models with input data. In order to make financial judgments, such factors as inflation, taxes, interest rates, exchange rates, etc. have to be considered.
6. The model has to be evaluated in accordance to initially defined criteria. Sensitivity analysis is performed in order to identify major cost contributors.
7. The results should be presented in consistent form and supported by the summary of the most significant assumptions. It is recommended that final report would include such points: executive summary, purpose and scope, model description, model analysis, discussion and conclusions.

3.8 Cost breakdown structure

Development of generic cost breakdown structure (GCBS) for Normet's products is one of the main targets of this thesis and essential step in life cycle costing as well as life cycle cost model development. The GCBS for Normet's products will serve as a data collection framework and tool for possible cost effective suggestions. For that reason in this sub-chapter the description of CBS and various cost elements will be presented.

3.8.1 Concept and development of cost breakdown structure

Fabrycky and Blanchard (1991, 28-30) cost breakdown structure can be defined as a logical subdivision of cost by functional area, major elements of the system or more discrete classes of common items. It serves as a framework for defining life cycle costs and communication for cost control, analysis and reporting. CBS links objectives and activities with resource requirements. Moreover, the CBS can be coded in a way that enables analysis of specific areas as well as separation of producer, supplier and consumer costs. The example for CBS can be seen in figure 16.

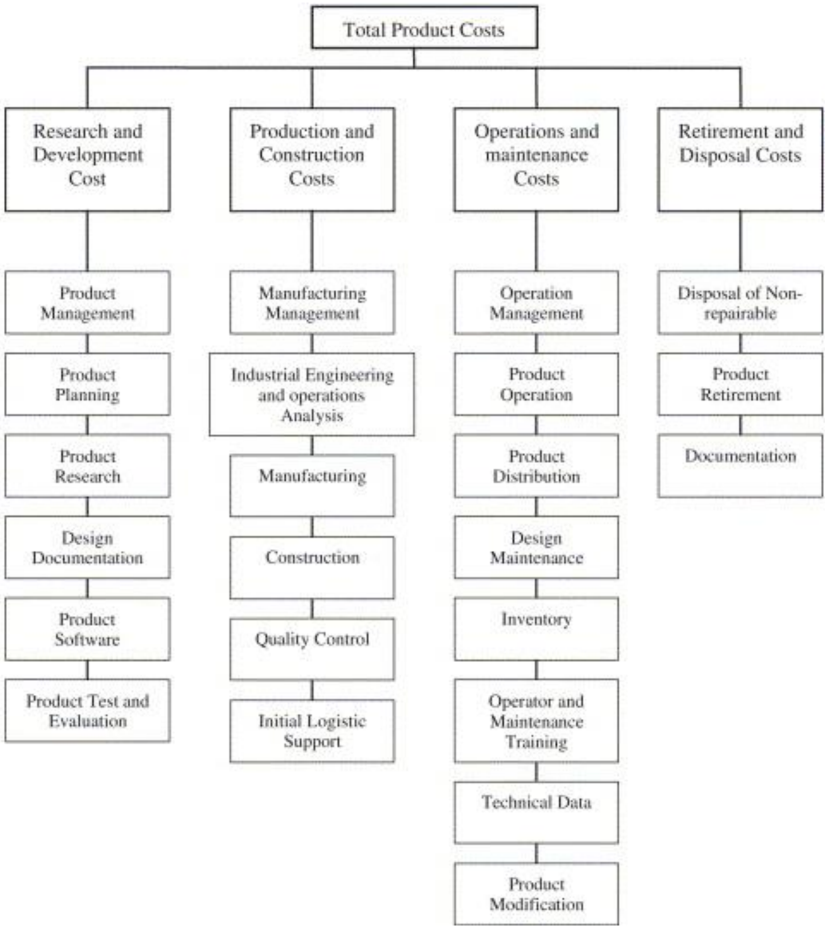


Figure 16. General cost breakdown structure (Fabrycky and Blanchard 1991)

N. U. Ahmed (1995) defines CBS as a breakdown of total product life cycle costs into hierarchical cost categories. Moreover, CBS is main tool that indentifies cost components and their relationships. In table 8 you can see the summary of requirements and characteristics of CBS.

Table 8. Characteristics and requirements of CBS

	Characteristics and Requirements
Fabrycky and Blanchard (1991)	• All relevant LCC costs have to be included; • The costs are broken down to a level needed to meet LCC analysis objectives; • The cost categories have to be well defined and understood; • Categories have to be chosen according to the specific interests of analysis; • The CBS has to be compatible with other relevant policies, systems, documents, etc.

Ahmed (1995)	• Must have major items and activities that have the same meaning throughout organization; • The design should enable the identification of cost change impact in particular area; • Should be compatible with data requirements for cost reporting and control.
NSW Treasury (2004)	• Most influential cost generating activity components; • Time in the life cycle when the activity is to be performed; • Relevant resource cost categories such as labor, materials, transportation etc.
NATO RTO (2003)	• The CBS must be easily developed, used and updated; • All major cost items have to be identified; • At a certain level, CBS could be compared, combined, etc.; • Cost definitions must be clear; • CBS must be flexible and able to be adapted to all products.

While CBS common layers can be identified, in general, cost breakdown structure differs for every system/product/project in deeper breakdown levels. Lowest levels of CBS are usually represented by cost concepts, which are defined by certain formulas and input of data. (R. Enparantza et al. 2006) Costs that are associated with LCC elements can be allocated between recurring and non-recurring or fixed and variable, etc.

In NATO RTO (2003,4-1) report the development of generic cost breakdown structure consisted of two major steps: 1) identification of all relevant cost items associated with a system and 2) putting all the cost items into CBS. Further the overview of different cost elements and categories is presented.

3.8.2 Cost elements and categories

Identification of cost elements is very essential step in order to have accurate and clear picture of life cycle costs. Such elements can be indentified and grouped according to many factors: level of detail, cost type, application, product type, life cycle stage, perspective (society, manufacturer, user, etc.). Various costs associated with different life cycle stages were already introduced earlier. However, more detailed cost elements should be reviewed from the perspective of CBS development. More detailed cost element review from user perspective (TCO) will be presented in chapter 4.

Cost elements are often defined in the systematic manner. In the report by Y. Kawauchi and M. Rausand (1999) based on international standard of LCC (IEC 60300-3-3) state that CBS development and cost element identification is defined by three independent axes: "Life cycle phase", "Product/work breakdown structure", and "Cost categories" (figure 17).

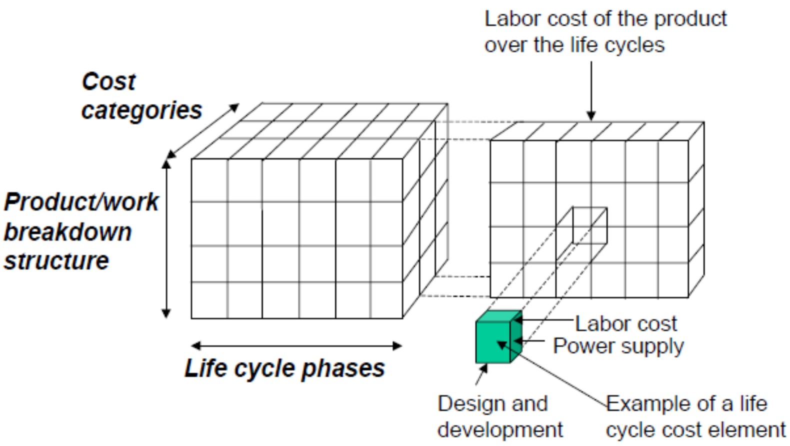


Figure 17. The concept of cost element (Y. Kawauchi, M. Rausand 1999, 13)

In NATO Research and Technology Organization technical report about cost structure and life cycle costs for military system, generic cost breakdown structure (GCBS) is build from cost elements that are associated with resource, activity and a product. For that reason, cost elements are usually defined from combination of product tree, activity list and recourse list (figure 18).

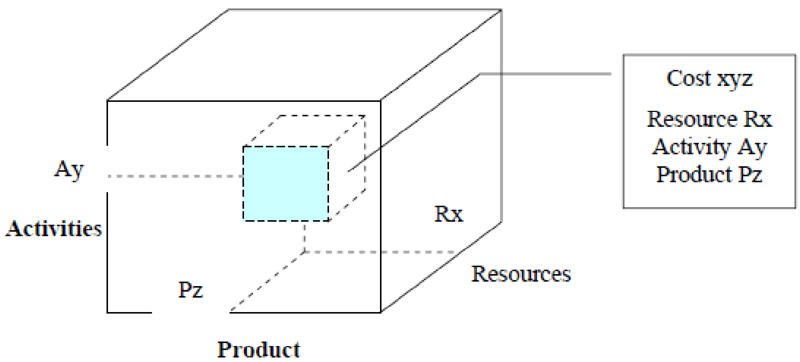


Figure 18. Cost element structure (NATO RTO 2003, 4-2)

Cost element structure can be built in certain layers, which represent different level of details. Such levels, for instance, can be comprised from: (G. Huppes et al. 2004, 12):

- Economics (budget, market cost, alternative cost, etc.);
- Life cycle stages (R&D, primary production, manufacturing, etc.);
- Activity types (development, extraction, purchase, management, maintenance, etc.);
- Cost elements (overheads, materials, electricity, taxes, warranties, etc.).

M. A. El-Haram et al. (2002, 146) present cost breakdown structure for construction industry, which is divided into five levels:

- Project – Overall costs;
- Phase – Breakdown into cost categories;
- Category – Breakdown into cost elements;
- Element – Breakdown into tasks or activities;
- Task – Breakdown into cost of resources.

While developing LCC model, it is very important to indentify all cost elements that significantly affect whole costs of the product. There are many cost classifications, such as: linked and non-linked, direct and indirect, fixed and variable, recurring and non-recurring, etc. J. U. Ahmed (1996) divide costs in recurring and non-recurring, where the former one includes costs associated with design, engineering, development, manufacturing, assembly and count for about 50% for all LCC. The rest 50% can be defined as recurring costs, which are generated in operation, support and service of the product. In addition, P.P. Datta and R. Roy (2010) define hidden costs and risk uncertainty costs, which can be cost of relationship management, communication costs, reverse logistics, flexibility of response, cost of cultural changes/change management and other. These costs are hard to indentify and estimate.

Variable costs, as the name already implies, fluctuate according to the characteristics of the system and operational activity, such as production volume, etc. Fixed costs are relatively constant during changes in operational activity and often are more associated with the organization and not particular products. Direct costs can be easily allocated to a certain product, while indirect costs usually can be associated with several products and should be shared between them. (NATO RTO, 2003; Fabrycky and Blanchard 1991, 23)

From the design point, manufactures costs can be classified in reliability design costs (inspection, life testing, training, management, R&D, etc.), internal failure costs (yield loss, diagnostic, repair, rework, scrap and wastage, etc.) and external failure costs (after-sales service, replacement, warranty, loss of reputation, etc). (B.K. Lad, M.S. Kulkarni 2008, 79-80)

As it was mentioned before, categorization of cost elements should be adapted to every system/product/project. However, certain categories in highest level can be defined, which are more applicable to wide range of products, such as acquisition costs, ownership costs, operation costs (OPEX), capital costs (COPEX), etc. (Y. Kawauchi, M. Rausvand 1993).

Fabrycky and Blanchard (1991, 125) define such cost groups: research and development cost (initial planning, market analysis, feasibility studies, product research, requirements analysis, etc.), production and construction cost (industrial engineering and operations analysis, manufacturing, facility construction, process development, production operations, quality control, etc.), operation and support cost (consumer or user operations, product distribution, sustaining maintenance, etc.) and retirement and disposal cost. The visualized CBS was presented in figure 16.

Such LCC elements are indentified for pumping systems: initial costs, purchase price, installation and commissioning cost (including training), energy costs, operation costs, maintenance and repair costs, down time costs (loss of production), environmental costs and decommissioning/disposal costs. (Hydraulic Institute et al. 2001, 4). Another academic article (I. B. Utne 2009) gives example of CBS for a fishing vessel with such cost elements: capital expenditure (CAPEX), operational expenditure (OPEX), risk expenditure (RISEX), environmental expenditure (ENVEX) and retirement, disposal, and decommissioning costs (DISPEX), as showed in figure 19.

