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Predicting product cost development throughout production life cycle

Master's Thesis

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ABSTRACT

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The objective of this thesis was twofold – first to assess how product cost development can be estimated at the early phases of product development and second to evaluate how organization could improve its product cost management practices. Study complied with case study strategy and combined both quantitative and qualitative research methods. Also, design science approach was used in empirical section to establish product cost development estimation method and to give recommendations how organization could improve its product cost management.

Organization has an effective process to track actual product costs but there are shortages when it comes to cost estimation of new products. Product cost management process focuses mainly on active products and operative accounting. Organization does not have systematic process or clear principles for cost estimation of new products at product development phases. Neither scenario analyses nor estimation of confidence levels are efficiently used which weaken the reliability of estimates. As result, recommendations were given how organization could improve and hybrid method for product cost estimation was developed. Method was built combining elements from existing estimation methods and using organization's past production cost data. Organization's labour costs followed learning curve in proportion to cumulative production volume and there was a clear correlation between the number of assembled components and assembly hours. Material costs development did not behave as expected. Product material structure was observed to remain similar among products which was used to develop material cost estimation method.

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Tällä diplomityöllä oli kaksi tarkoitusta – tutkia kuinka tuotekustannuksen kehitystä voidaan ennustaa jo tuotekehityksen alkuvaiheessa sekä arvioida kuinka yritys voisi parantaa tuotekustannusjohtamisensa nykytilaa. Tutkimus toteutettiin tapaustutkimuksena soveltaen sekä kvalitatiivisia että kvantitatiivisia tutkimusmenetelmiä. Myös konstruktiivista tutkimusotetta hyödynnettiin työn empiriaosuudessa tuotekustannuksen estimointimenetelmän ja kehitysehdotusten laatimiseksi.

Tutkimuksessa todettiin, että yrityksellä on tehokas prosessi toteutuneiden kustannusten seurantaan, mutta uusien tuotteiden kustannusennustamisessa on puutteita tuotekehitysvaiheessa. Tällä hetkellä yrityksellä ei ole systemaattista prosessia eikä selkeitä yhteisiä toimintatapoja ennusteiden tekemiseksi. Myöskään skenaarioanalyysia tai luottamusvälejä ei hyödynnetä riittävän tehokkaasti, mikä heikentää ennusteiden luotettavuutta. Ongelmien korjaamiseksi esitettiin kehitysehdotuksia ja rakennettiin hybridimenetelmä tuotekustannuksen ennustamisen tueksi tuotekehitysvaiheessa. Malli rakennettiin yhdistelemällä elementtejä olemassa olevista ennustemenetelmistä sekä hyödyntäen yrityksen tuotantokustannushistoriaa. Työkustannus noudatti selkeää oppimiskäyrää ja komponenttien lukumäärä korreloi asennustuntien kanssa. Materiaalikustannuksen kehitys ei puolestaan käyttäytynyt odotetusti. Tuotteen materiaalirakenteen havaittiin pysyvän samanlaisena eri tuotteissa, mitä hyödynnettiin menetelmän laatimisessa.

FOREWORDS

Closing this Master's Thesis project means also the end of my studies at LUT University. I would like to express my gratitude towards Eero Korhonen for his guidance and advices throughout this thesis. Also, I want to thank the whole ABB Oy Solar for the chance to work with great people and especially Kimmo Salmi for making this possible.

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Essi Kajander

TABLE OF CONTENTS

1 INTRODUCTION ... 9

1.1 Background and motivation ... 9

1.2 Research objectives, questions and limitations ... 13

1.3 Research methodology ... 13

1.4 Structure of the research ... 15

2 PRODUCT COST DEVELOPMENT AND MANAGEMENT IN PRODUCTION LIFE CYCLE ... 18

2.1 Definition of costs and cost drivers ... 18

2.2 Product and production life cycle ... 22

2.3 Product cost development ... 27

2.4 Product cost management ... 29

3 PRODUCT COST DEVELOPMENT ESTIMATION ... 34

3.1 Background of the product cost estimation ... 34

3.2 Estimation methods ... 35

3.2.1 Qualitative methods ... 36

3.2.2 Quantitative methods ... 38

4 GAP ANALYSIS OF ORGANISATION'S PRODUCT COST MANAGEMENT AND ESTIMATION ... 42

4.1 Current state of product cost management and cost estimation ... 42

4.2 Targeted future state and detected gaps ... 45

4.3 Recommendations and actions to close the caps ... 48

5 METHOD FOR PRODUCT COST DEVELOPMENT ESTIMATION ... 51

5.1 Recognized solar inverter cost drivers ... 51

5.2 Data collection and structure ... 53

5.3 Data analysis and results ... 54

5.4 Further product cost estimation ... 64

5.5 Evaluation of the method and future development ... 72

6 CONCLUSION ... 75

6.1 Answers to research questions ... 75

6.2 Validity and reliability of the study ... 79

6.3 Aspects for further study ... 80

7 SUMMARY ... 81

REFERENCES ... 83

LIST OF TABLES

Table 1 Structure of the thesis....17
Table 2 Typical cost drivers in manufacturing industries....18
Table 3 Product development phases....26
Table 4 Qualitative estimation methods....37
Table 5 Quantitative estimation methods....39
Table 6 Detected gaps and targeted future states....46
Table 7 Recommendations and actions to close the gaps....49
Table 8 Main characteristics of products' production life cycles....53
Table 9 Cost drivers and hypotheses....56
Table 10 Results from analysis and data for further estimation....63
Table 11 Cost-component-ratio in three products....66
Table 12 Summary of gap analysis....77

LIST OF FIGURES

Figure 1 Solar photovoltaic system principle 10
Figure 2 Solar inverter 11
Figure 3 Keywords utilized in the literature review 14
Figure 4 Cost classification........ 19
Figure 5 Product life cycle in six phases 22
Figure 6 Product life cycle in four phases 23
Figure 7 ABB life cycle model 24
Figure 8 Production life cycle in this thesis........ 25
Figure 9 Product cost accumulation during product life cycle 27
Figure 10 Target costing process 32
Figure 11 Product cost estimation methods........ 36
Figure 12 Learning curve of solar PV modules 40
Figure 13 Organization’s current product cost management process........ 43
Figure 14 Main cost drivers in solar inverters 52
Figure 15 Cost data analysis process 55
Figure 16 Labour costs development over time........ 58
Figure 17 Labour costs and cumulated production volume in four periods 59
Figure 18 Labour cost histograms 59
Figure 19 Labour costs in product B without specific options 60
Figure 20 Labour costs in product B with specific options 60
Figure 21 Material cost development in product A 61
Figure 22 Material cost development in product B 61
Figure 23 Labour cost estimation method 67
Figure 24 Estimated labour cost development........ 68
Figure 25 Product breakdown structure and direct material costs........ 69
Figure 26 Material cost estimation follow up........ 70
Figure 27 Material overhead calculation 71
Figure 28 Estimated material cost development........ 72

ABBREVIATIONS

ABC Activity-based costing

AC Alternate current

BOS Balance of system

BOM Bill of material

BPNN Back-propagation neural network

CBR Case-based reasoning

DC Direct current

DSS Decision Support Systems

OH Overhead

OpEx Operational Excellence

PV Photovoltaic

SCM Supply Chain Management

1 INTRODUCTION

1.1 Background and motivation

The pressing need to decarbonize energy systems while combating climate change has highlighted the importance of renewable energy sources and technologies (Strupeit & Neij 2017). Over the past decade, solar photovoltaic (PV) has risen globally as a significant alternative to replace fossil fuels in meeting future energy targets (Trappey et al. 2016). Solar PV has appeared as one of the most promising technologies due to its capability to generate electricity in a clean and decentralized manner without consuming fuels (Strupeit 2017). The spread of solar PV has faced numerous challenges such as high up-front investments and capital costs (Strupeit & Neij 2017) which have hindered its growth. Hence, solar PV has been forced to constantly improve its cost competitiveness.

Markets for solar PV have experienced dramatic growth coupled with remarkable changes in business environment, volatility in costs (Candelise et al. 2013) and decrease in system prices (Comello et al. 2018). According to Nemet (2006) PV system costs have declined by a factor of nearly 100 since the 1950s. Clear historical cost drivers have been learning curve effect (Trappey et al. 2016), market expansion (Candelise et al. 2013), public policies such as direct incentives, renewable energy targets and environmental concerns (Mir-Artigues & del Rio 2016) as well as increasing power demand in emerging economies, energy independency (Comello et al. 2018) and costs of key production inputs (Trappey et al. 2016). Researchers have evaluated that further cost decline is still needed (Strupeit & Neij 2017).

Simplified, solar PV systems can be divided into two main parts. First, the module which converts sunlight into electricity and second, the balance of system (BOS) which means everything else needed for the system such as inverter, cables, bolts, labour and grid connection (Elshurafa et al. 2018). PV systems are typically completed with different control and monitoring solutions (ABB 2018). Solar photovoltaic system principle is presented below (Figure 1).