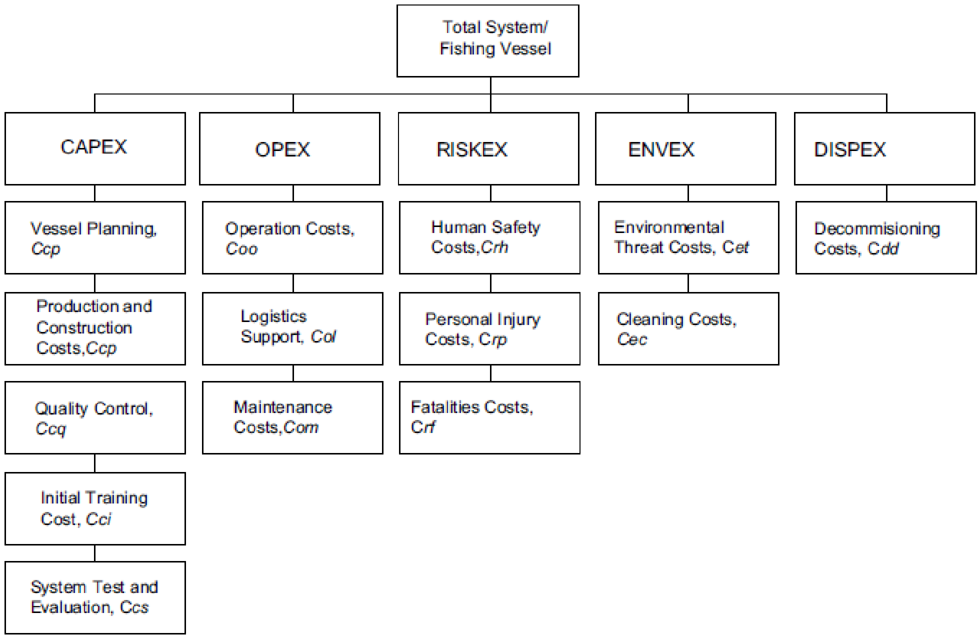


Figure 19. CBS for fishing vessel (I. B. Utne 2009, 339)

H.P. Barringer and D.P. Weber (1996, 3-20) define such structural LCC models:

- LCC = non-recurring costs + recurring costs;
- LCC = initial price + warranty costs + repair, maintenance, and operating costs to end users;
- LCC = manufacturer's cost + maintenance costs and downtime costs to end users;
- LCC=acquisition costs + operating costs + scheduled maintenance + unscheduled maintenance + conversion/decommission.

4 TOTAL COST OF OWNERSHIP

As it was mentioned, total cost of ownership (TCO) usually refers to life cycle costs that occur for the customer from acquiring, owning and disposing the product. Many research articles and other sources (e.g. R. Enparantza et al. 2006; Lissa Ellram1993, 1994, 1998) define LCC particularly from the customer point of view and the methodology is often identical to the producer's LCC process.

In nowadays competitive markets customers more often require life cycle cost information from producers as a part of the offering. Such information is used for supplier evaluation and selection as well as for strategic planning purposes. Moreover, operational and support costs can often be more important than acquisition costs. Very often the agreements between suppliers and users are based on some kind of LCC guarantee, which in general refers to certain limitation of overall ownerships costs. (R. Enparantza et al. 2006).

For many reasons the information about total ownership costs is very important for the producer as well. First of all it can gain a competitive advantage by optimizing the ownership costs. Secondly, by analyzing TCO supplier can introduce cost effective solutions, e.g. support services, design corrections, maintenance schedules, etc.

Lissa Ellram (e.g. 1993, 1994, 1998) extensively studies total cost of ownership (TCO) as a strategic tool and defines it as "a purchasing tool and philosophy which is aimed at understanding the true cost of buying a particular good or service from a particular supplier". The process involves the identification of all important cost drivers that occur within pre-transaction, transaction and post-transaction flows. Increasing focus on quality of purchased services and products, increasing global competition, significance of purchasing expenditures and other trends increase the application of TCO in many companies. In general it can be stated that TCO is a systematic approach, which enables better understanding, analyses, management and reduction of total costs of the product. It also supports more extensive communication and cooperation between customer and supplier. (L. Ellram 1993a,b; 1995).

4.1 Applications, barriers and benefits

TCO can have many important applications in purchase decisions and other organizational activities as well as increase the knowledge and drive improvement within organization. It can be applied for various purposes and in different stages of product life cycle. L. Ellram (1994; L. Ellram, S. P. Siferd 1998) defines some of the possible reasons for using TCO approach from the case studies:

- Support supplier selection;
- Award supplier for excellent performance;
- Support supplier improvement;
- Plan future and manage ongoing supplier performance;
- Establish data as a base for negotiation;
- Support internal and external communication;
- Concentrate resources on limited number of most significant purchases;
- Drive improvement in terms of cost optimization, performance, processes, etc.;
- Increase cost knowledge and understanding of processes.

From extensive applications that are presented, it is easy to notice considerable benefits that TCO can provide for organizations. Such benefits can range from improved decision making processes to increased cost knowledge and better understanding of supplier performance. All the benefits that come from TCO approach have synergetic effect and are strongly interdependent. However, there are certain barriers to TCO applications as well, such as data availability, complexity and corporate culture. Moreover, the complexity of TCO approach is not solved by any extensively developed standards or manuals. In table 9 you can see some of the summarized benefits and barriers of TCO application:

Table 9. Benefits and barriers of TCO approach. (adapted from L. Ellram 1994, 1993a,b, 1995; L. Ellram, S. P. Siferd 1993, 1998)

Benefits	**Barriers**
Performance Measurement ✓ Provides framework for supplier evaluation	**Complexity** ✓ Time consuming and hard to understand TCO concept

✓ Tool to measure supplier improvement and perform benchmarking **Decision Making** ✓ Provides basis for supplier selection and quantification of tradeoffs ✓ Provides an environment for structural problem solving **Support improvement** ✓ Support suppliers to work on important issues ✓ Helps to identify cost-effective improvements ✓ Points out how customer requirements can increase the ownership costs ✓ Increase professionalism in purchasing decisions **Communication** ✓ Improves internal and external communication with partners and suppliers **Knowledge/insight** ✓ Provides data for cost trend analysis, comparative supplier performance, negotiation, target pricing ✓ Helps to increase knowledge about most important cost factors and concentrate on long-term and wider perspective	✓ Complex modeling approaches ✓ Lack of common structures, terminology and expert experience ✓ Model has to be flexible for constant changes **Organization culture** ✓ Resistance to change ✓ To change the single emphases on price ✓ Government regulations and contracts ✓ Fear that TCO application will eliminate jobs ✓ Need of convincing users of TCO benefits ✓ Requires new knowledge and skills from users **Data and resource availability** ✓ Lack of available data and systems to support the TCO processes ✓ Requires a lot of labor resources **Proper use and relevance** ✓ Is not applicable to all purchases ✓ Should be used proactively and not as weapon against suppliers ✓ Should reduce user resistance to change and standardized format

4.2 TCO modeling approaches

Total cost of ownership models can be classified according to various factors, such as application goals, corporate culture, the type of purchases/products, user's experience in TCO application, availability of IT support, etc. TCO models are classified depending on the number of criteria into: standard or unique, dollar-based or value-based approach, pilot study or full implementation and other types. (L. Ellram 1994, 1993b, 1995)

In standard TCO models the basic framework is established for every purchase and product with a certain number of factors. It usually has computer-based support and is rapidly adapted to wide ranges of products and purchases. It is mainly used, when organizations are repeatedly purchasing similar products or when the most important cost factors are relatively same across various purchases. However, organizations more often tend to use unique models, which are developed to a certain product or certain range of purchases. This type of models often has shared set of cost factors, such as quality, service, delivery, but cost data has to be developed separately for each purchase. Nevertheless, that unique models require more time and resources to develop, organizations use them more often, because purchases often significantly vary and flexibility is often essential. (L. Ellram 1994, 1995)

Dollar-based TCO approach relies on the cost framework that enables cost data collection for every TCO element. This approach can also use a certain formula for total cost allocation. However, dollar-based technique is time consuming and not flexible for various kinds of purchases. Value-based approach aims to define cost data as well as other performance data, which cannot be easily valued in cost terms. Such models tend to get very complex as qualitative features have to be transformed into quantitative data and, consequently, they have very limited amount of cost factors included. Pilot study aims to pick relatively small amount of items, which are significant for organization and have large transactional costs. Pilot study is every useful for learning purposes and to show the importance of TCO practices. Organizations that skip pilot study usually try to fully implement TCO model, which basically implies that organization fully understands the significance of TCO and supports its application. (L. Ellram 1993b, 1995)

Lisa Ellram in her research article "A Framework for Total Cost of Ownership" (1993a) suggests such general TCO implementation process:

1 Identification of need – the goals of TCO implementation are usually formed by internal interest or external pressure.

2 Determine the purchase/product for analysis – purchase or product should be significant enough and have a potential for possible cost savings.
3 Form a team – team should be formed with a clear leader and the members, who have expertise in different areas.
4 Identification of relevant costs – includes such sub-steps as cost identification, selection of critical costs, gathering and developing cost data, and documentation.
5 Testing and implementing the model – the stage where team enters the cost data into the model.
6 Fine tune the model – includes such stages as analyses of the results, application of changes and TCO scope determination.
7 Linking TCO to other relevant systems – such systems include supplier monitoring systems, education and training systems and other computer systems.
8 Update, monitor and maintain – the system has to be constantly monitored and reevaluated in order to meet goals.

4.3 TCO elements

TCO cost elements vary extensively depending on the kind of product or purchase. However certain larger groups of cost elements can be identified that are usually common to various kinds of items. One way to divide TCO into elements is to separate different kinds of purchasing activities: 1) quality 2) management 3) delivery 4) service 5) communications and 6) price (L. Ellram, S. P. Siferd 1993). Cost elements can be also divided according to when they are incurred: pre-transaction, transaction and post-transaction. Cost elements divided into these three categories a showed in table 10. (L. Ellram 1993b)

Table 10. TCO cost elements (adapted from L. Ellram 1993b)

Total Cost of Ownership	
Pre-transaction	• Identification of need • Source investigation • Source qualification • Supplier adding • Educating
Transaction	• Price

	• Order placement • Delivery • Tariffs • Billing • Inspection • Return of parts • Correction
Post-transaction	• Line fallout • Rejection of defective goods • Reputation • Field failures • Repair in field • Cost of repair parts • Cost of maintenance

Many academic articles (e.g. R. Enparantza et al. 2006, B.K. Lad, M.S. Kulkarni 2008) related to life cycle costing and total cost of ownership generally group costs that occur for the users into three categories:

1) Acquisition cost
2) Ownership cost
3) Disposal cost

Acquisition costs usually include the purchase price plus other associated costs, such as installation, administration, delivery and initial training. Ownership costs consist mainly from operation and maintenance of the product, which often count as the largest cost group in the product lifetime. Disposal or recovery costs vary significantly depending on the product, sector, specific legislation of the country and other factors. (R. Enparantza et al. 2006)

5 PRODUCT LIFE CYCLE SUPPORT SERVICES

Another important goal of this research is to define certain empty spots for new cost-effective and value adding support services that could be introduced into the total offering. For that reason it is important to shortly overview certain trends that shape industrial service sector. Moreover, to point important features of product-service systems and certain value points in after-sales services.

Together with increasing attention to life cycle costs, traditional manufacturers of capital goods starting to concentrate on value adding services that can support products through their whole life cycle. As the potential earnings from the products are relatively limited, various services, that are included into the total offering, have high potential for suppliers as well as customers. After-sales services are especially important and are almost obligatory for more complex products in order to be purchased. Such trends are often related to the terms of product life cycle management, life time services or extended products. (Saaksvuori and Immonen 2004, 111-112)

Manufacturers of capital goods are looking for more steady cash flows, improved predictability of sales, independence from cyclic trends, increase in competitiveness and closer relationships with the customers. In figure 20 you can see importance of services during the life cycle of the product and the effect on the general cash flow stability for the supplier. Some important trends in manufacturing industry connected with increasing emphases on services could be named as better knowledge of hardware installed by the customers, standardized value added services, fast and easy availability of product related data for the customers, renewals and updates of old devices, planned maintenance and remote diagnostics, e-commerce and Internet applications in service sales and other. (Saaksvuori and Immonen 2004, 112-113)

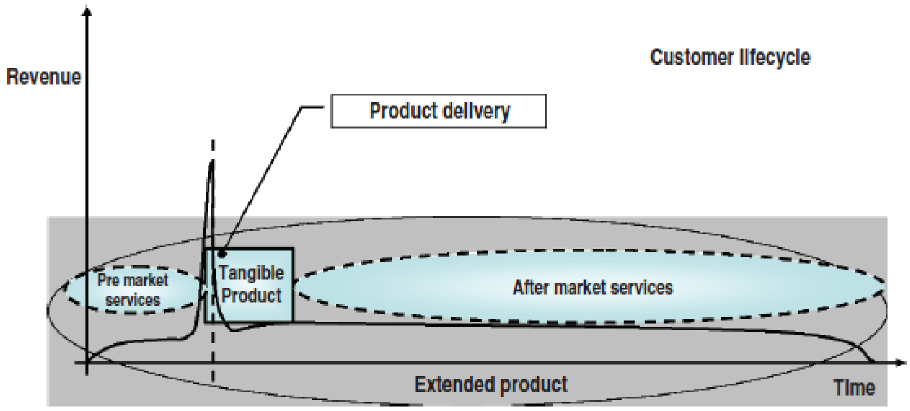


Figure 20. Extended product and services (Saaksvuori and Immonen 2004, 113)

However, development of such new value added services require certain conditions within the organization as well. First of all, very strong product management enables extensive documentation, data and product tracking through the whole life cycle and individually for separate customers. Product life cycle management (PLM) is the group of systems that enables information processing and product management through all stages of its life cycle. (Saaksvuori and Immonen 2004, 114-115)

Product-service system as a concept refers to the integration of product and service into the total offering. Such interdependency between product and services are shaping the organizations and transforming supplier-customer relationships. Possibility to adapt services to the needs of every customer increases the value of supplier's total offering as well as creates unique competitive advantage. For that reason the boundary between products and services in traditional manufacturing industries is becoming increasingly blurred. However, such transformation can be demanding and hard to implement for organizations as they have to execute managerial, technological, supply chain and other changes. (Saaksvuori and Immonen 2004, 115)

5.1 After-sales support and maintenance services

Range of support services have increased dramatically in recent years. Maintenance, service and repair as traditional support elements are expanded by many other, such as commissioning, documentation, warranty, installation, upgrading, etc. In figure 21 you can see the overview of various service types. Product support strategies depend on many factors, such as product characteristics, customer's skills and capabilities as well as operational environment. (T. Markeset, U. Kumar 2003)

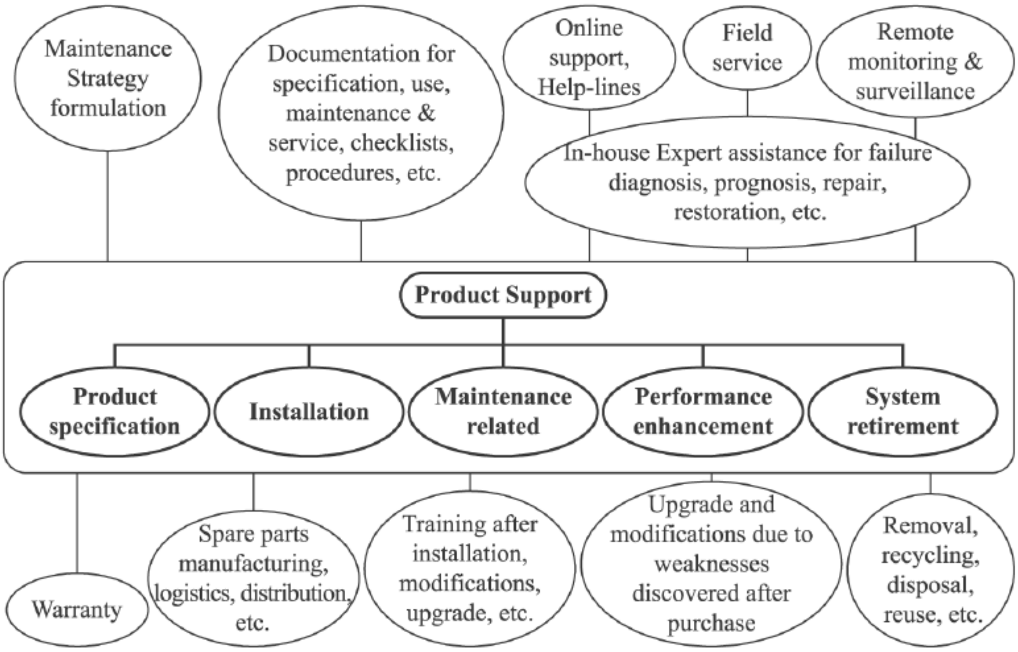


Figure 21. Product support and service types (T. Markeset, U. Kumar 2003, 381)

Operating and support costs usually are most significant part of LCC and very hard to predict as well. Most often these costs exceed the initial purchase price number of times. Having in mind the significance of such costs, after-sales support and maintenance become crucial for many industrial capital products. The product that is effectively serviceable and reliable guarantees high customer satisfaction and maximum availability. Manufacturers are trying to design such products, which can be serviced in short time, lower costs and minimum support resources, such as labor, spare parts, test equipment, facilities, etc. (Y. Asiedu, P.Gu 1998, 888)

It is very important that supplier has a strategic life cycle view of the product already in the design stage. Such concepts as design for serviceability, maintainability, supportability, life cycle and reliability have a straightforward connection with after-sales strategies. P. Gaiardelli, S. Cavalieri and N. Saccani (2008) analyze the connection between design for X methodologies and certain features in after-sales strategies. In figure 22 you can see the summarized connection between these two concepts.

A “product support” after-sales strategy is connected with “design for reliability” methodology. In this strategic approach, which usually fits to low value products, after-sales support costs have to be avoided or minimized and there is no significant value added services delivered for the customer. In such case, reliability of the product is the most important competitive feature as it is usually less costly to replace the product rather than maintain it. “Cash generator” is described as a strategy, where after-sales support generates revenues for supplier mainly trough physical services, such as spare parts, upgrades, etc. For that reason the maintainability of the product is directly connected to the profitability of such services. “Business generators” offer much wider range of intangible value added services than “cash generators”. For this after-sales strategy the maintainability as well as serviceability are needed in order to provide efficient physical support and other important features, such as effective upgrades, remote and self-diagnostic tools, etc. “Brand fostering” requires serviceability and life cycle design features of the products in order to provide wide range of tangible and intangible value-added services. “Design for life cycle” supports strategic aspects of this after-sales profile, where the satisfaction and loyalty of the customer are essential. It aims for cost minimization through the whole life cycle of the product. (P. Gaiardelli, S. Cavalieri and N. Saccani 2008, 270)

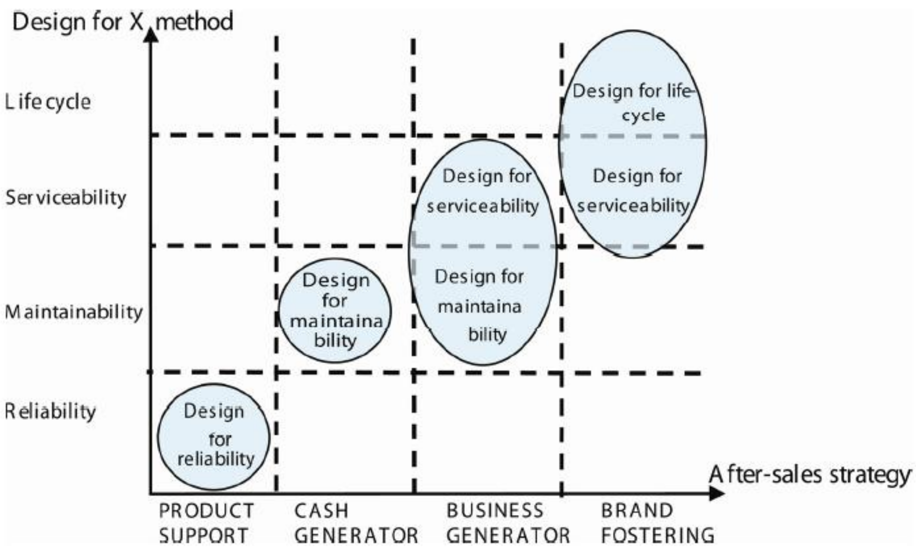


Figure 22. Connection between design for X method and after-sales strategy (P. Gaiardelli, S. Cavalieri and N. Saccani 2008, 269)

5.2 Maintenance related services

One of the most important product support services are in the area of maintenance and remote diagnostics. Maintenance as a support service can be divided into tangible and intangible, as well as proactive and reactive. While in the tangible support, the exchange of physical parts, such as tools, components, documentation and manuals takes place, intangible support involves online support, expert, advice, training, etc. Planned or proactive support is connected to training, preventive maintenance, while unplanned support can be mainly referred to corrective maintenance, when product fails unpredictably. (T. Markeset, U. Kumar 2003)

Modern information technologies together with wireless networks enable preventive maintenance in various environments: mines, plants, forests and other. Customers are willing to transfer the maintenance responsibility to suppliers, which have best expertise and knowledge about the equipment. Remote diagnostics enable to gather real time data about functioning of the equipment, which allows quick response to occurring problems. Such data also increases the knowledge for the supplier, which can introduce new value added services. However, remote diagnostics are still relatively new approach and require precautions as data has to be transferred in secure ways. (Saaksvuori and Immonen 2004, 114)

Maintenance services are often complex and involves different forces and requirements, such as management, operations, logistics and technology. Having in mind, that production efficiency is one of the most important factors for the customer, supplier should aim at superior maintenance support performance, maintainability and reliability in order to assure high availability performance. In table 11 you can see the classification of maintenance service offerings by customer segments. (V. Ojanen et al. 2011, 3021)

Table 11. Types of maintenance offerings (V. Ojanen et al. 2011, 3022)

Maintenance service offering	Characteristics
Basic	Price-focused Short-term Spare parts and maintenance
Extended basic	Long-term contracts

	Technical support
Availability/full service	Reliability centered maintenance Service contracts Spare parts, maintenance, training, inspections
Performance partnering	Focus on overall equipment efficiency Service contracts Spare parts, maintenance, training, inspections, consulting
Value partnering	Focus on customer's business process Service contracts and long-term relationship Same as performance partnering plus business consulting

Such emerging maintenance approaches as total productive maintenance (TPM) and reliability centered maintenance (RCM) are being widely adapted by manufacturing and process industries for optimization of maintenance practices (T. Markeset, U. Kumar 2003, 389). RCM can be defined as a process that aims to develop cost-effective maintenance program in order to increase reliability by defining the criticality of failure modes. Moreover, it aims to prioritize the maintenance requirements for all failure modes and choose the most effective maintenance activity for the critical ones. General RCM process could be defined from six steps: 1) setting boundary for RCM studies 2) collecting maintenance data 3) identification of critical failure modes 4) identification of failure causes 5) maintenance task selection and 6) task comparison. (P. Vanittanakom et al. 2008, 1)

5.3 Disposal and end of life services

Such factors as energy consumption, waste management and air pollution play important role in manufacturing industry. Retirement of products is a very important step in the life cycle as it has to be done in environmentally clean way. Increasing amount of legislation, customer demands, increasing waste disposal costs and other factors raise the need and attention of products and manufacturing techniques that have less negative impact to the environment. Accordingly, as it was mentioned earlier, life cycle assessment (LCA) is often used in order to measure the environmental impact of products and processes. Several product end-of-life options can be named that are used by organizations: (Asiedu, P.Gu 1998, 888-889)

- Recycling – basically refers to the use of waste material as a raw material for products.
- Remanufacturing – application of certain restoration processes that can make unserviceable products functional.
- Reuse – refers to the use of a waste product in its original form.
- Disposal – elimination of a product without recovery.

Reverse logistics refer to the term used in order to reflect the material flow back from the end users to the producers of the products. Reverse logistics is aimed to manage such material flow as well as associated information flow. It comprises such activities as transportation, material handling, warehousing, inventory, packaging and other. Reverse distribution channels and large transportation costs are one of the biggest obstacles in product end-of-life activities. The information management connected with reverse logistics, such as product related, location related, legislative, market, process are very important in order to assure effective processes in end-of-life activities. In deciding what processes to apply in the end of product life cycle supplier has to take economic, technical and ecological factors into consideration. (N. Ferguson, J. Browne 2001; A.K. Parlikad, D. McFarlane 2009)

5.4 Availability-based contracts

The industrial products are getting more complex and require strong support services in order to achieve best functional performance. For that reason customers and users often enter into the service contracts, which reduce the risk of poor product performance. Such performance based contracting includes a series of clearly defined objectives and indicators by which the performance of supplier can be measured and certain consequences defined if the required performance goals are not met. Such contracts dramatically increase the importance of life cycle support services especially in operational phase, where supplier is responsible for satisfactory results of their products.

Availability type contracts or, in general, performance based contracts are often used when instead of offering single physical product, supplier offers wider bundle of product and support services. In such contracts customer is focusing not just on acquisition of the product, but on its total performance and in that way transferring more risk to the suppliers. These types of contracts are relatively new approach and require the ability to actually measure the availability, which can be very challenging for pure services. Costing such kind of product-service system offerings with certain performance and availability promises, is a very complex and resource demanding process. All the risks and relevant costs have to be taken into account and information collected from different aspects, such as user requirements, historical operations, maintenance data, industry standards, expert opinions, user top-level budgets, etc. (P.P. Datta, R. Roy 2010)

6 GENERIC LIFE CYCLE COST MODELING IN CASE COMPANY: NORMET

In the practical part of the thesis generic life cycle cost modeling in the case company Normet will be presented. The cost modeling process will be limited and detailed data allocation and cost calculations will be excluded due to thesis limitations. For that reason, the main goal is to provide certain cost structure emphasizing on the cost elements in the after-sales stages of product life cycle. Moreover, generic system cost model will be proposed, which would serve as framework for data collection in further life cycle cost modeling process steps. In the first parts case company Normet and current life cycle cost calculations will be described in order to provide clear base for further cost modeling. Further, the life cycle costing process and limitations will be described. The process itself will contain three main parts: description of the problem and goals, development of generic cost breakdown structure and description of proposed generic life cycle model. The most essential part is to develop detailed life cycle cost structure with the emphasis on after-sales stages and description of main cost elements. In the end of this chapter possible use cases and suggestions for further development will be presented.