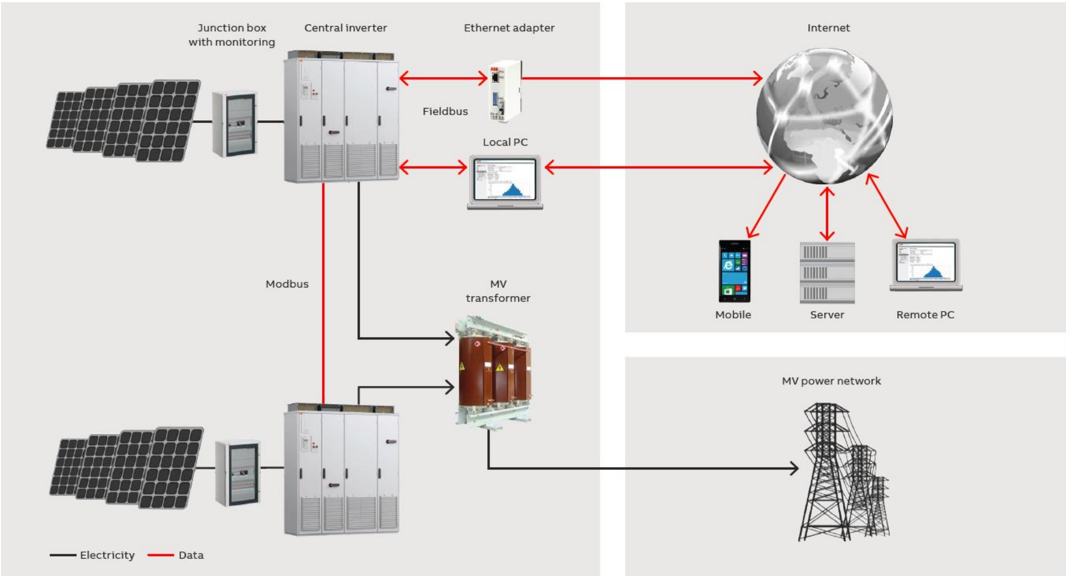

Figure 1 Solar photovoltaic system principle (ABB 2018)

In this thesis, the focus is on solar inverters. Solar inverters are devices that convert direct current (DC) from solar panels to alternate current (AC) of the required frequency which is then supplied to the electric grid (Fraunhofer ISE 2015). Inverters can be categorized into three types – centralized inverters, string inverters and micro inverters according to their power ratings (Obeidat 2018). The proportion of inverter costs of the whole PV system costs has varied over time. For instance, Strupeit & Neij (2017) have evaluated that inverter costs have typically been around 14 % of total system costs, whereas Xue et al. (2011) have estimated that costs have been around 8-12 %. One example of solar inverters is presented below in figure 2.

Figure 2 Solar inverter (ABB 2018)

Previous studies have mainly focused either on the costs of PV modules or entire PV systems. For instance, Mir-Artigues & del Rio (2016) have highlighted that a profound study of the technological and economic trajectory of solar inverters has been missing. Only few studies have evaluated the costs of solar inverters (Strupeit & Neij 2017) even though inverter manufacturers are also under constant cost pressure. One significant challenge for researchers has been, that accurate cost information from solar inverters has been difficult to obtain due to its sensitivity to inverter manufacturers (Elshurafa et al. 2018).

It is undisputed that inverter costs and market prices have continually reduced. Borenstein (2008) have evaluated that costs of solar inverters have been going down annual by 2 % in real terms. Typically, decline has been evaluated using learning curves and learning rates. Learning rate is based on the observation that costs change by an individual percentage every time the cumulative production volume doubles. Inverter manufacturer SMA have suggested learning rate of 18.9 % between years 1990 and 2014. (Fraunhofer ISE 2015) Also, Richter et al. (2013) have evaluated that the inverter learning rate has been around the range of 10 %.

Due to the high competition and constant cost pressure, product costs, efficient cost management and estimation of future product costs have risen to a crucial role and to key focus for design and operational strategies (Candelise et al. 2013). As development of solar inverters takes typically several years, it has become more critical to be able to estimate future product costs already during the early phases of product development. For instance, Oancea et al. (2010) have highlighted that products must be designed and manufactured rapidly with competitive costs and good quality.

Product cost estimation is a complex process which must deal with many uncertainties. First product cost estimates are typically done with inadequate information as actual cost information is not yet available. Rapidly changing dynamics of solar PV business, volatility in costs as well as the complex mix of underlying drivers deep challenges for estimation. (Candelise et al. 2013) It is not surprising that estimation of product costs in new product development has been a challenge for both academia and practitioners (Mousavi et al. 2015). Researchers have agreed that estimation methods used this far are not accurate enough to estimate product costs in a sufficient manner (Candelise et al. 2013) and one-size-fits-all mentality doesn’t work in product cost estimation by any means. Hence, there is an active need for improving and developing product cost estimation methods.

This thesis is done in collaboration with ABB Oy Solar which develops and manufactures solar inverters. Organization has recognized a growing need to develop its practices considering solar inverter cost estimation throughout inverters’ production life cycle. Also, organization wishes to evaluate its current state of product cost management in order to detect the main shortages and improvement possibilities. Organization’s main aim for this thesis was to find ways to improve operation throughout more efficient and systematic product cost management and to enhance the ability to estimate product costs in a more comprehensive manner already at the early phases of product development.

1.2 Research objectives, questions and limitations

The objective of this thesis was twofold. First, to analyze how product cost development can be estimated already at the early phases of product development and second to evaluate how organization could improve its product cost management practices. To achieve these research objectives, three research questions were identified. Answers are given in the conclusion chapter.

- What are the main cost drivers in solar inverters?
- What should be considered in organization to ensure more efficient product cost management?
- How future product cost development can be modeled and estimated?

Limitations are done according to organization's assignment to solar inverters developed in Helsinki. The focus is on product costs and especially on material and labour. Both direct and indirect costs are considered. Costs incurred from product development project, marketing, sales, distribution and logistics as well as associated risks are excluded. Also, product life cycle is limited to production life cycle starting from product development and ending up to the end of the production. Hence, costs caused from commissioning, usage and disposal are excluded.

1.3 Research methodology

This thesis consists of theoretical and empirical sections and complies with case study strategy. In general, case study strategy concentrates on a specific case or problem by describing and examining it profoundly (Saunders et al. 2016). In this thesis, case and problem refer to organization's current product cost management practices which need profound evaluation and improvements. Case study strategy does not aim to make a description of the whole phenomenon and hence, the generalizability of the gained results is always limited (Saunders et al. 2016).

At first, theoretical framework is conducted as a literature review. Theoretical section sheds light on previous research on product cost management and product cost development estimation. Also, typical cost classifications are presented.

Research material is gathered from existing literature, articles and internet sources. Main keywords utilized in the literature review are presented below (Figure 3).

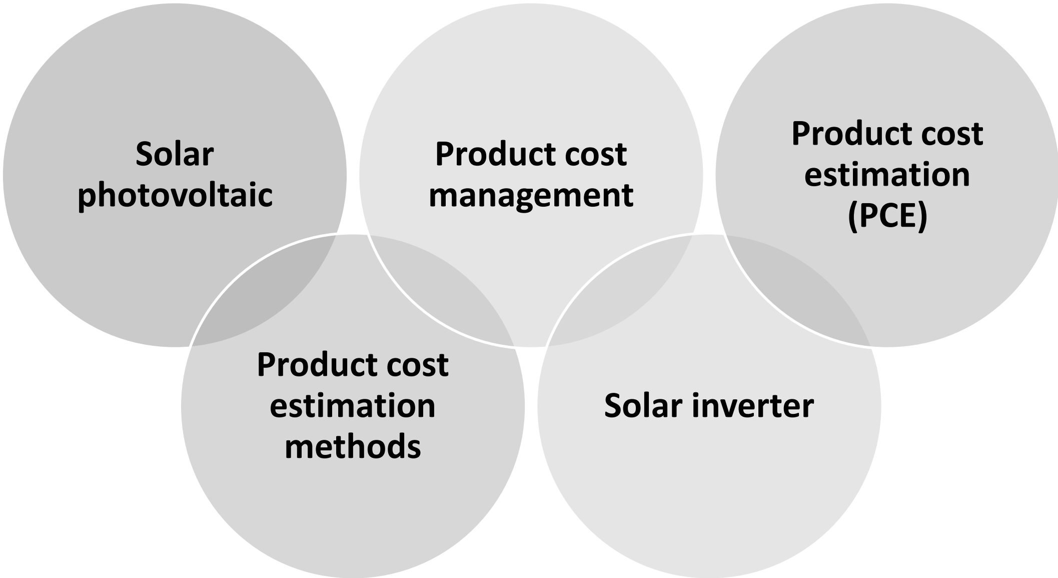

Figure 3 Keywords utilized in the literature review

After theoretical section, empirical research is conducted. Empirical research consists of evaluating organization's current state of product cost management and product cost estimation practices, ending up to the creation of a new product cost development estimation method and giving recommendations for organization's further product cost management. Empirical research is done using design science approach. In practice, design science approach aims to develop valid knowledge to be used in the improvement of the performance of existing entities and to design solutions to specific problems (Aken 2004). In this thesis, improvement proposals and developed product cost estimation method are results from utilizing design science approach.

Empirical research material is based interviews, gap analysis and cost data analysis. Interviews were used to gather knowledge of organization's current product cost management and product cost estimation practices. Interviewees were local product group manager, business controller, quality manager, project managers, product managers and product development manager. Due to interviewees' different positions in the organization, common question template could not be used. Besides formal interviews, information was also gathered through discussions.

Gap analysis was used to detect and define organization's main gaps, shortages and improvement areas related to product cost management and product cost estimation. Gap analysis was selected as it is a useful tool to narrow the gaps between existing and desired performance levels (Chevalier 2010). Costing data was gathered mainly from organization's ERP system and different databases. Costing data was used to evaluate the main cost drivers of manufactured solar inverters as well as to analyze inverters' cost behavior over time. Actual analysis and calculations were done using Microsoft Excel and Minitab software. Results from cost data analysis were used to develop the new product cost development estimation method.