6.1 Description of case company: Normet

Normet Oy is a Finnish company that specializes in development, production and sales of equipment and vehicles for underground mining and tunnel construction. Company was founded in 1962 and since then has become one of the market leaders in its product segments. The main products of Normet include concrete sprayers, lifting and charging equipment as well as underground transport vehicles. Moreover, it has very strong and growing service provision spectrum for lifetime care of its products. The machines include modern technical features that are developed by professional R&D department as well as in close cooperation with the customers.

Normet has a strong international orientation with offices in 16 countries worldwide and production units in Iisalmi, Finland and Santiago, Chile. The production facilities have a combined space of 26, 000 square meters. The headquarters of the company as well as R&D functions are located in Iisalmi, Finland. It employs more than 600 professionals and the number is constantly growing as the company growing as well, while the turnover in 2010 was EUR 115 million. Normet has worldwide acknowledged certifications like ISO 9001 and ISO 14001:2004 standards. In order to increase agility and flexibility the headquarters in Switzerland were established in order to coordinate the distribution and service network.

6.1.1 Products and services

Generally, Normet provides products and services in such process fields:

- Concrete spraying and transportation
- Explosive charging
- Lifting and installations
- Underground logistics
- Scaling

In addition company has several separate product lines, such as Semmco Product Line, which includes specialized spraying robots and low profile transmixers for application of wet spayed concrete. Newly acquired Normet Scandinavia AB (former Essverk Berg AB) is a Swedish based product line, specialized in design and manufacturing of special equipment for underground construction and primarily equipment is made for installation and finishing works of infrastructure tunnels.

Relatively recently established Life Time Care (LTC) concept aims to develop stronger customer-supplier relationship by offering support services through the whole lifetime of the machine. Wide network of sales and service locations guarantee fast and reliable support for the customer. Company has a wide range of services and products offered through the whole lifecycle of the machine: training, audit, maintenance, service contracts, documentation, spare parts, rebuilding, etc. For this reason it is very important to have a deep understanding about the products and services from the lifecycle point of view.

Service contracts are very important part of the total offering, that build stronger relationship between customer and Normet. It shifts more risk to the supplier, which is taking responsibility to guarantee smoothly running processes for the customer. It can be tailored to the needs of every customer and includes such service programmes as spare parts supply, scheduled inspections, supervision programmes, periodic maintenance and other. Such service contracts help to improve safety, availability, reliability, security and benefits customer as well as supplier. Basic training services include training program, training material and certificate. Classroom and practical sessions aim to provide knowledge for operation and maintenance personnel. Additionally Normet provides onsite audit of the machines, documentation (e.g. training materials, workshop manuals) and extended warranty services. Moreover, the life time care tangible services include provision of spare parts, upgrade parts and modifications as well as rebuilding services.

In the end it can be said that Normet has a strong life cycle orientation of business and for that reason deeper knowledge about various costs that occur during the whole life time of the product has to be established.

6.1.2 Overview of current life cycle cost calculations

Current life cycle cost calculations are mainly done to define life time cost of the machine from the sales point of view. Such cost information is often required by the customer in order have a better understanding about the total cost of ownership (TCO) and not just the acquisition related costs. However, current life cycle cost allocation is limited in that way, that it considers mainly the costs that appear from maintenance point, such as ware parts, periodical maintenance parts, lubricants, service labor costs, etc. Other cost elements, such as operational, training, downtime costs, financial and management costs from customer point of view are not taken into account.

The current life cycle cost calculation is based on sales manuals, that define what kind of services and parts will be needed in a specific period of time in order to assure the maximum performance of the equipment. In table 12 you can see the summarized draft example of sales manual for one of the Normet concrete spraying machines. Such sales manual consists from services required for the main components of the machine (e.g. engine, transmission, axle) in specific periods of time. Moreover, the needed service parts, quantity and price are also included. From the specifications of time required to perform each service it is possible to calculate the labor costs as well. In general the life cycle cost in this case includes:

- Periodical maintenance parts consumed in specific periods of time;
- Service labor;
- Lubricants such as engine and transmission oils;
- Wear parts;
- Other main components replaced during specific period of time.

Table 12. Sales manual draft

	Service schedule					**Required time for each service**			
Service	First 50 h	Daily	Every 125 h	Every 1000 h	Required parts no. and quantity	First 50 h	Daily	Every 125 h	Every 1000 h
Engine Service 1 Service 2 ………..					xxxxxxx xxxxxxx xxxxxxx	0,03 0,03 0,03	0,03 0,03 0,03	0,03 0,03 0,03	0,03 0,03 0,03
Transmission …………					xxxxxxx	0,03	0,03	0,03	0,03
Axles …………					xxxxxxx	0,03	0,03	0,03	0,03
Carrier …………					xxxxxxx	0,03	0,03	0,03	0,03
Carrier hydraulic system ………					xxxxxxx	0,03	0,03	0,03	0,03
Electrical system ………..					xxxxxxx	0,03	0,03	0,03	0,03
Compressor ………					xxxxxxx	0,03	0,03	0,03	0,03
Spray boom …………					xxxxxxx	0,03	0,03	0,03	0,03
Concrete pump ………					xxxxxxx	0,03	0,03	0,03	0,03
…………….					xxxxxxx	0,03	0,03	0,03	0,03

In general it can be said that in order to provide more accurate life cycle cost estimations for the customer as well as for inner purposes (e.g. cost-effective solutions) it is important to have wider cost related knowledge as more detailed cost structure and identification of cost elements. Allocation of various cost elements should be also defined from the closer collaboration with customers that can provide valuable data of some hardly visible costs.

6.2 Proposed process of cost modeling and limitations

The life cycle cost modeling process was established and is showed in figure 23. The general process includes six main steps from problem definition to evaluation and result reporting. However, due to thesis limitations and certain aims that were established for this research, the limitations to the general life cycle costing process should be defined. Having in mind that the main purpose of this life cycle cost modeling is to increase the awareness of total cost of the product with wider set of cost elements as well as provide cost model framework for more accurate cost estimations, it is possible to limit the general process to main three first steps. The rest of the process steps like data collection and development of cost profiles and estimates will be excluded as it requires large amount of resources (e.g. time, data sources, labor) in order to be completed and are not essential for answering the research goals.

As you can see from the figure 1 first two phases of LCC modeling process are marked in red, which refers that these steps will be completed thoroughly. The third step marked in grey, which is, basically, a system modeling or cost modeling, will be established just as a data collection framework, which includes certain data blocks, from which cost information could be collected for the further costing steps.

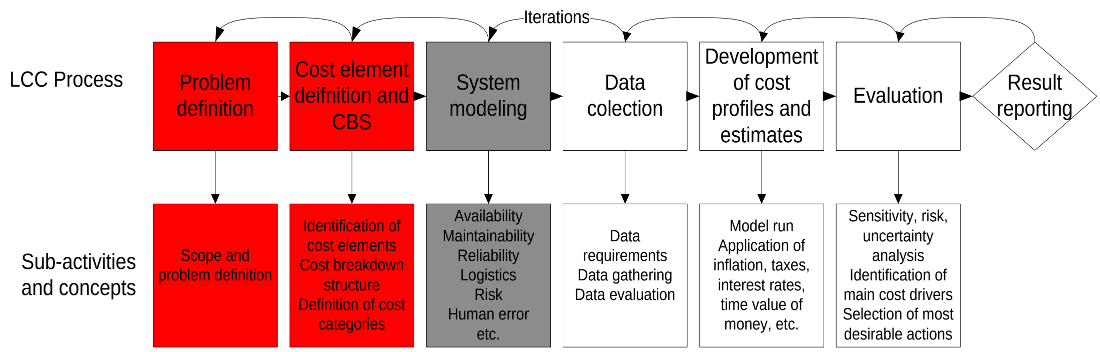


Figure 23. Life cycle cost modeling process and limitations

The first step of the LCC analysis is very essential and requires the clear establishment of aims, objectives and the scope of the work. The scope should include certain limitations and define what aspects of the LCC modeling should be taken into account. Such aspects as which program phases should be modeled, scope of life cycle stages, scope of equipment and other certain limitations. The clearly defined scope is essential in order to get properly defined cost elements, which are the basis of the LCC process. Generally, the clearly defined problem definition is important as it changes and shapes the LCC study process itself. Depending on the objectives the general LCC modeling process should be adapted and limited. Moreover, the aims of the study often depend on which stage of life cycle the product is analyzed and from which perspective (e.g. supplier, buyer, society) the study is conducted.

Second and most essential step of the process is to identify all relevant cot elements that have significant influence to total LCC of the equipment. The definition of the most important cost elements should be defined in the systematic way and result in cost breakdown structure (CBS), as it was presented in the previous chapters of the thesis. In this LCC modeling process the CBS will be based on life cycle stages, types of costs and break down from larger cost groups into smaller elements in the hierarchical way. CBS should be also tailored for every piece of equipment and also application area of LCC analysis, which means that CBS should accommodate flexibility. Moreover, CBS should be easy to follow and understand as well as maintain, update and compare between different equipment and applications. In general, as it was mentioned before, cost element usually can be associated with three basic elements: a resource, an activity and a product. However, such association is not always clearly visible and at higher level of cost breakdown structure the cost element can refer to only e.g. activity, but include other elements as well.

Third and last step in this LCC process will include the development of generic life cycle cost model, which will serve as a framework for data collection. Different models and perspectives will be arranged in one system in order to provide a framework, which can be used for cost element quantification. The system can be modeled from different perspectives, such as availability, maintainability, logistics, etc. The modeling itself should be emphasized on allocating certain relations between input parameters and the cost elements. If some elements can be computed from already existing models and practices, as showed in sub-chapter 6.1.2, than such models should be utilized. If such models do not exist than new ones should be established in order to fill the gaps for data collection. In this case, one of the most important aspects can be named as availability and maintainability, as they affect wide range of different cost elements especially in operation and support life cycle stage.

6.3 Problem definition

The main problem which leads and shapes the LCC process can be identified as lack of more detailed cost knowledge during the life cycle of the product. The main aim of the this LCC study is to define the major cost elements that influence total life cycle cost of the product as well as construct generic cost breakdown structure. Moreover, certain life cycle cost model should be suggested that would serve as framework for cost element quantification. Finally, the life cycle cost modeling should provide a background for further development of more accurate assessment of total life cycle costs. The scope of the study is limited from different perspectives:

- The LCC process is limited, excluding the data collection and cost estimations;
- The cost break down (CBS) structure will be generic, which means that it will still have to be adapted to separate Normet products;
- The most detailed cost break structure (CBS) will be developed for middle of life (MOL) stage of product life cycle.
- The system modeling will include just major data blocks for further cost element quantification.

The use case examples and suggestions for further development of this LCC study will be defined in later sub-chapter. However, certain applications of this LCC study can be named as follows:

- Definition of LCC elements from different perspectives can provide a foundation for more accurate cost information for the customer.

- Identification of cost elements and analysis of CBS should help to define major cost drivers and gaps for cost-effective improvements, like modifications in services or development of new offerings that fit into the customer's value chain.
- Supplier (Normet) could introduce or improve their sales strategies which would emphasize on best lifetime results and not just low initial acquisition cost.

Suggestions for cost-effective improvements and possible introduction of improved or new services will be presented in the next chapter of the thesis as well.

6.4 Development of cost breakdown structure

The development of cost breakdown structure (CBS) for machines was done in cooperation with Normet. First of all, as many as possible cost elements were identified that might occur through the life cycle of the machine. Later these elements were sorted and most relevant ones were distributed into bigger groups. Finally, the major cost groups were compiled into generic cost breakdown structure (GCBS).

6.4.1 Major generic cost breakdown structure

It is important to mention that most detailed analysis of cost elements were made in middle of life (MOL) stage or so called in-service stage of Normet equipment. This was done, because the biggest area of interest was to define cost elements which are most visible and occur for the customer, who buys and operates the machine in order to notice available spots for new cost-effective solutions and services as well as to provide more accurate life cycle cost data, when sales are performed. For that reason in-service cost elements were defined from both points, supplier (Normet) and customer (total cost of ownership/ TCO). Another important goal was to identify larger groups of cost elements in end of life (EOL) stages of the product with the interest to locate more possible actions, when product is not suitable for service. In the beginning of life stage (BOL) just the major groups of cost drivers were identified in research and development as well as production and construction. The full list of all cost elements and CBS are presented in appendix 2, and due to limitations of this thesis volume, more detailed explanation of cost elements will be presented just for MOL and EOL phases of life cycle.

Another important feature of this CBS is that it has wide application area. The generic cost breakdown structure (GCBS) presents wide range of cost elements that are optional and do not necessary occur for every machine. Consequently, GCBS has to be “tailored” to every separate product or application area. The GCBS was created according to the life cycle stages as you can see in figure 24. The major elements in BOL stage were identified as R&D as well as production and construction related costs. The MOL stage was divided in two major blocks, which represent different point views: 1) distribution and operation related costs, which can be also described as total cost of ownership (TCO) represents the customer point of view and 2) support and maintenance related costs represent Normet point of view. The cost elements in these two groups overlap extensively, but the ways how the costs occur for customer and supplier are different.

The EOL phase was divided into seven major parts: 1) management and administration related costs 2) documentation costs 3) Reverse logistics costs 4) Recycling costs 5) Scrapping costs 6) Disassembly and recovery costs and 7) Environmental costs. These parts represent major cost groups that are also options for EOL phase decisions. As an example, if the machine will be scrapped or recycled, than the recovery costs will not be included, etc.

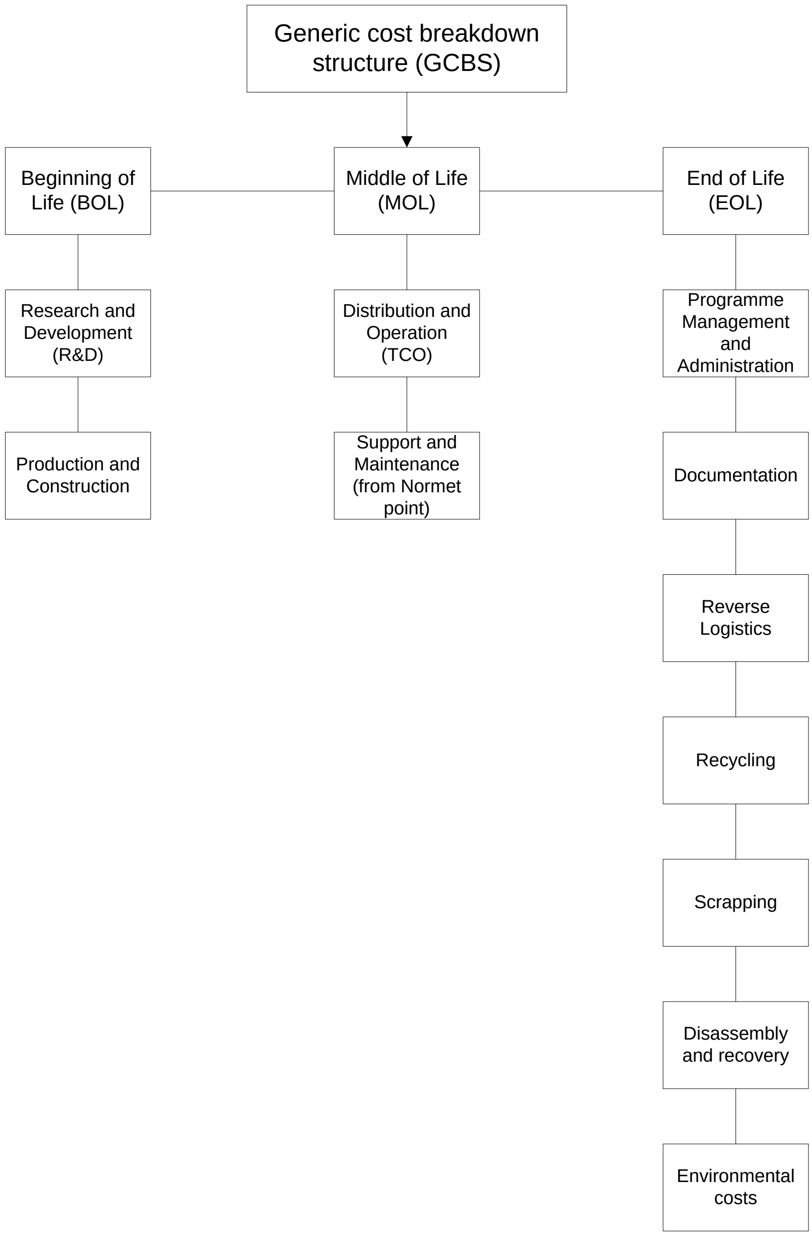


Figure 24. Major generic cost breakdown structure

6.4.2 Overview of cost elements in beginning of life (BOL) stage

The cost elements in BOL, as mentioned before, were divided into major groups:

1. Research and development costs
2. Production and constructions costs

Research and development costs include such costs as programme management, product planning and research, engineering design, quality management, testing and others. The phase of BOL starts from initial idea and ends when the product is ready to be delivered to the customer.

For instance, programme management costs are related to overall planning, direction and coordination of all phases of the project, which is done by internal management as well as by communicating with other actors, such as partners, suppliers and customers. The costs can include risk management, patent analysis, quality management, configuration management, performance measurements, etc.

Engineering design costs include system engineering, electrical design, mechanical design, reliability, availability, maintainability and safety analysis (RAMS), etc. Costs are related to technical specifications development, testing, quality assurance, engineering drawings, part lists, design changes and other functions.

Another major cost group, which occurs in BOL stage, is production and construction related costs. These costs generally consist from management, industrial engineering, operational analysis, manufacturing, facilities, initial logistic support and quality control.

The major part of costs occur from manufacturing, which includes fabrication, part manufacturing, tooling and test equipment, subassembly and final assembly, quality control and other relevant functions that are needed in order to transform raw material into a final product.

BOL phase in this case, as it was mentioned before, includes just most major parts and could be still expanded. However, as most of the Normet machines have already stable and clearly defined development and production processes, the main emphasis was set on in-service and EOL phases of the product.

6.4.3 Overview of cost elements in middle of life (MOL) and end of life (EOL)

In table 13 you can see the list of major cost groups defined in MOL phase. The list is provided in order to present the comparison of cost elements from different points of view: Normet and customer’s.

Table 13. Major elements in MOL phase from different perspectives

Middle of Life (MOL) Stage	
Distribution and Operation (customer TCO)	**Support and Maintenance (from Normet point)**
Initial costs	*Initial costs*
• Acquisition cost	• Marketing and sales
• Delivery cost	• Distribution costs
• Initial Training cost	• Initial Training cost
• Initial Spares and Consumables Investments	• Initial Spares and Consumables Investments
• Facility Investments	• Facility Investments
• Support Equipment	• Support Equipment
• Technical Data and Documentation	• Technical Data and Documentation
• Support logistics analysis	• Support logistics analysis
• Initial product modifications or on-site integration (software)	• Initial product modifications or on-site integration (software)
• Administration cost	• Administration cost
• Warranty cost	
Recurring costs	*Recurring costs*
• Downtime Costs	• Product life-cycle management and Administration
• Maintenance Costs	• Maintenance Costs
• Financial costs	
• Upgrade and modification costs	• Upgrade and modification costs
• Operation costs	
• Customer support	• Customer support
• Life Termination Cost\Rebuild	

From the table it is visible that many elements overlap extensively. However, the ways how those costs occur are different. The main cost elements are described below.

The first line of initial cost group presents the acquisition costs for the customer, which varies accordingly to the type of the machine and other features. Acquisitions costs constitute for a large amount of total costs of ownership, however, other costs like operational and maintenance often exceed acquisition costs in quite short period of time. For that reason the awareness of total cost among customers is increasing and very often detailed cost information is required from suppliers at sales point. Acquisition costs can have various attributes that are included (e.g. basic warranty costs) or goes as an addition to main cost (e.g. service contracts). From Normet point marketing and sales costs can be identified, which comprise all activities that are aimed to support sales of the product. This can be costly and time consuming as customers often want customized solutions and various service packages.

Distribution costs include such elements as packaging material, storage, transport means, customs, etc. It includes all activities that are needed to deliver the major product and supporting equipment in the acceptable condition. It is also often referred to deployment and includes not just delivery but needed on-site installations.

Initial training costs are usually provided together with the machine and include certain practical and theoretical courses in order to provide needed knowledge for operation and maintenance of the machine. Cost elements can be associated with training the trainers, preparation of training material (e.g. workshop materials), travel and labor costs, etc.

Initial spares and consumables investments are usually made in order to support the machine and to build the initial stock, which helps to insure the availability. The spares and consumables can include major components as well as basic wear parts, engine oils, hydraulic oils, etc.

Facility investments can be optional and cannot be directly associated with every machine. It can include investment related costs from Normet or customer point for storage, operational, maintenance and other facilities.

Support equipment includes all the costs of the additional equipment required to maintain, test or operate the machine. Various maintenance tools as well as monitoring equipment costs are included in this group.

Technical data and documentation refers to all the costs associated with developing, maintaining and updating of needed documents and technical data that support the machine. Costs can be related to such items as operation and maintenance manuals, spares manuals as well as various procedures and instructions.

Support logistics analysis includes all the costs associated with organization of machine support, such as spares modeling and maintenance analysis. Spares modeling costs occur from development of models, which define how much spare parts machine will need. Maintenance analysis aims to manage and optimize the maintenance actions for the machine.

Initial product modifications or on-site integration costs are also optional and do not occur in every case. For instance, in some cases when machine is delivered to certain mine, it has to be delivered in several pieces as it does not fit through the entrance. In such situation machine still has to be assembled on-site.

Administration costs are related to all administrative issues that have to be performed in order to assure smooth product delivery and integration. The last cost element from initial cost group is warranty costs, which basically refer to extended warranty costs, if the customer requires it.

The first cost group of recurring costs is downtime costs on customer side, which can be very high, depending on the machine's availability, reliability, maintainability, logistics support and other factors. As mentioned before, various service contracts aim to reduce downtime costs by effectively maintaining and supporting the product. The downtime costs occur when the machine cannot perform its major function, which, for example, results in production loss, or so called deferred production. Further, such costs can be divided accordingly to the downtime causes, such as major or component breakdowns or during scheduled maintenance. On the other side, Normet incurs recurring costs that are associated with life cycle management of the machine and administration costs. These costs are associated with all managerial and administrative functions that are performed in order to assure effective product support, like product and customer data management, service development, inventory management, etc.

Maintenance costs can constitute one of the largest cost groups through the whole life cycle, especially when machine's reliability, maintainability and other factors are low. Such costs include the ones that occur from maintaining main product as well as support equipment and include activities like inspection, detection, trouble shooting, preventing, testing, overhaul, replacement of parts, components, etc. It can include the costs associated mainly with labor, material and logistics needed for maintenance. It can further be divided in periodical maintenance and corrective or un-scheduled maintenance. The first one refers to the maintenance actions either done by customer or Normet, which are planned and done on regular time and performance intervals. The former one refers to corrective and unplanned maintenance actions that are needed in order to repair the major breakdowns, defective equipment, etc. Such maintenance can be done either on field or in factory, which, in that case, causes additional costs such as energy and transportation.

Financial costs refer to the costs that occur for the customer during the operation time of the machine. It can include such costs as interests, which, for example, occur if the customer decides to take the loan for acquiring the machine. Various insurance costs also fit in this category.

Upgrade and modification costs are also optional and occur if the customer decides to upgrade or modify underground vehicles, equipment or processes in order to follow the latest standards , increase productivity and safety, or to change the application of the equipment. This includes all costs associated with upgrade or modification of the products, such as devices, components, labor, logistics and other costs.

Operational costs can constitute for a large group of total life cycle costs as well. Such costs depend dramatically on the type of vehicle or equipment. The major costs can be associated with direct labor hours, consumables, energy, operational taxes, management and administration (e.g. recurring item management), waste management, cleaning and inspections, further transportation, storage and safety costs.

Customer support includes all activities provided by Normet, such as engineering support, training updates, technical publication updates, logistics support updates. Customer support can be done in various ways, from various locations as well as on customer’s site.

The last group of costs that occur for the customer and represent the final element of total cost of ownership (TCO) is the life termination or rebuild costs. Various costs and EOL options are presented below:

- Programme management and administration costs – includes all the costs that are associated with the managerial and administrative activities that are needed in order assure smooth processes in the end of product life cycle. Such activities include technical and economical analyses including legal regulations in order to find best economical way to manage the machine after in-service period.

- Documentation – includes the costs associated with preparation of needed documents depending of an EOL option.
- Recycling costs – all the costs associated with the physical recycling of material, including various payments due legal regulations.
- Scrapping cost- all the costs that occur from physical disposal of machine or components.
- Reverse logistics – refer to the costs associated with the activities that occur from material flow back from the end users to the Normet. It includes transportation costs, warehousing, packaging, material handling and other.
- Disassembly and Recovery- so called “second life” service from Normet. Includes all the activities and materials needed to economically recover the machine for new service period. Costs can be associated with identification of need, audit, solution design, rebuilding, commissioning, training, warranty, etc.
- Environmental costs – include the costs that occur from various environmental regulations and legislation.