1.4 Structure of the research

This thesis consists of seven chapters. Chapter one is introduction, which includes general information of the background, objectives and goals of this thesis. Also, research questions and major limitations are presented. Chapter one is followed by chapter two, where product cost, product cost development, product and production life cycles as well as product cost management are defined as a concept. It is also presented the main challenges related to product cost definition and accounting in general. Chapter three presents typically used product cost estimation methods. Chapters one, two and three construct the theoretical framework of this thesis.

Chapters four and five construct the empirical section. In the fourth chapter, a gap analysis is conducted considering organization's product cost management and product cost development estimation practices. First, organization's current state is described which is then followed by defining the targeted future state. Second, gaps between current and targeted states are defined and named. Lastly, recommendations of actions to close the gaps are presented.

Chapter four is followed by chapter five. At first, main solar inverter cost drivers from existing studies and literature are presented. Then, cost data analysis process is described in general. Recognized solar inverter cost drivers from literature are used to establish hypotheses for actual cost analysis. Based on results from gap analysis, cost data analysis and literature findings, hybrid product cost estimation method is developed.

Chapter six contains the conclusion of the study where the theoretical and empirical sections are brought together. Also, answers for research questions are presented. Last, validity and reliability of the study are evaluated and aspects for further study assessed. Chapter seven is summary which outlines the general picture of the whole thesis. Structure of the thesis is presented below using input-output-chart (Table 1).

Table 1 Structure of the thesis

Input	Chapter	Output
Background and motivation	1 Introduction	Objectives, research questions, limitations, methods and structure of the thesis
Existing product cost and product cost management literature and previous studies	2 Product costs development and management in production life cycle	Understanding of product cost classifications, product cost structure, challenges related to product cost definition and general view on product cost management
Existing product cost estimation literature and previous studies	3 Product cost development estimation	Understanding of typical product cost development estimation methods and main shortages related to them
Understanding of product cost management principles as well as results from interviews, discussions and observations	4 Gap analysis of organization’s product cost management and estimation	Organization’s main gaps named and defined, targeted future states set, and recommendations given how organization could close the gaps
Detected shortages through gap analysis, production cost data analysis and gathered understanding of existing product cost estimation methods	5 Method for product cost development estimation	Method to help in establishing the first product cost estimate and to support in estimating product cost development throughout production life cycle
Theoretical framework of the study and results from empirical section	6 Conclusion	Answers to research questions, evaluation of the reliability and validity of the research and aspects for further study
The whole study	7 Summary	General picture of the whole thesis

2 PRODUCT COST DEVELOPMENT AND MANAGEMENT IN PRODUCTION LIFE CYCLE

2.1 Definition of costs and cost drivers

In this thesis, costs refer to the sum of the money spent in terms of labour, materials and use of equipment to produce a product (Layer et al. 2002). Nonetheless, costs are defined in several ways in existing literature. Costs can be determined as a monetary value of all those resources that are used to perform activities (ISO 14051 2011) or as a cash equivalent value needed to achieve targets such as produce a product (Kinney & Raiborn 2009, 752). Cost drivers refer to all those factors that affect costs (Horngren et al. 2006, 32) and have a clear cause and effect relationship to specific cost items (Kinney & Raiborn 2009, 28). Cost drivers can be categorized in multiple ways and for example into volume-related and non-volume-related cost drivers (Kinney & Raiborn 2009, 106). In turn, categorization can be much wider when cost drivers are used as determinants in activity-based costing (Bhimani et al. 2012, 128-129). Activity-based costing is presented in chapter 2.4. Typically used cost drivers in manufacturing industries have been labour hours and production volume (Ben-Arieh & Qian 2003). A few cost drivers are presented below (Table 2).

Table 2 Typical cost drivers in manufacturing industries (adapted from Bhimani et al. 2012, 33; Ben-Arieh & Qian 2003)

Activity	Cost drivers
Product development	Number of engineering hours Number of design tools used Number of new product proposals
Production	Production volume Labour hours Machine hours Number of production setups Number of workers
Distribution	Labour hours Weight of items delivered

Costs can be classified according to various criteria and from different perspectives. One fundamental classification has been to divide costs into variable and fixed costs (Neilimo & Uusi-Rauva 2012, 56) depending on how they change as the level of a cost driver changes (Bhimani et al. 2012, 33). Variable costs such as raw materials, semi-finished products and subcontracted services are expected to develop in direct proportion to changes in the cost driver. In other words, variations in the specific cost driver explain the changes in the related cost item. (Neilimo & Uusi-Rauva 2012, 56) For example, when production volume increases, typically more raw material is needed.

Fixed costs are expected to remain constant over the certain period despite all the possible changes in the cost driver (Horngren et al. 2006, 30: Bhimani et al. 2012, 34). Depreciations, costs of capital, rent of manufacturing plant, electricity and heating are typically considered as fixed. Fixed costs are mainly originated from sustaining organization’s production capacity. (Kinney & Raiborn 2009, 26)

It is possible that cost has both fixed and variable cost behavior elements and is then called *mixed cost* (Bhimani et al. 2012, 79-80). Mixed cost does not change in direct proportion to changes in the cost driver, nor does it remain constant (Kinney & Raiborn 2009, 27). Nonetheless, whether costs can be classified fixed or variable depends always on the length of the considered period (Bhimani et al. 2012, 38) as it has been observed that over longer period all costs will appear variable (Drury 2013, 30). One traditional cost classification is presented below in figure 4.

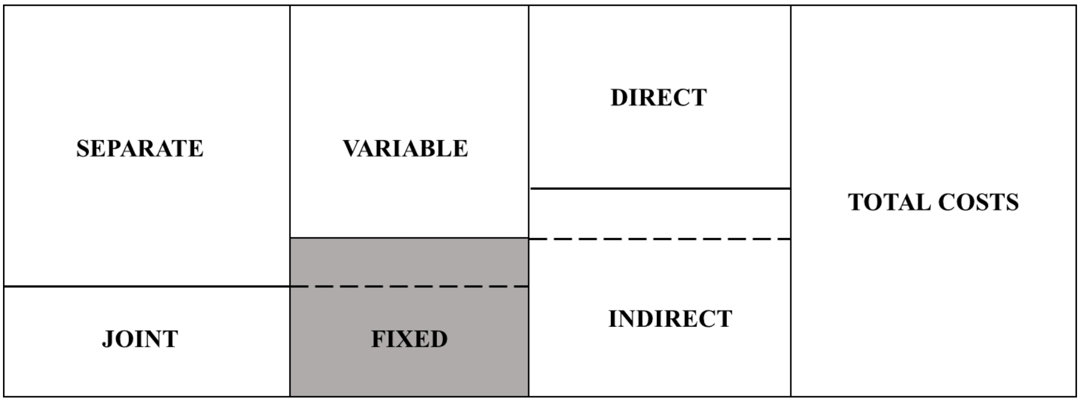

Figure 4 Cost classification (Neilimo & Uusi-Rauva 2015, 55).

Especially in product costing, fixed and variable costs are typically divided further into direct and indirect costs, depending on their traceability to the finished products (Drury 2013, 26). Direct costs such as raw materials and labour can be clearly assigned to the product in an economically feasible way (Horngren et al. 2006, 27: Bhimani et al. 2012, 118). Direct material is typically the biggest cost item in industrial products (Neilimo & Uusi-Rauva 2015, 89). In turn, direct labour refers to all that labour that can be traced to the product such as wages paid to assembly workers who convert direct materials to the finished products (Horngren et al. 2006, 42).

Indirect costs are related to the product but those cannot be directly assigned to it. For instance, depreciations on production equipment (Bhimani et al. 2012, 118), energy costs (ISO 14051 2011), insurances (Oancea et al. 2010) and leasing expenses (Ben-Arieh & Qian 2003) are typically considered as indirect costs. Different cost allocation methods are used to assign indirect costs to the products. Typically used methods use volume-based measures such as labour hours (Tyagi et al. 2015) or costs (Lere 2001) as allocation denominator. Allocation methods have been widely criticized as they always estimate the approximate cost instead of accurate cost (Tyagi et al. 2015).

Appropriate handling of indirect costs is crucial as inadequate handling of costs can cause an unprofitable product to appear profitable. Researchers have recognized that most organizations succeed to handle their direct costs but there are shortages when it comes to their indirect costs. (Lere 2001) Also, Bhimani et al. (2012, 139) have outlined that typically the greater the proportion of direct cost, the greater the accuracy of organization’s understanding of costs.

Also, costs can be categorized into separate and joint costs. Separate costs are originated from the production of a specific product and those do not exist, if organization decides not to manufacture the product (Neilimo & Uusi-Rauva 2015, 59). Joint costs relate to more than one product and those cannot be assigned to an individual product (Bhimani et al. 2012, 548). Joint costs such as rent of manufacturing plant will stay even one product is decided not to manufacture or production volume changes (Neilimo & Uusi-Rauva 2015, 59).