6.5 Suggestion of generic cost model

In figure 25 you can see the developed generic life cycle cost model, which presents main data blocks and serves as a framework for further data allocation as well as cost estimation. By retrieving and allocating data from this generic model it is possible to define the ways of actual life cycle cost estimation, such as maintenance, operation, downtime, etc. Moreover, it is important that LCC model and analysis would provide the background for cost-effectiveness analysis. The model itself is generic, which as well as with earlier presented CBS, refers that LCC model should be adapted according to objectives of the cost evaluation.

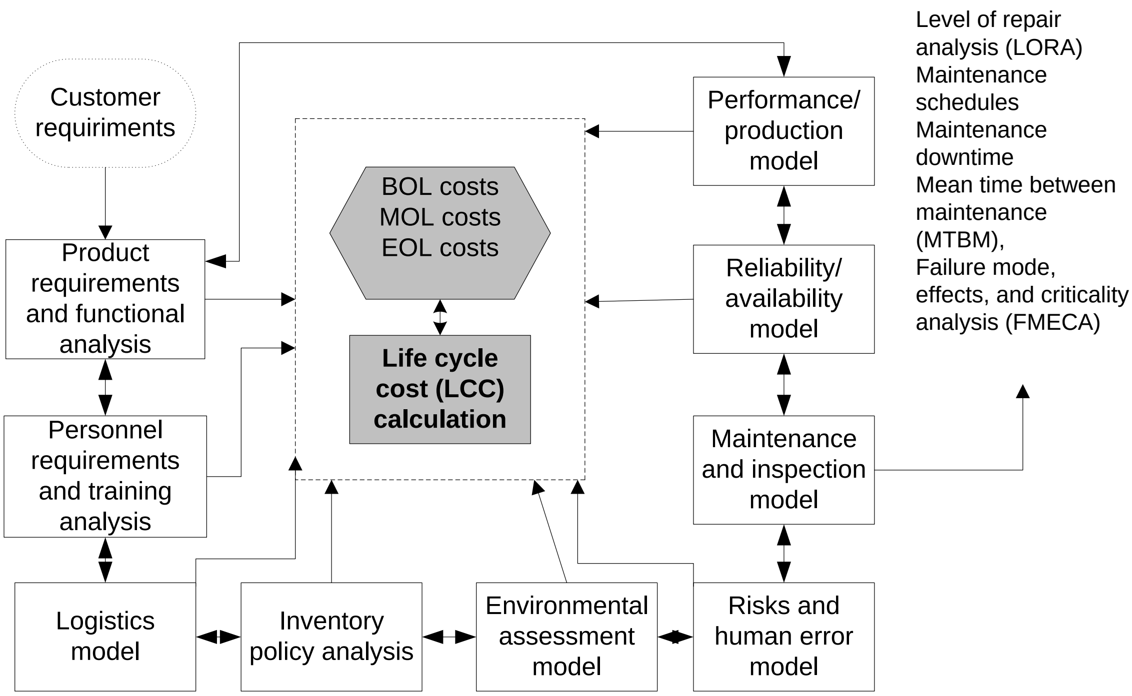


Figure 25. Generic life cycle cost model

As you can see from figure 25, all data blocks are interrelated and often cannot be viewed as single units. The complexity of the model depends on LCC analysis objectives and especially on the complexity of the product itself. Analysis of customer requirements incorporated into real product requirements and functions helps to identify major product characteristics, which can be quantified. Product requirements and functional characteristics have significant influence to other models. Major data blocks and models are described below.

Major elements of developed generic life cycle cost model could be identified as maintenance and reliability/availability analysis models as they affect large number of cost elements described in GCBS. The availability of the product has major impact on costs associated with downtime or deferred production, which depends on the production selling value. As some of the mining products have high selling value, the availability of the machine becomes an essential feature. The actual availability data could be gathered from operational sites, and can include such predictive parameters as mean time to failure (MTTF), mean time to repair (MTTR), the mean corrective maintenance (MCT), mean time between maintenance (MTBM), etc. Moreover, the estimation of total system availability utilizes such methodologies as reliability block diagram (RBD), fault free analysis (FTA), Markov modeling, Petri net, etc. (Y. Kawauchi M. Rausand 1999, 16-20)

The maintenance analysis is very essential as it significantly influences already mentioned availability as well as operating costs. The preventive maintenance costs can be analyzed and quantified by already established sales manuals and maintenance schedules. However, certain measures that comprise corrective or un-scheduled maintenance have to be established. The maintainability of the product can be analyzed including such parameters as mean time between maintenance (MTBM), mean time between replacement (MTBR), maintenance downtime (MDT), turnaround time (TAT), maintenance labor hours per product operating hours, maintenance cost per product operating hours, etc. (Y. Kawauchi M. Rausand 1999, 16-20)

Logistics modeling is a complex process, which depends on logistics system and can be measured by costs associated with functions needed to guarantee effective and smooth support of the product. It can include such elements as support equipment, maintenance facilities, supply support, training support, technical data, transportation, packing, customs, spares modeling, etc. (Y. Kawauchi M. Rausand 1999, 23)

Performance or production modeling basically describes if product is performing its functions and meeting the needed demand. It includes such concepts as total system availability, production availability as well as deliverability, which is the ratio of planned deliveries including compensating production from other producers and buffer storage. In general, production regularity or performance can be measured by various parameters, including production availability, demand production availability, on-stream production availability and others. (Y. Kawauchi M. Rausand 1999, 24-26)

Risk modeling includes quantification of certain loss from unwanted events as well as frequency of such events. It can also include warranty related costs, which can be assessed by defining the costs and frequency of warranty claims trough specified period of time. Human error includes the actions that have negative impact on the performance of the product and can be divided into omission error, action error and extraction error. The measurements of human error include Human Reliability Quantification (HRQ), including THERP (Technique for Human Error Rate Prediction), HEART (Human Error Assessment and Reduction Technique), SLIM (Success Likelihood Index). (Y. Kawauchi M. Rausand 1999, 27-28)

Environmental assessment model includes the quantification of all costs connected with the environmental impacts that can be associated with the product. It can include costs in terms of various taxes, permissions, documentation, regulations, standards, etc.

6.6 Uses cases and further development

In this part, short overview of possible use cases and applications of LCC model will be presented. Moreover, several suggestions for further development of LCC model will be provided as well. As it was already mentioned before, deeper cost knowledge through product life cycle gives certain benefits for Normet as it can be applied for various purposes: internal and external. Internal GCBS applications vary from more effective costs analysis by identification of major cost drivers to opportunities for cost-effective improvements. Moreover, it can help to shape the sales strategies and GCBS framework can be applied for different projects and products as well as provide essential information for the management team.

External applications are associated with provision of important cost data for suppliers, partners and customers. Definition of more extensive number of cost drivers are often required by customers prior the purchase in order to define real total cost of ownership. In that case Normet provides data that improves the value of the total offering with the best lifetime results.

During the lifetime of the product there can be many reasons for making certain costs analysis. In some cases full life cycle cost analysis is needed, and sometimes just partial analysis process with various limitations can be used. The access to the needed data, applications of LCC analysis as well as the level of details depends on which life cycle stage of the product the analysis is made. Moreover, the LCC analysis differs according on the chosen perspective. LCC can be used as management or engineering tool, which aims to forecast and optimize the costs of the product through the life time. From the customer point of view, one of the main purposes of LCC analyses is to define option with the best "value for money" criteria. However, as it was mentioned, the biggest opportunities to reduce the LCC are in the early phases of product life time as later on the costs are locked-in. Despite that, in later stages LCC is often used for optimization and decision making in order to distinguish best combination of time, cost and performance.

As in Normet case, most of the products that LCC will be used are already in the middle of life stage and the needed information is also developed and can be accessed. However, products and projects are often customized, which requires different adaptations for each case in order to develop needed forecasts and estimations. For that reason, application of CBS reflects the specifics and characteristics of the product ordered by the customer. In order to establish strong forecasting capabilities, there should be a good knowledge and collection of cost information during the life cycle of the product, especially in in-service phase. Such cost knowledge would allow analyzing the variation between the forecasted and actual costs as well as to build cost databases, develop management control, identify major cost drivers, etc. In any case LCC appraisal should provide support for managers in forecasting expenditures, various decision making processes, management of existing budgets and others tasks. Various other LCC usage scenarios in different life cycle stages are presented below:

- Selection of partners and suppliers in the early stages of product life cycle by LCC analysis in order to evaluate business proposals.
- In the early development of the product, certain LCC analysis can support decisions for concept and design changes in order to define most economical product with optimized life time costs.

- Reduce the time of offering proposal for the customer, by rapidly developing total cost of ownership data.
- LCC analysis in-service phase can help to identify the possible shortcomings in design of the products, which basically refers that machine or equipment does not perform as expected. LCC analysis can support decision making in how to deal with such shortcomings. Moreover, it can help to define certain breaking point after which the machine cannot be maintained in economical way and needs to be rebuilt or disposed.

For the further suggestions of LCC model development, there can be several points mentioned associated with LCC process and support elements. First of all, very defined and reasonable limitations and goals have to be established prior the project according to available resources, purposes, available data, products, point of view, etc.

Pilot study, which was described in previous part of the thesis, could be very helpful in this case as current LCC practices are not yet fully established. Pilot study could be used for learning purposes and provide essential knowledge for further more standardized LCC modeling process. Such study should have strong limitation and involve small, but significant elements. Cost estimations should be done by utilizing the existing models as well as developing new ones for the cost elements that cannot be assessed. As the products are already fully established, quantitative parametric and analytical approaches can be used. Moreover, expert opinions and utilization of analogical product cost data are very important as well. IT tools for cost analysis can be utilized as well, which are based on cost calculation on predefined CBS. One of the tools that could be mentioned is Windchill LCC (previously Relex LCC) that has a wide application area and allows LCC calculations based on cost tree structure and functions with local or global variables.

7 COST-EFFECTIVE SUGGESTIONS

In this chapter of the thesis several cost-effective and service enhancing suggestions will be given. The suggestions were defined from literature analysis as well as analysis of life cycle cost elements, which can be addressed by new solutions. The limited analysis of companies in similar sectors was also made in order to analyze existing support services. However, such cost-effective proposals are just preliminary and more detailed analysis is needed in order to have sufficient base for implementation of cost-effective improvements. Moreover, the absence of actual data collection and cost assessment limits the reliability of such suggestions. Analysis and overview of cost elements was also aimed to find empty spots for new or enhanced services that would fit and enrich customer's value chain. Nevertheless, closer collaboration with chosen customers should be performed in order to define more specific needs. Furthermore, the discussions with sales personnel, service staff as well as other experts are needed in order to spot more latent needs of the customer.

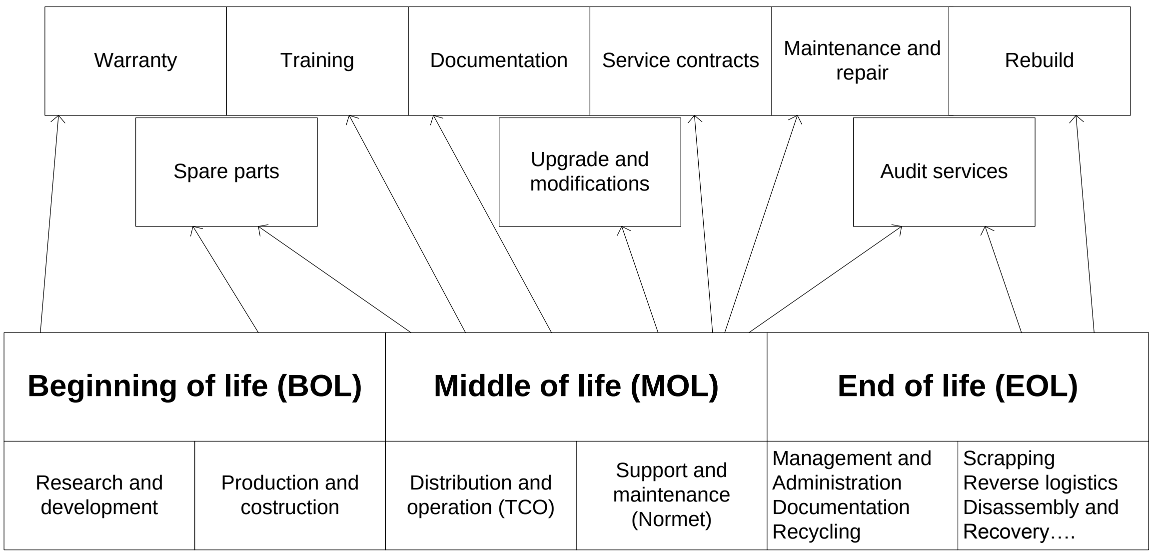


Figure 26. Normet service package

As you can see from figure 26 Normet has quite extensive support service package that covers the whole life cycle of the product. In the BOL phase customizations are often made before the product is produced according to the customer needs as well. Product customization according to customer demands can be very costly and not efficient.

More standardized and defined services for product customization could be introduced in order to reduce such costs. Modularized product structure can enable mass customization and reduce costs of development and production. Certain online tools could be introduced, which would allow user to customize and design their own machines that best fit their needs. This would reduce the costs and other resources connected with long period of negotiations and specifications of the product. As most of the costs that occur in middle of life stage are locked in already in the beginning of the product development, deeper analysis of life cycle costs could help to introduce the certain design changes, which e.g. could improve the maintainability of the equipment.

7.1 Maintenance related proposals

Normet has strong support in MOL phase, which guarantees high availability and smooth functioning of the machine. However from the literature and several companies review, certain suggestions can be proposed.

One of the most important and rapidly spreading support services in manufacturing industries can be associated with remote diagnostics. Normet has certain tools that are used in order to monitor the usage of the machine, however, such tools do not allow remote control and can be accessed just on-field. For that reason more extensive set of technologies and tools could be used in order to monitor, diagnose and prevent machine breakdowns as well as improve general product performance. Introduction of remote diagnostic services could help to enhance the reliability and performance as well as significantly reduce labor and travel costs. Centralized product support could help to increase the support expertise and involve such services as performance and usage monitoring, software upgrades, performance of maintenance checks, execution of certain repairs, etc. Moreover, when the issue cannot be resolved remotely, service engineers would have more extensive knowledge about the problem characteristics, which significantly reduces the time needed to resolve the issue. Furthermore, such systematic machine performance tracking helps to build certain knowledge and data that can be stored and used for development of more effective product support as well as help to design more reliable products. In any case remote diagnostics can enhance current service package as customers are willing to transfer more risk and responsibility to suppliers, which have the best knowledge and expertise about the products. However, the remote diagnostics often face security issues, which have to be resolved by creating safe ways of performance data transferring between customer and Normet.

Scheduled maintenance helps to improve the reliability and prevent the failures of the machine. However, certain issues often appear and the challenge to reduce maintenance costs together with reduced downtime of the machine, still remains. As the frequency of maintenance and inspections considerably affects the total LCC and especially TCO, new maintenance strategies have to be considered in order to improve efficiency of maintenance activities. Such techniques as total productive maintenance (TPM) and reliability centered maintenance (RCM) should be highly considered by Normet. RCM could help to develop more cost-effective maintenance program by prioritizing maintenance requirements and defining best actions for various failure modes. M. Rausand (1998) presents the RCM methodology steps that could be applied in Normet case as well:

1) Study preparation
2) System selection and definition
3) Functional failure analysis (FFA)
4) Critical item selection
5) Data collection and analysis
6) Failure mode, effects, and criticality analysis (FMECA)
7) Selection of maintenance actions
8) Determination of maintenance intervals
9) Preventive maintenance comparison analysis
10) Treatment of non-critical items
11) Implementation
12) In-service data collection and updating

Risk based inspection (RBI) can also be utilized in order to prioritize and plan inspections by analyzing the probabilities and consequences of failures. Assessment of risk levels helps to develop a prioritized inspection plan for a machine and efficiently allocate scarce maintenance resources.

The review of several companies' service packages in mining equipment industry, similar service concepts were observed. However, the service called "component exchange" was often mentioned, which could be considered by Normet as well. As an example, U.S. based company "Joy Mining Machinery" develops and produces underground mining machinery. It has introduced component exchange program that helps to reduce production downtime by rapidly supplying needed component, assembly or part to the customer, who doesn't have to wait for it to be fixed. The failed item is inspected, repaired and returned to exchange inventory. Other companies like "Finning" or " P&H MinePro Services" also have similar services available. Similarly Boeing (2009) has component exchange services program, which aims to reduce component inventory and maintenance costs by providing airlines the access to the pool of critical parts, which are available to be shipped within 24 hours from request. The program allows certain airline companies to reduce their inventory of high value line replaceable units (LRU) and save even to 30 percent of component repair and inventory costs. The process itself can be seen in figure 27.

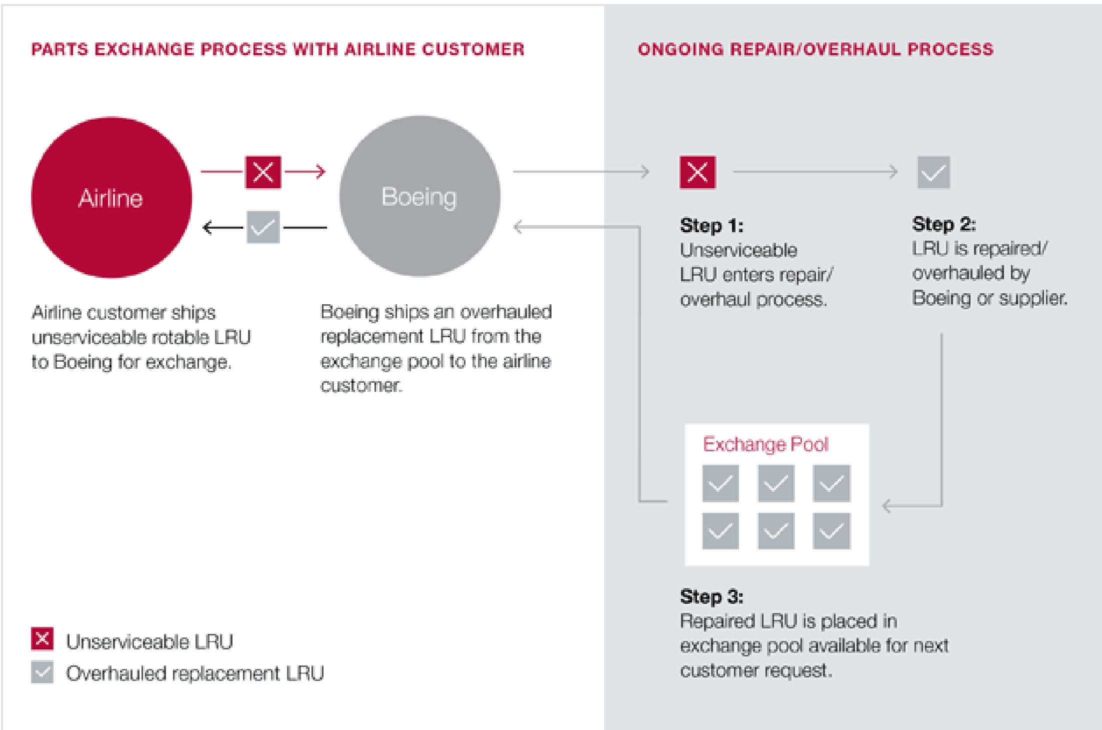


Figure 27. The process of component exchange service program by Boeing (2009)

As you can see customer will receive the needed component in 24 hours from the request, which allows rapid replacement of the item without having to repair and maintain it. The failed component is treated by Boeing, which repairs and upgrades the item before it is returned to the exchange inventory pool. Such general advantages from component exchange services could be named as:

- Reduced downtime costs;
- Reduced lead times of needed parts, assemblies, modules, etc.;
- Reduced inventory management and holding costs;
- Stabilized long-term maintenance budget planning ;
- Cheaper components as supplier can utilize economies of scale;
- Opportunities for supplier to upgrade and modify exchange components;
- Improved management of component repair cycle.

Despite all the obvious benefits that the implementation of component exchange services could bring, deeper e.g. cost-benefits analysis should be performed before considering such project. Such analysis is needed in order to compare various costs that implementation of new services will bring with benefits as reduced downtime and inventory costs for the customer.

7.2 End of life related proposals

Despite certain services provided by Normet in end of product life cycle, more defined and expended service package could be developed in order to assure smooth processes after the machine is not suitable for service and reduce costs associated with EOL practices. Extensively developed EOL service package could help customers to efficiently renew or dispose the machine. As such factors like waste management, air pollution, recycling and other related costs have increasingly significant role in manufacturing industry, supplier support in product retirement becomes essential part of total life time offering.

Very often large amount of documentation and various kinds of permits, associated with increased legislation, are needed in the retirement stage of the product. Normet could support documentation processes and various legislative analyses. More importantly, careful inspection of the product is needed in order to asses and define best options for the specific piece of equipment. Without proper analysis, there is a possibility that the product is disposed in not environmentally and economically effective ways, e.g. parts that can be used are disposed. Moreover, by performing LCC analysis it would be possible to define certain breaking point after which product is not economically worth to maintain and certain options should be proposed.

As it was visible in GCBS, EOL cost groups present certain options for product retirement. Such options can include recycling, scrapping, rebuild, reuse, etc. However, the provision of EOL services requires certain costs that can be associated with facilities, personnel, reverse logistics and other factors. The support logistics, or so called reverse logistics, could be the most challenging system to establish as it requires detailed modeling of many different activities, such as transportation, warehousing packaging, material handling, material flow management and related data management, such as legislative, process, product, etc. In order to define best EOL services and solutions Normet has to analyze various factors from financial, technical and environmental sides.

8 DISCUSSION AND CONCLUSIONS

In the last chapter of the thesis discussion and overview of content should be provided. It is important to review the thesis from the research questions position and try to identify gaps for further studies. It is needed to state that general LCC process has wide area of application and requires large amount of resources in order to be successfully implemented. For this reason, this thesis was strongly limited and did not include cost assessment and computations, which requires deep analysis of data. The life cycle cost model could have been modeled from the narrow perspective, e.g. maintenance. However, the main purpose was not to perform full LCC analysis, but to develop certain methodology and increase the structural knowledge of total cost of the Normet products. Another important success factor of LCC execution is the certain corporate culture, which needs to be strongly oriented to product lifecycle. Without certain existing PLM and PDM functions within organization, it would be very challenging to collect needed data for LCC analysis.

As chapter two revealed, product lifecycle management is becoming almost obligatory tool for manufacturing companies worldwide, as it helps to manage and capture the increasing amount of product related data and use it in the most efficient ways. It is becoming clear that the separation between the tangible product and support services is becoming not viable. The separate life time care department at Normet shows that company has strong life cycle orientation and acknowledges the importance and potential of life cycle practices. The close collaboration with the customers is needed in order to expand and upgrade existing life cycle service package. In any case, the product lifecycle management practices will support increasing number of enterprise activities in the future. It is essential to increase inner and outer collaboration with customers, partners, academic and research institutions, and even competitors in order to have most up-to-date knowledge and utilize it in the provision of products and services.

Life cycle costing practices are increasingly being applied within various types of enterprises. Companies acknowledge the importance of understating the total cost of the products and projects. As the products and support services comprise total solutions or offerings, it is obvious that the costs occurring through the life time of the product have many different sources and elements as well. Customers want best life time value and not just low acquisition price. For that reason, product characteristics, such as serviceability, maintainability, reliability, productivity and others as well as supporting services are becoming essential for manufacturing companies. Life cycle cost analysis can provide valuable data in order to improve product design characteristics and develop best package of supporting services. Chapter three was aimed to provide deeper overview of life cycle costing and develop certain supporting methodology for LCC process in Normet. It was important to distinguish the differences and applications of various related concepts, such as total cost of ownership, whole life costing and other. However, the research revealed that often such concepts refer to the same principles and processes and differ just in the area of application (e.g. whole life costing is more used in construction industry). From the third chapter it is clearly visible that it includes wide spectrum of aspects related to LCC, of which not all were applied in the case study (e.g. life cycle cost estimation approaches). This is because one of the aims of this thesis was to provide wider knowledge related to LCC, which can be used in later LCC processes within Normet. Very essential parts of third chapter included the overview of various cost elements as well as development aspects of cost breakdown structure. The theoretical body was applied in the case study for cost element identification, which were later comprised into generic cost breakdown structure. Moreover, the overview of several LCC modeling processes helped to establish general LCC process structure (figure 15), which was later with certain limitations (figure 23) applied in the case study.

Another very important part of this thesis is presented in chapter four, which overviews the LCC customer point of view. This is very essential, because as it was mentioned before, one of the main targets of this research was to provide more comprehensive life cycle cost knowledge for the customer from the sales point of view. Understating the cost elements that occur for the customer from using the products, are essential for Normet in order to have strong competitive position and establish closer relationships with the users. The last chapter in the theory part was the overview of life cycle support services, especially related to after-sales and maintenance. The chapter five was aimed to provide more knowledge about origin of certain occurring costs as well as to define possible cost-effective services or improvement of already existing service package provided by Normet.