Classification of costs can be extremely challenging. It is not always obvious, is cost direct or indirect either fixed or variable. Researchers have recognized several problems related to cost accounting and product cost definition in general. Neilimo & Uusi-Rauva (2015, 41-43) have determined four problems. The first one is called scope problem which means that it can be complicated to determine which costs should be included in accounting. Usually, the principle has been that such costs are counted which are directly caused from the production of a certain product. The second problem is called allocation problem which consists of two sub-problems. The first one considers decisions on how capital costs are allocated to the product and the second how corporate level indirect costs are allocated. (Neilimo & Uusi-Rauva 2015, 41-43)

The third problem is called valuation problem. Valuation problem considers decisions which values are used in actual accounting. This problem originates from the observation, that it is possible that there are multiple values which could be used. For instance, material and components can have different prices such as their original purchase price, actual inventory value or actual replacement value and decision must be done, which of these are used. The fourth problem is called measurement problem, which refers to the overall complexity of obtaining reliable and accurate measurements. (Neilimo & Uusi-Rauva 2015, 41-43)

Detection of major cost drivers and cause and effect relationships can be complicated as well because multiple factors cause cost incurrence (Kinney & Raiborn 2009, 28). If cost drivers are used as denominator to allocate indirect costs to products, this is extremely critical. Organization must evaluate which cost drivers are beneficial to consider and assess how significant is the degree of correlation between cost drivers and cost items. Organizations should have a reliable selection of cost drivers in order to evaluate product costs efficiently. At the same, costs caused from data collection and processing should be minimized. (Levitan & Gupta 1996)

2.2 Product and production life cycle

Researchers have presented various models over time to describe product life cycle. Their perspectives have varied from single product to the whole product generation and from the entire product life cycle to the limited life cycle phases. According to ISO 14040 (2006) life cycle can be defined as a consecutive and interlinked stages of a product system starting from raw material procurement and ending up to disposal. For example, Layer et al. (2002) have divided product life cycle into three phases - product creation, use and disposal. In turn, Kärri et al. (2015, 31) have recognized six phases and divided product life cycle into conceptual design, design and development, production, commissioning, usage and maintenance and last disposal (Figure 5).

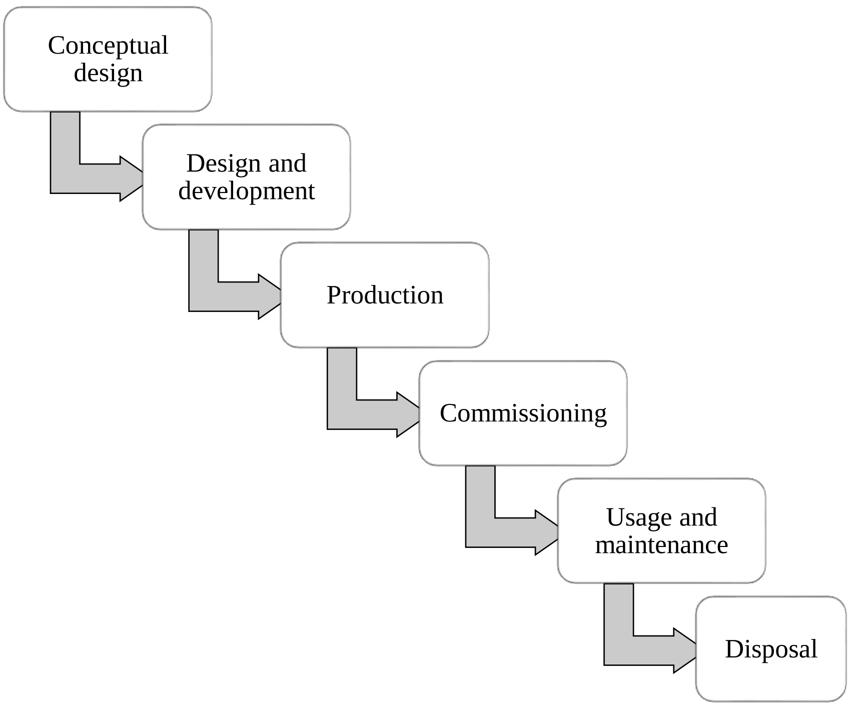

Figure 5 Product life cycle in six phases (adapted from Kärri et al. 2015, 31)

According to Bayus (1998) product life cycle refers to the time between product's introduction to the market and withdrawal from markets. Thus, life cycle can be defined as the evolution of units sold over the entire product lifetime. Product lifetime can be further divided into introduction, growth, maturity and decline phases. Kinney & Raiborn (2009, 676) have defined introduction phase as the life cycle phase where product has been launched and its sales volume is still relatively low. Introduction phase is followed by growth phase where sales volume increases. After growth, sales volume stabilizes at maturity phase and then decreases gradually at decline phase. This model is presented below (Figure 6).

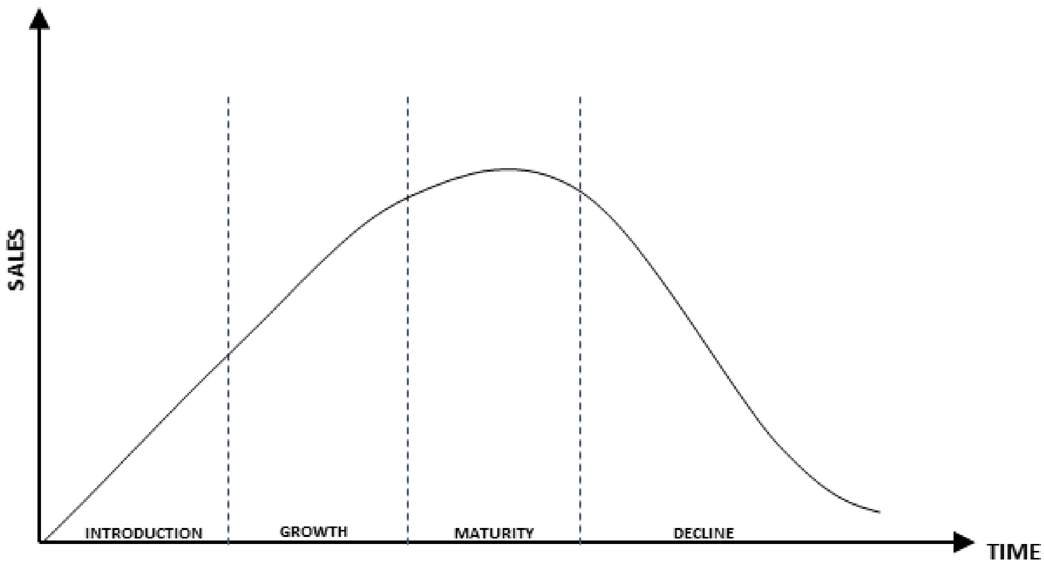

Figure 6 Product life cycle in four phases according to Bayus (1998)

The shape of the product life cycle curve can vary among different products and industries. For instance, some products can stay in maturity phase for extended period. (Taylor & Taylor 2012) Also, there are industries such as mobile phones, where the product generations follow each other in a relatively fast pace which significantly influences on the shape of the curves. Technology-based industries such as electrical equipment and energy are characterized by a longer life cycles. (Fortuin & Omta 2007)

In addition, companies such as ABB have presented their own product life cycle models. ABB's model starts from product's active phase and ends up to obsoleting phase. ABB's model is presented below (Figure 7).

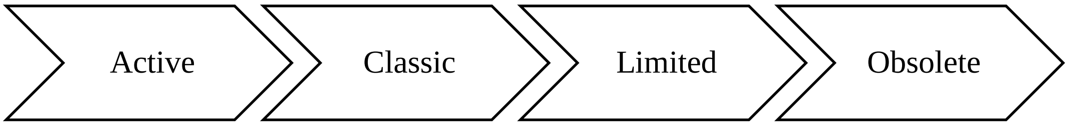

Figure 7 ABB life cycle model **(**adapted from ABB 2011**)**

In ABB’s model, active refers to the life cycle phase where product and related spare parts are available and product is fully supported with a range of services and product design enhancements. Also, sales and marketing activities are actively done. In classic phase product has been replaced by a new active product and marketing activites are finished. Product may still be available as a spare part or for extension purposes. In addition, product life cycle enhancements are supported through upgrade and retrofit solutions and spare parts are available. In limited and obsolete phases product is no longer available and migration to new active product is highly recommended. The difference between limited and obsolete phases is that spare parts are still available in limited phase. (ABB 2011) ABB’s perspective differs significantly from traditional life cycle models presented above, as the focus is especially on end users’ services. Also, consideration is limited from introduction to the market to the withdrawal from markets and related aftersales services.

In this thesis, the focus is on life cycle phases from product development to the end of the production. This is further named as production life cycle. Production life cycle phases are divided into concept phase, design phase, production ramp up, production and production ramp down according to organization’s own classification. Production life cycle is presented below (Figure 8).

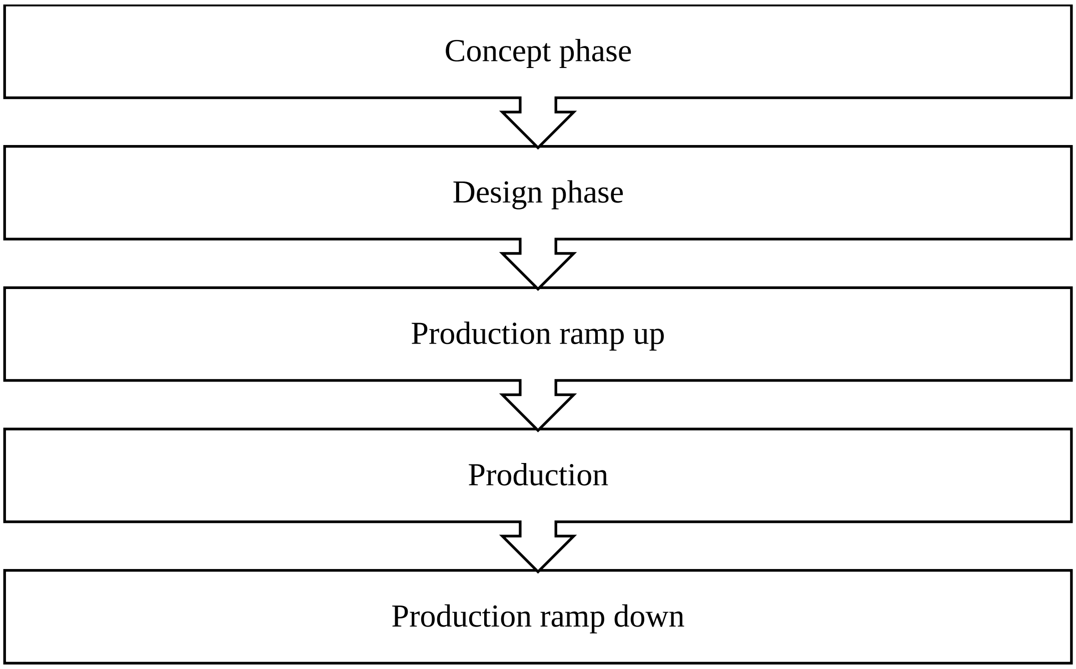

Figure 8 Production life cycle in this thesis

Researchers have recognized that changes in manufacturing technologies and continuously increasing customer requirements as well as intensive global competition have caused product life cycles to be shortened. For this reason, the role of the new product development has highlighted (Bayus 1998). At the same time, shorter product development times as well as getting products faster to markets have become critical (Layer et al. 2002). First mover advantages and importance of more demanding product functionalities have been emphasized (Relich & Pawlewski 2018). For instance, Wu & Chang (2011) have outlined that nowadays product development will not only promote the competitive advantage but also keep the business alive.

According to Davila (2000) product development process can be divided into planning, conceptual design, product design, testing, and production start-up phases (Table 3).

Table 3 Product development phases according to Davila (2000)

Phase	Actions
Planning	Define target customers and the main characteristics of the product
Concept design	Specify the product specification and requirements for product development project
Product design	Actual development of the product
Testing	Confirm that product meets its objectives and targets
Production start-up	Prepare product

Typically, product development starts with planning phase, where organization defines the main characteristics of the product to be developed. Characteristics can consider for instance general product functionalities, performance requirements and target price. In concept design phase, product specifications are determined in more detail and requirements for the actual product development project are set. Typically, requirements consider design costs, market release date and allocation of organization's resources. Concept design phase is followed by product design phase, which means the actual development of the physical product. In turn, testing and production start-up are needed to ensure that product meets defined targets and requirements and it is ready for the introduction to markets. (Davila 2000)

Nowadays, new product development projects are typically started while previous product generations are still developed. Also, product development processes rely usually heavily on previous products and gathered organizational experience and knowledge. (Tyagi et al. 2015). According to Relich & Pawlewski (2018) modern products are seldom designed totally from scratch.

2.3 Product cost development

According to Layer et al. (2002) product costs can be defined as the sum of the costs incurred in manufacturing. Hence, product costs include product development costs, production planning costs as well as material and labour costs. Product development phases are count mainly responsible for determining product costs. Researchers have evaluated that almost 80 % of the product costs are locked during the early phases of production life cycle. (Tyagi et al. 2015) Cost development and cost accumulation in one product during its production life cycle is illustrated below (Figure 9).

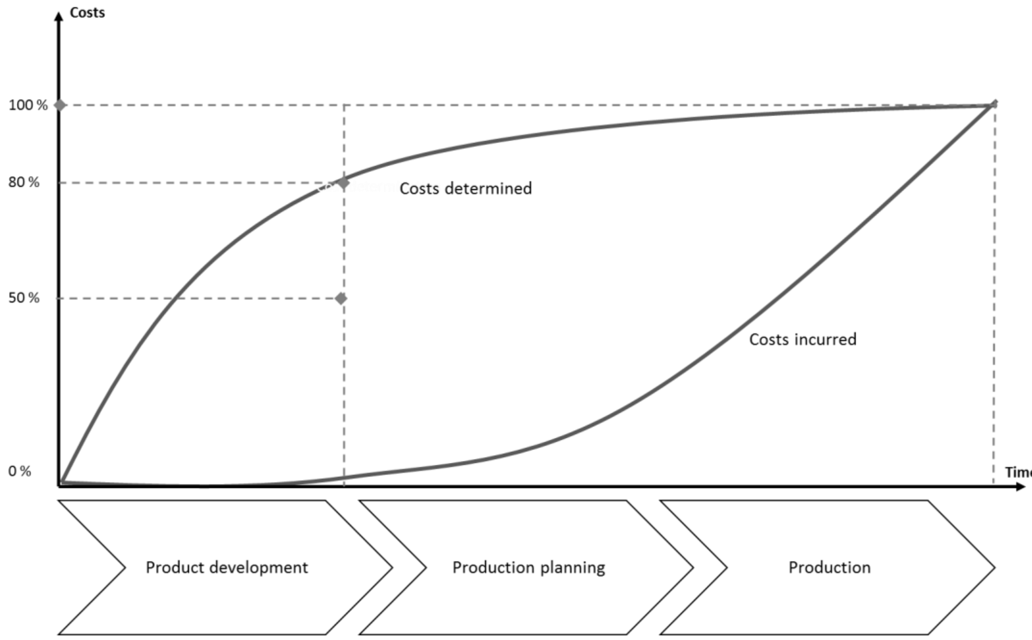

Figure 9 Product cost accumulation during product life cycle (adapted from Layer et al. 2002; Uusi-Rauva & Paranko 1998)

When considering the whole product generation from the first produced units to the last produced units, product costs typically change. Kinney & Raiborn (2009, 674-675) have evaluated that during the product introduction phase, product costs can be significant mainly due to low sales volumes and costs caused from activities such as marketing. In turn, product costs are typically at their lowest level in the maturity phase where sales volume is at its highest. This can be explained by scale effects, where fixed costs can be distributed over a larger number of units (Strupeit 2017).

On the contrary, in decline phase, production costs typically increase because fixed costs are spread over a smaller production volume (Kinney & Raiborn 2009, 675).

Groth & Kinney (1994) have stated that product costs change for a variety of reasons including changes in supply and demand. For instance, labour costs can develop during production life cycle due to organizational learning, gathered experience (Weber 2013) and changes in overall labour markets (Samadi 2016). The economic value of organizational learning can vary and be either positive or negative. Organizational learning can be divided into learning by doing, production volume learning, production quality learning, process quality learning and design learning. For instance, production can become faster when employees get familiar with products and used methods and tools. Also, as more and more units are manufactured, understanding is gathered how production could be improved. For example, organization can detect waste and bottlenecks in its manufacturing processes which can be eliminated. (Weber 2013)

Material costs can vary for instance due to raw material price fluctuation (Trappey et al. 2016), volatility in existing currency rates (Groth & Kinney 1994), product design changes, technology advancements and spillovers from other technologies (Samadi 2016). Also, organization can gain scale effects when purchasing components and materials while production volume increases (Strupeit 2017). However, Tyagi et al. (2015) have questioned the effect of product design changes on material costs because they have observed that today's incremental innovations are not radically changed, and products are only improved versions of existing designs.

There are also several political and regulatory factors which can influence on product costs and product cost development. For instance, Candelise et al. (2013) have highlighted the effect of international trade practices and market support mechanisms. Also, Samadi (2016) have pointed out, that environmental, health and safety standards have become stricter over time. Even though Samadi (2016) has considered standards and requirements from the perspective of electricity generation technologies, those can concern also manufacturers of high-tech products.

2.4 Product cost management

Competitive business environment exerts an increasing pressure on effective cost management. Cost management has raised among the most important managerial tools and techniques among manufacturing companies. (Diefenbach et al. 2018) There is no general definition of the scope of the cost management and hence, it has been defined by several ways. According to Ho (2015) cost management refers to the management of business operations through accurate measurements and thorough understanding of the total costs of organization's processes, products and services. In turn, Zengin & Ada (2010) have stated that the main purpose of cost management is to maintain organization's profitability and to achieve competitive advantage. Diefenbach et al. (2018) have defined cost management as actions to influence on costs and sales in order to increase the organization's efficiency. Also, Diefenbach et al. (2018) have mentioned, that cost management can be referred to tool or set of tools to gather and deliver information for strategic management purposes. Also, Günther & Gäbler (2014) have stated that the fundamental purpose of cost management is to influence on organization's total or unit costs, cost structure and cost development.

Cost management can be divided into reactive and proactive cost management (Günther & Gäbler 2014). Reactive cost management consists of punctual and non-permanent activities and it tries to respond to short term changes (Diefenbach 2018). In turn, proactive cost management is continuous and comprehensive process (Günther & Gäbler 2014). Cost planning, control and monitoring, management of outputs to maximize cost-benefit-relationships (Diefenbach 2018) as well as structural functions such as creation of cost culture in organization and training can be considered as part of cost management activities (Günther & Gäbler 2014).

Product cost management is needed to balance customer satisfaction, product quality and functionalities while trying to minimize product costs. Product cost management is sometimes mixed up only with product cost reduction activities. (Zengin & Ada 2010) Product cost information is also needed for financial accounting requirements and to provide useful information for managerial requirements. For instance, comparisons between planned and actual costs allow organization to evaluate the profitability and to support in further decision making. (Drury 2013, 70)

Product cost management has received constantly more attention especially in product development phases. Traditionally, budgets have been more important than product costs and product development projects have been rarely killed because they have not met cost targets. Typical challenge that companies have faced has been how to consider product costs efficiently during product development phases without shifting the attention on costs and away from critical objectives such as time-to-market and customer requirements. (Davila & Wouters 2004) Also, Tyagi et al. (2015) have questioned design engineers' capability to evaluate costs while they are trying to optimize product designs.