The main aim of the case study was to identify all relevant cost elements during the life cycle of Normet products, with an emphasis on after-sales stages. Moreover, it was important to define generic cost model, which could serve as a framework for further data collection in order to quantify the identified cost elements. First of all, the description of the case company Normet and existing life cycle costing practices were presented. It became clear, that existing practices lack more comprehensive view and should include more cost elements, especially connected with operation of the product. The LCC process in this thesis was limited to three main steps which included problem definition, identification and description of cost elements, development of generic cost breakdown structure (GCBS) and development of generic cost model. The description of developed GCBS revealed large number of cost elements that are often hard to identify and quantify. It was important to show the cost breakdown structure from different points: customer and Normet. It became clear that issue of total cost visibility, described in chapter three, is still relevant and has to be solved by Normet as well. The use cases of developed GCBS revealed certain benefits that can be gained by applying LCC processes. Moreover, as the theoretical body serves as wider LCC support methodology, it was important to give suggestions for further development of LCC analysis. The sixth chapter of the thesis was aimed to answer first two research questions. In the end it can be stated, that the comprehensive list of cost elements as well as generic cost breakdown structure, which should be applied to different products, was developed. Moreover, the generic cost model, which consisted from various data blocks for further cost element computation, was established. Such cost model should be further adapted depending on the limitations and perspectives of LCC analysis. However, it is important to state that in order to purify the developed cost structure and model, further analysis and especially closer collaboration with several customers are needed. As the CBS and cost model are generic, it means that the customer could provide essential input in choosing the most important cost elements while performing LCC analysis.

The chapter seven was aimed to provide suggestions for cost-effective improvements by analyzing established theoretical body, GCBS and limited number of companies' service packages that operate in similar fields as Normet. Such analysis was aimed to answer the last research question of the thesis (What could be the cost-effective improvements?). The suggestions provided directions for new cost-effective services or improvements to already existing ones. These suggestions included more standardized services for product customization by modularized product structure, increased remote diagnostics, improved schedule maintenance practices by applying such techniques as reliability centered maintenance, implementation of component exchange programme and expansion of EOL service package. However, the economic validity of proposed cost-effective improvements cannot be assessed without deeper analysis. Moreover, the lack of cost element computations limited the knowledge needed for provision of most relevant cost-effective suggestions. Further LCC analysis and closer collaboration with customers are needed in order to identify most important cost drivers and spot opportunities for new service development.

In the end it can be said that full LCC analysis is needed in order to receive all the mentioned benefits. However, this thesis provided valuable information that could strongly support further LCC development. Moreover, the structural cost knowledge can be utilized in existing practices within Normet.

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APPENDICES

APPENDIX 1: LCC RELATED STANDARDS

The list of codes, standards and manuals, adapted from Y. Kawauchi M. Rausand (1999) and expanded, is presented below:

LCC standards:

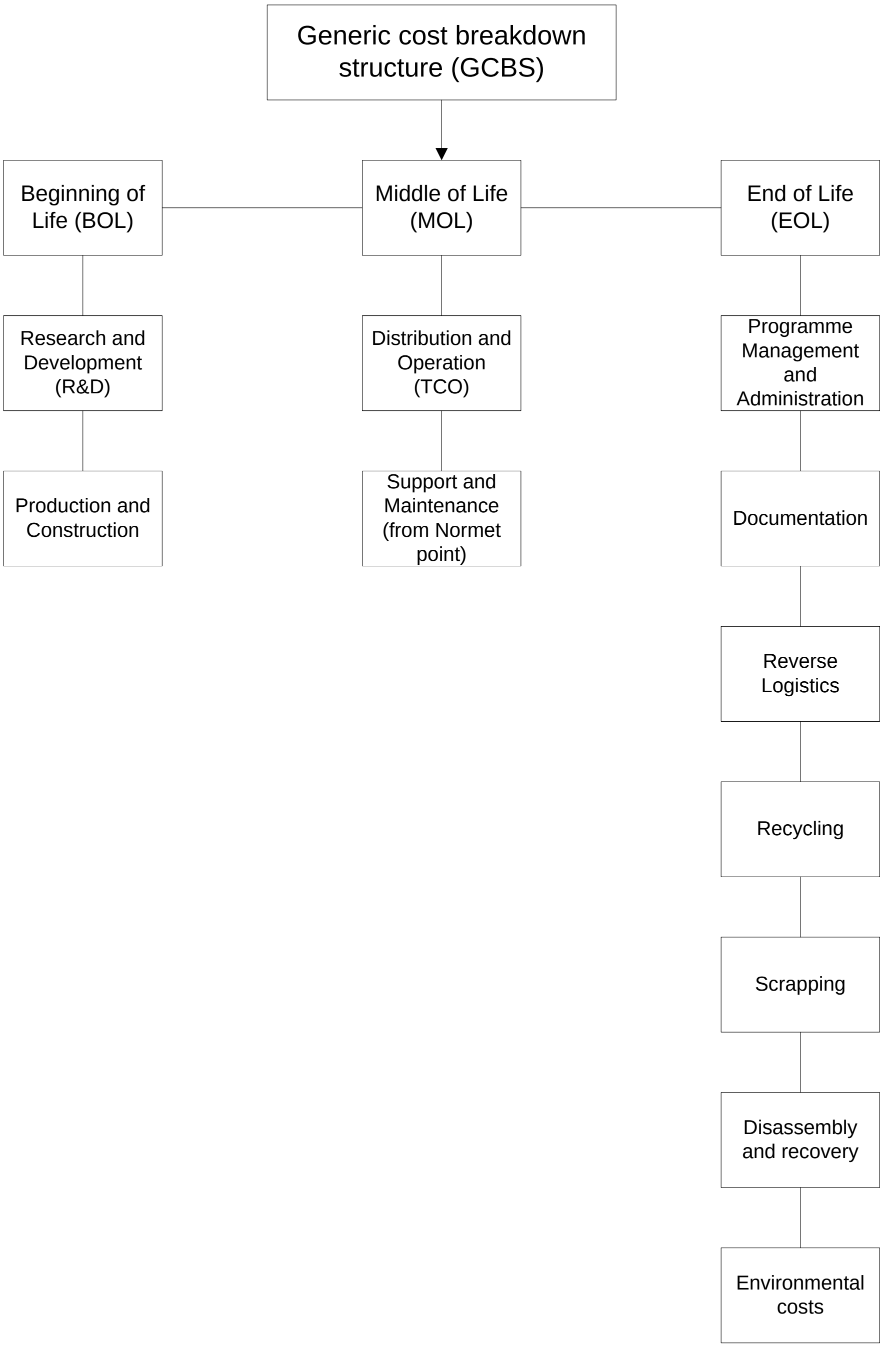
- IEC60300-3-3: Life cycle costing
- ISO15663:Petroleum and natural gas industries -Life cycle costing
- ISO 15686-5 Buildings and constructed assets – service life planning – Life-cycle costing
- NORSOK O-CR-001: Life cycle cost for systems and equipment
- NORSOK O-CR-002: Life cycle cost for production facility
- SAE ARP-4293: Life cycle cost - Techniques and applications
- SAE M-110 Standard
- VDI 2884 – Purchase, operating, and maintenance of production equipment using Life Cycle Costing (LCC)
- AS/NZS 4536 Life Cycle Costing - An application Guide
- ASTM-E 917-02 Standard Practice for measuring Life-Cycle Costs of Buildings and Building Systems
- NATO RTO - TR-058 - Cost Structure and Life Cycle Costs for Military Systems

Specific standards:

- API RP 580/581: Risk based inspection
- BS5760: Part2: Guide to the assessment of reliability
- EPA 40CFR68: Chemical accident prevention provisions
- EPA/630/R-95/002B Proposed Guidelines for Ecological Risk Assessment
- IEC60300-3-1: Analysis techniques for dependability: Guide on methodology
- IEC60300-3-2: Collection of dependability data from the field
- IEC60300-3-9: Risk analysis of technological systems
- IEC60300-3-11 Reliability centered management
- IEC60706-1: Guide on Maintainability of Equipment: Introduction, requirements and maintainability programme
- IEC60706-4: Guide on Maintainability of Equipment: Maintenance and Maintenance Support Planning
- IEC61025: Fault tree analysis (FTA)
- IEC61078: Analysis techniques for dependability - Reliability block diagram method

- IEC61165: Application on Markov techniques
- IEC61508: Functional safety of electrical/electronic/programmable electronic safety-related systems
- ISO14224: Collection and exchange of reliability and maintenance data for equipment
- NORSOK Z-013: Risk and emergency preparedness analysis
- NORSOK Z-016: Regularity management & reliability technology
- NORSOK Z-CR-008: Criticality classification method
- MIL-STD-1388-1A: Logistic support analysis

APPENDIX 2: GENERIC COST BREAKDOWN STRUCTURE FOR NORMET EQUIPMENT



1 The Beginning of Life

1.1 Research & Development Cost

- Product\System\Programme Management
  - Product Planning
    - Market research

        - Feasibility study
        - Project planning
    - Quality Management
- Product research
    - Applied research
    - Research Facilities
- Engineering Design
    - System Engineering
    - Electrical Design
    - Mechanical Design
    - Reliability, Maintainability, Human Factors, Producibility...
    - Logistic Support Analysis
- Design Data and Documentation
- Software Development
- Support Equipment Development
- Training Development
- Test and Evaluation
    - Planning, Modeling, Evaluation, Data & Reporting
- Modification costs

1.2 Production & Construction

- Production\Construction Management Costs
- Industrial Engineering and Operations Analysis
    - Plant engineering
    - Manufacturing Engineering
    - Production Control
- Manufacturing
    - Tooling & Test equipment
    - Fabrication
    - Material and Inventory
    - Parts manufacturing
    - Subassembly\assembly
- Facilities
    - Manufacturing, Test, Maintenance, Training and other facilities
- Initial Logistic support costs
- Quality control

2 Middle of Life

2.1 Distribution & Operation Cost (TCO) (from customer point)

- Initial cost
  - Acquisition cost
  - Delivery cost
      - Packaging, handling, storage, transport means, customs
  - Initial Training cost
    - Maintenance training
    - Operator training
    - Training data
  - Initial Spares and Consumables Investments
    - Initial Inventory Management
  - Facility Investments
    - Needed Modifications of Facilities
  - Support Equipment
    - Testing
    - Maintenance tools
    - Monitoring equipment
  - Technical Data and Documentation
    - Operation and maintenance manuals
    - Procedures, Instructions, Failure reports, etc.
  - Support logistics analysis
    - e.g. Spares modeling
  - Initial product modifications or on-site integration (software)
  - Administration cost
  - Warranty cost
- Recurring Cost
  - Downtime Costs
    - During Maintenance
    - Major and Component Breakdowns
    - Other causes
  - Maintenance Costs
    - Periodical Maintenance
      - PM Parts
      - Labor
      - Lubricants
        - Engine oil, Transmission oil, Axle oil, Hydraulic oil
      - Wear parts
    - Reactive\Corrective\Un-scheduled Maintenance
      - Field maintenance
        - Other costs
        - Labor
        - Parts
      - Factory maintenance
        - Other costs
        - Labor

        - Parts
    - Financial costs
        - Insurance Costs
        - Interests
    - Upgrade and modification costs
        - Upgrade parts
        - Upgrade kits
    - Operation costs
        - Direct Labor Hours
        - Consumables
        - Energy costs
        - Operational taxes
            - e.g. Gas emissions
        - Management and administration
            - Recurring Item Management
        - Waste management
        - Cleaning and Inspections
        - Transportation and storage
        - Safety Costs
    - Customer support
        - Engineering support, training updates, audit services, technical publication updates, etc.
- Life Termination Cost\Rebuild

2.2 Support and maintenance (from Normet point)

- Initial cost
    - Marketing and sales
    - Initial Training cost
        - Maintenance training
        - Operator training
        - Training data
    - Initial Spares and Consumables Investments
    - Facility Investments
    - Support Equipment
        - Testing
        - Maintenance tools
        - Monitoring equipment
    - Technical Data and Documentation
        - Operation and maintenance manuals
        - Procedures, Instructions, etc.
    - Support logistics analysis
        - Spares modeling
        - Maintenance schedules
    - Initial product modifications or on-site integration (e.g. software)
    - Administration cost
    - Distribution
        - Packaging, handling, storage and transport means, customs
- Recurring Cost
    - Product life-cycle management and Administration

        - e.g. inventory management
        - Product and customer data management
        - Life-cycle service development
    - Maintenance Costs
        - Periodical Maintenance
            - PM Parts
            - Labor
            - Lubricants
                - Engine oil Transmission oil Axle oil Hydraulic oil
            - Wear parts
        - Reactive\Corrective\Un-scheduled Maintenance
            - Field maintenance
                - Other costs
                - Labor
                - Parts
            - Factory maintenance
                - Other costs
                - Labor
                - Parts
                - Energy costs
    - Upgrade and modification costs
        - Upgrade parts
        - Upgrade kits
    - Customer support
        - Engineering support, help-desk, training updates, audit services, technical publication updates, etc.

3 End of Life

3.1 Programme Management and Administration costs

3.2 Documentation

3.3 Recycling costs

3.4 Scrapping cost

3.5 Reverse logistics

3.6 Disassembly and Recovery

3.7 Environmental costs