Technology challenges and demand for fast time-to-market limit the attention that designers can assign to product cost estimation in product development. When fast time-to-market and technology are key to organization's profitability, product development have neither time nor attention to evaluate all design alternatives or their costs. Hence, designers look for such alternatives that solve problems quickly and move to the next problems. Cost reduction acitivities often get postponed until the product reaches the production phase. (Davila & Wouters 2004)

Several methods have been developed to support in product cost management at different phases of production life cycle (Zengin & Ada 2009). Typically used cost management methods have been activity-based costing (ABC), budgeting (Diefenbach 2018), product life cycle costing (Günther & Gäbler 2014) and target costing (Davila & Wouters 2004). However, Günther & Gäbler (2014) have evaluated in their study, that the proportion of those organizations that use systematically target costing, product life cycle costing either activity-based costing in their product cost management, is below 30 %. Hence, there is an active need to improve organizations' product cost management practices in general.

For instance, ABC system accumulates indirect costs for each of the activities performed to produce a product and assigns the cost of activities to the product (Bhimani et al. 2012, 128-129). Traditionally, ABC systems have been criticized due to their complexity and time-consuming implementation. Still, those have given more accurate results than traditional costing systems. (Ben-Arieh & Qian 2003) For instance, Lere (2001) has highlighted that ABC systems are less likely to misstate product's profitability than traditional methods. Also, Ben-Arieh & Qian (2003) have stated that using ABC method can help organizations to detect and eliminate non-value adding activities as well as to improve the accuracy and relevance of product costing.

In turn, target costing approach was first introduced in 1960s in Japan as a proactive cost management tool. Since, it has been implemented in several industries. Target costing aims to manage product costs during the whole product development phase. It complies market requirements by integrating customer requirements, technical requirements and cost information into the product design phase. (Zengin & Ada 2010) The fundamental idea has been, that costs are considered as input to the product design rather than output (Tyagi et al. 2015). In practice, price and profit margins are taken as given from the markets and those together determine the maximum cost the organization can spend (Bhimani et al. 2012, 199). Zengin & Ada (2010) have highlighted, that target costing approach should be understood as a comprehensive cost management method rather than a cost reduction technique. Simple target costing process is presented below (Figure 10).

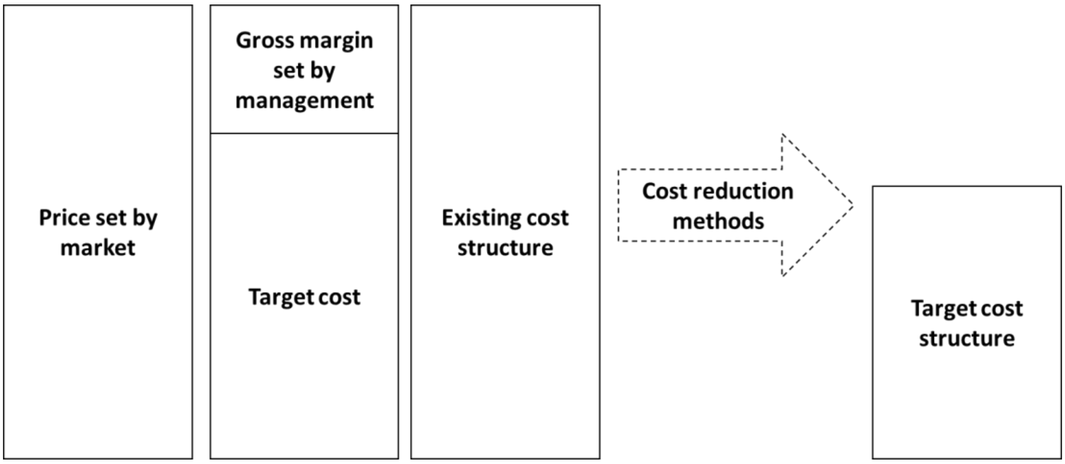

Figure 10 Target costing process according to Bhimani et al. (2012, 200)

For instance, Zengin & Ada (2010) conducted a case study to one manufacturing company about implementation of target costing approach. At first, they analyzed customer requirements by sending questionnaires to testing system experts and companies that use their products. As a result, 10 critical quality factors were defined. Market research was conducted in order to evaluate the target selling price based on market conditions and customer requirements. Then, profit margin and target cost were defined. After defining the target cost, product cost was determined using the target costing approach. Then, the main cost drivers were subjected to cost reductions through product design. After the target cost was reached, idea of continuous improvement was implemented. Despite some challenges in the beginning, such resistance of a change and some technical and practical difficulties, implementation led into cost reductions, cost advantages and elimination of non-value-added functions of products.

Overall, cost management efforts should be moved from production to the product development phases. Davila & Wouters (2004) have highlighted that this could lead to larger profits when cost reduction advantages could accumulate already from the first units. Also, it would enable organizations to use product development resources more efficiently to innovative ideas instead of modifying existing product designs to reduce costs. If costs are neglected in the beginning of product development, it can force organization to reduce costs at later stages. (Davila & Wouters 2004) Davila & Wouters (2004) have compared product cost reduction projects after product introduction to market even to quality problems. While the product design is still unsettled, it is usually easier and cheaper to do design changes than after product launch. What makes things even more complicated is that typically knowledge of costs increases during the product development project but at the same time the possibilities to make design changes decrease. (Davila & Wouters 2004)

For instance, Günther & Gäbler (2014) have evaluated what are the key requirements for successful product cost management in general. They have highlighted especially the importance of available organizational resources such as humans and tools, management support, organizational knowledge and continuous approach towards cost management. Also, Diefenbach (2018) have outlined goal-orientation, cost-conscious organization culture, top management commitment and efficient methods for actual measuring, controlling and influencing on cost relevant decisions and processes.

3 PRODUCT COST DEVELOPMENT ESTIMATION

3.1 Background of the product cost estimation

According to Huang et al. (2012) cost estimation aims to determine the quantities and costs of producing items. In turn, Park et al. (2002) have stated that cost estimation is typically involved in estimating the cost of a product which includes for instance research and development activities, actual design, manufacturing and marketing. Cost estimation and understanding the costs are essential for efficient operation and competitive production (Ben-Arieh & Qian 2003). Researchers have agreed that an accurate and robust cost estimation can offer competitive advantage (Tyagi et al. 2015). Nonetheless, accurate cost estimation has been a challenge for both academia and practitioners due to its complexity (Mousavi et al. 2015).

Importance of product cost estimation has highlighted especially during product development phases where the product costs are mainly locked (Zhang et al. 1996). Constantly more efforts should be put in evaluating the desing alternatives to make the product more cost-effective and competitive (Tyagi et al. 2015). Ahn et al. (2014) have underlined the importance of cost estimation especially during conceptual design phase. Also, Huang et al. (2012) have assessed, that those companies which fail to estimate their product costs at the conceptual design phase, have a higher probability of schedule delays and product cost increases at later development phases. Clear benefits of having accurate product cost estimates include identification of major cost drivers as well as critical activities for economic success of the products (Tyagi et al. 2015).

Different cost estimation methods have been developed over time for various kind of needs and manufacturing applications (Ben-Arieh & Qian 2003). All methods have aimed to estimate product costs and product cost development in more accurate manner and with less information than previous methods. Still, one right way to estimate costs has not been found. (Tyagi et al. 2015) Quite less effort is put on product cost estimation at the early stages of product development to the entire production life cycle (Shehab & Abdalla 2002). One fundamental challenge has been, that complete theoretical model has not been existed or used. Cost estimation during early phases of product development is also more difficult because not all design decisions are agreed, and cost estimates must be done with inadequate information. (Tyagi et al. 2015)

The current trend in product cost estimation uses feature technology such as estimating costs by calculating the amount of various activities performed to produce a product (Layer et al. 2002). Also, the focus has been on getting more accurate results by developing integrated systems by combining elements from different methods (Relich & Pawlewski 2018). According to Davila & Wouters (2004) typical limitations of product cost estimation in high-technology industries have been that estimation is time and resource consuming and may shift the attention away from the key acitivities. Challenge has been how to integrate cost estimation into product development phases efficiently (Layer et al. 2002).

According to Tyagi et al. (2015) most of the existing methods use statistical data in estimation and typically inherit associated drawbacks. For instance, Layer et al. (2002) have stated that methods are not able to identify cost-driving product characteristics in a sufficient manner. Also, methods are typically based on past data and valid only under the current circumstances (Heidrich et al. 2007). Methods have been widely criticized about their lack of accuracy and incomplete estimates. For instance, Layer et al. (2002) have stated that none of the existing methods is able to determine costs with required accuracy. Also, existing methods cover only specific phases of production life cycle, interrupting the cost estimation workflow (Layer et al. 2002).

3.2 Estimation methods

Niazi et al. (2006) constructed hierarchical classification by grouping different estimation methods with similar features into same groups. They classified methods into qualitative and quantitative methods. Qualitative methods were further divided into intuitive and analogical methods whereas quantitative into parametric and analytical methods (Figure 11). This classification is also used in this thesis.

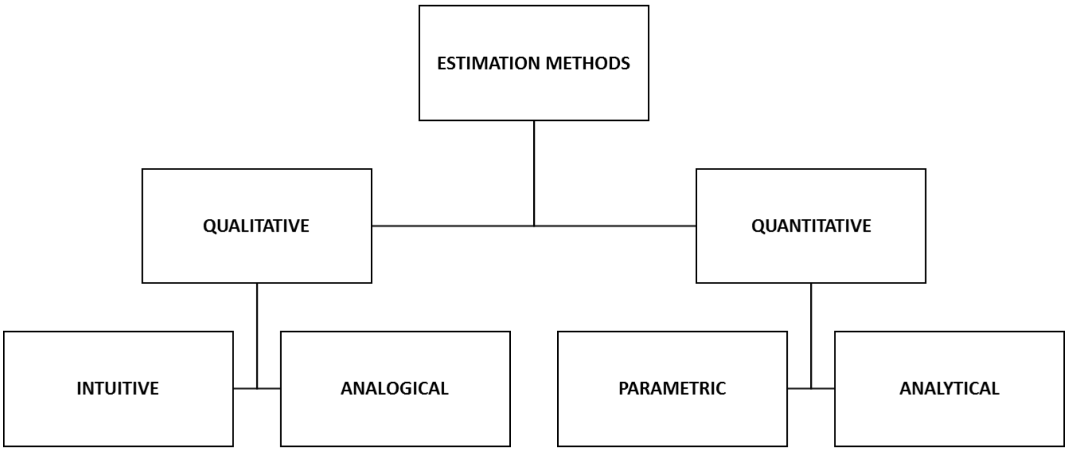

Figure 11 Product cost estimation methods according to Niazi et al. (2006)

Researchers have not agreed how cost estimation methods should be categorized. Several categorizations have been presented over time. Zhang et al. (1996) have divided product cost estimation methods into traditional detailed-breakdown, simplified-breakdown, group-technology-based and activity-based methods whereas Chevalier et al. (2010) into analogy-based, parametric and engineering approaches. In turn, Shehab & Abdalla (2002) have categorized methods into intuitive, parametric, variant-based and generative, and later into knowledge-, feature-, function- and operation-based approaches.

3.2.1 Qualitative methods

The main principle of qualitative estimation methods is to identify similarities compared to previous products. The purpose is to implement similarities and use them in designing a new product. Gathered experience and knowledge reduce the time and efforts compared to product cost estimation totally from scratch. Key requirement for efficient usage of qualitative methods is, that design and manufacturing data from previous products are available and can be used. (Niazi et al. 2006) According to Huang et al. (2012) qualitative methods are more appropriate to implement in such situations, where estimation time is limited, and fast and rough estimate is needed. Qualitative methods and their typical characteristics are summarized in table 4.

Table 4 Qualitative estimation methods applied from Niazi et al. (2006)

Method	**Advantages**	**Typical limitations**
Case-based methodologies	Innovative design approach	Needs historical data for comparisons
Rule-based systems	Can provide optimized results	Time-consuming methods
Fuzzy logic systems	Can handle uncertainties	Complexity
Expert systems	Can give fast and accurate results	Typically need complex programming
Regression analysis	Simple method	Suitable only for linear problems
Back propagation neural networks	Handle uncertainties and non-linear problems efficiently	Dependency on past data, typically expensive to establish

Intuitive product cost estimation methods are mainly depended on experience and gathered knowledge. Experience is applied either directly or through various types of storages such as decision trees. (Huang et al. 2012) Intuitive methods can be divided into case-based methodologies and decision support systems (DSS) (Niazi et al. 2006). Case-based methodologies are also called case-based reasoning (CBR). Case-based methodologies aim to solve a problem by comparing the solutions of past problems. For instance, CBR can efficiently help to evaluate the amount and type of required materials, processes as well as assembly time. Researchers have assessed that case-based methodologies can significantly reduce the time and costs needed to complete the product development project. (Relich & Pawlewski 2018) One major disadvantage has been, that usage is strongly dependent on past data (Huang et al. 2011). Usage of case-based methodologies begins typically with collecting the data of product requirements which is followed by specification of attributes as well as selection and weighting the attributes according to their impact on costs (Relich & Pawlewski 2018). Case-based methodologies have been praised due to their capability to generate innovative designs (Huang et al. 2011).

Decision support systems are defined as interactive computer-based systems that help in decision making by utilizing data and models to solve unstructured problems (Kingsman et al. 1997). Niazi et al. (2006) have highlighted that decision support systems are useful especially in evaluating and comparing various alternatives together. The main purpose is to support estimation by using stored knowledge. Decision support systems can be divided into rule-based systems, fuzzy logic systems and expert systems. (Niazi et al. 2006) For instance, fuzzy logic was first introduced as a mathematical way to present uncertainties in everyday life (Bezdek 1993).

Analogical estimation methods can be divided into regression analysis models and back-propagation neural-networks (BPNN) (Relich & Pawlewski 2018). Regression analysis uses historical data to establish linear relationships between product costs and the values of certain selected variables. The main purpose is to use detected relationships to forecast the costs of a new product. (Niazi et al. 2006) In turn, neural networks can be defined as computational networks that simulate biological neural networks to process information (Zhang et al. 1996). Neural networks can be trained to store knowledge to deduce answers to questions. Neural networks are useful in uncertain situations and those can deal with nonlinear problems (Niazi et al. 2006). For instance, Auvinen (2016) applied neural networks for cost estimation of components in his thesis.

3.2.2 Quantitative methods

According to Niazi et al. (2006) quantitative methods are based on detailed analysis of product design, product features and corresponding manufacturing processes instead of relying only on historical data, knowledge or experience. Costs are usually estimated using different types of mathematical formulas. Quantitative methods give typically more accurate results than qualitative methods, but their usage is normally limited to the final phases of the product development due to the requirements of detailed product design knowledge. Quantitative methods are more appropriate to implement when estimating time is longer, relationships of different cost variables can be clearly identified, and the needed accuracy of estimate is comparably high. (Huang et al. 2012) Typical quantitative methods and their characteristics are presented in table below (Table 5).

Table 5 Quantitative estimation methods applied from Niazi et al. (2006)

Method	**Advantages**	**Typical limitations**
Parametric cost estimation	Uses recognized cost drivers efficiently	Cost drivers must be identified
Operation-based cost estimation	Alternative plans can be evaluated and compared	Time-consuming method which require detailed data
Breakdown cost estimation	Easy method	Requires detailed cost information
Cost tolerance models	Cost effective design tolerances can be identified	Requires detailed design information
Feature-based models	Product features with higher costs can be easily detected	Difficulties in identifying costs of small and complex features
Activity-based models	Easy and effective	Require lead times at the early design stages

Candelise et al. (2013) have pointed out, that typically used quantitative method in photovoltaic industry has been learning curve. Learning curves were first introduced in 1936 by Wright in a mathematical model for production costs of airplanes (Fraunhofer ISE 2015). Technology learning, cost reductions and improvements have been observed to follow learning curve as a function of their accumulated production. In general, learning curves show non-linear relationship where the performance improves with practices. (Trappey et al. 2016) Typical learning curve is presented below where learning curve of solar PV modules is defined (Figure 12).

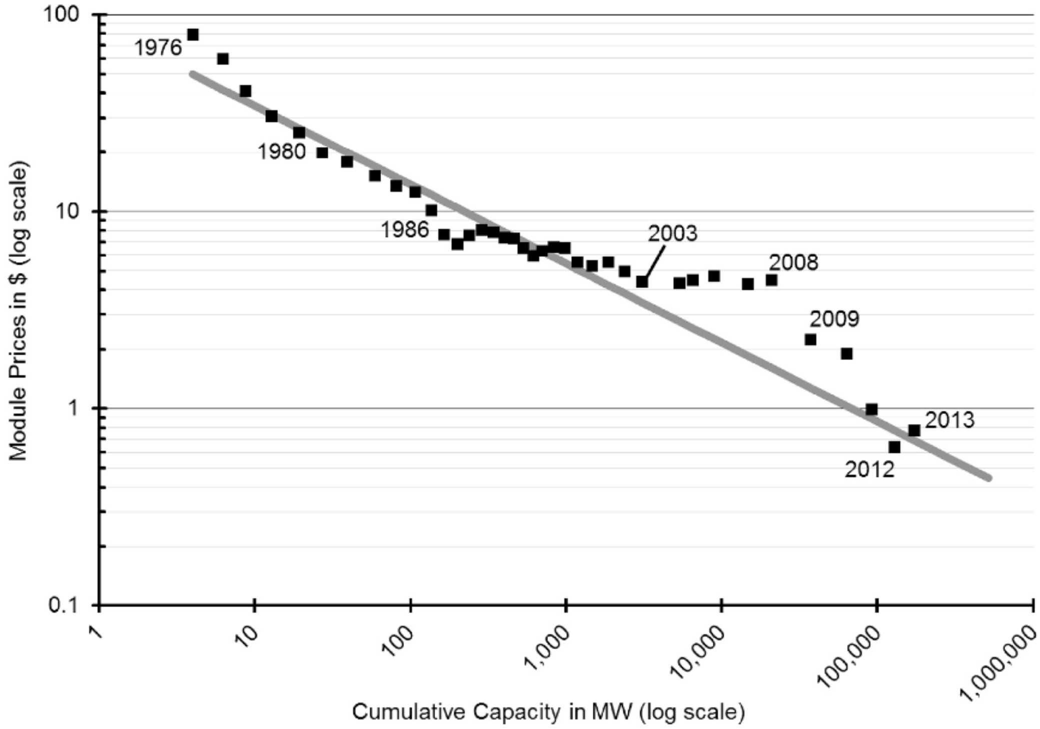

Figure 12 Learning curve of solar PV modules (Elshurafa et al. 2018)

Learning curves are sometimes called experience curves which is based on the theory that experience creates opportunities to reduce costs and costs reduce in logarithm proportion to increases in cumulative capacity (Nemet 2006). Learning curves have been criticized because they cannot consider changes in operational environment or cost drivers. For example, market dynamics and global economic conditions can significantly influence on the learning rates. (Elshurafa et al. 2018) Learning curves expect that cumulative capacity is the only cost driver and ignore the effect of experience and knowledge obtained from product development (Nemet 2006) as well as price reductions due to technological advancements (Elshurafa et al. 2018). Typically, in the early years of deploying a new technology, learning and advancements occur at a relative faster rate. After a reasonable amount of time, achieving additional cost reductions becomes more difficult and doubling the production quantity requires more time. (Elshurafa et al. 2018)

Niazi et al. (2006) have divided quantitative methods into parametric and analytical methods. Parametric product cost estimation methods evaluate costs from parameters characterizing the product (Ben-Arieh & Qian 2003). Production volumes and weights of typically used materials are commonly used parameters (Niazi et al. 2006). For instance, Huang et al. (2012) have stated that normally used cost estimating relationship in aircraft has been weight because typically when weight increases, production and utilization costs rise. Nonetheless, parametric methods are efficient only when parameters can clearly be identified (Niazi et al. 2006). Those are the most commonly used methods during the early phases of product development because their usage does not require detailed product design information (Ahn et al. 2014).

Analytical methods decompose a product into elementary units, operations and activities that present different resources used during the production cycle. Total costs are then assessed as a summation of all these components. (Niazi et al. 2006) Analytical methods can be further divided into operation-based approach, breakdown approach, tolerance-based approach, feature-based cost estimation and activity-based costing systems. (Relich & Pawlewski 2018) For instance, Shehab & Abdalla (2002) have evaluated that the most accurate cost estimation methods use analytical approach.

4 GAP ANALYSIS OF ORGANISATION'S PRODUCT COST MANAGEMENT AND ESTIMATION

4.1 Current state of product cost management and cost estimation

Gap analysis is a tool used to detect and identify gaps between current and targeted operational states. Gap analysis can be divided into four phases starting from defining the current state, describing the targeted future state, identifying gaps between current and targeted states, ending up to identifying the needed actions to close the gaps. (Chevalier 2010) Gap analysis was applied in this thesis to evaluate organization's current product cost management practices and product cost estimation. At first, interviews and discussions were used to gather understanding of existing state. At the same time, targeted future state was sketched. Lastly, improvement proposals to close the gaps were named and presented. Proposals were defined based on literature findings taking into account organization's capabilities and available resources. Actual implementation of recommended actions was not in the scope of this thesis.

At first, organization's current state of product cost management and product cost estimation was evaluated. Organization has defined its product cost management process using process mapping. Process focuses on such products, that are already in active phase and in production. Process is divided into five phases and it starts from define phase. Define phase includes determination and planning of which costs organization should measure and monitor. Define phase is followed by measure phase, where actual product costs are monitored. Measure phase is followed by analyze phase, where organization evaluates which costs could be reduced, how and how much. For instance, product designs and operational excellence (OpEx) actions are considered. Analyze phase is followed by improve phase, where organization schedules and defines needed cost reduction actions. The last phase is control phase, where organization ensures that corrective actions are in place and costs are on right level. Control phase includes actions such as long-term cost forecasting and comparisons between actual and targeted costs. Organization's current product cost management process is presented in figure 13.

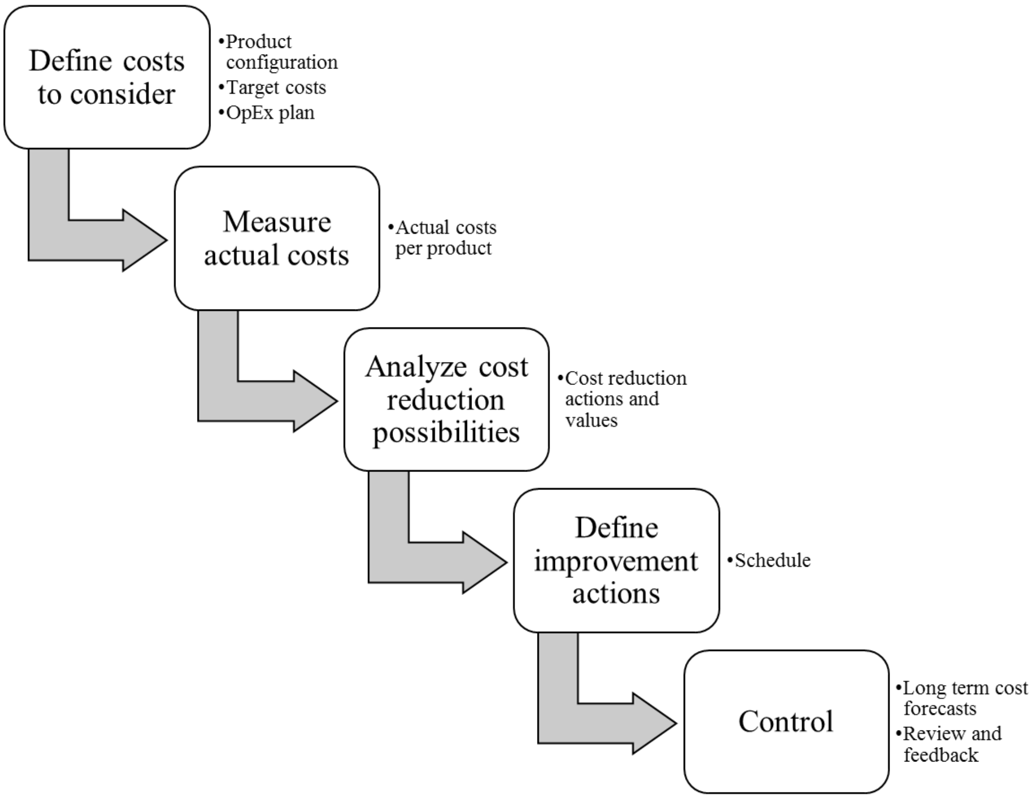

Figure 13 Organization's current product cost management process

Organization's product cost management process is continuous, and it starts always again after reaching the control phase. Each organization's function is involved in accomplishment of the process. For instance, product cost targets and market trends and visions come from product management whereas OpEx plan comes from operations management. The main purpose of current product cost management process is to enhance organization's cost awareness and products' cost efficiency, help to detect cost reduction opportunities as well as to improve organization's profitability and customer satisfaction in the long run. Based on findings, organization's actual product costs are tracked efficiently, and organization has a good understanding of product costs in a specific moment.

On the contrary, there are challenges when it comes to estimating costs of new products in product development phases. Cost estimates are done but systematic approach as well as common principles and methods seem to be missing. For instance, process description has not been defined or followed and used estimation methods vary among product development projects. Organization's current product development process requires product cost calculation at each development phase, but it does not specify how the calculation should be done. Organization has faced challenges especially at the earliest product development phases where actual product cost information is not yet available.

When organization's product cost items such as material costs are unknown, those are estimated using various methods. Accuracy and reliability of used methods can significantly vary. Some cost items, such as costs of specific components, can be estimated in quite accurate manner only based on their weights, dimensions and used raw materials. Also, products have typically a lot of similarities and even same components, and by recognizing these similarities some costs can be assessed quite properly. However, current new product cost estimation and evaluation of various design alternatives depend heavily on designers' expertise and knowledge. Based on interviews, data systems are not used with full potential to support estimation. Organization has tried for instance parametric cost estimation in the past, but detected that parameters can be used, and results are in reliable level only when new products strongly resemble previous products.

Actual labour costs are tracked efficiently and regularly in production. Organization faces challenges when it comes to labour cost estimation before actual production has started. The first labour cost estimate is typically done using information from previous products and then the first estimate is improved after producing the first prototypes. The accuracy of first labour cost estimates is currently quite poor. In addition, organization has not tried to evaluate the cost effect of organizational learning in new products.

Lack of common product cost estimation principles and systematic process has sometimes caused that some cost items have been totally excluded from the early product cost estimates. Some product development projects have included indirect costs in their estimates whereas some projects not. This has led to the situation, that organization's product cost estimates are challenging to compare together. Unclear principles weaken the reliability and validity of estimates. Currently, neither error margins nor scenario analyses are efficiently used to support in the assessment of estimates' accuracy.

Organization has encountered valuation problem in its current product cost estimation and related data gathering. There are many alternatives especially for material costs which could be used in cost estimation. The economic value of these alternatives can significantly vary. In addition, continuous quotation-offer-rounds between purchasing unit and suppliers make some material groups even more difficult to estimate.

4.2 Targeted future state and detected gaps

After analyzing organization's current state, detected gaps were named and targeted future states defined. One of the most significant gaps was observed to exists between organization's current and targeted states of new product cost estimation. Gap was named as estimation gap. Currently, organization's product cost estimation process and used estimation methods are not enough efficient for its needs. Also, estimation feels challenging and time-consuming. Due to other key requirements set for product development projects, profound cost estimation has been neglected. Product cost estimation process needs a thorough systematization. In the future, product cost estimation should be a more comprehensive process which would support better in making reliable product cost estimates in a systematic and efficient manner. Also, cost estimates should be done in a way, that their profound comparison would be possible among different products. New estimation method and common estimation template were set as concrete targets for the future.

Detected gaps and their clarifications as well as targeted future states are summarized in table below (Table 6). Different colours were used to describe the assessed severity of the gap.

Table 6 Detected gaps and targeted future states

Causes severe problems

Causes some problems

Causes minor problems

Gap	Clarification	Targeted future state	
Product cost management gap	Organization's focus is mainly on operative accounting and active products. Costs are not tracked and assessed as systematically in product development phases.	More comprehensive product cost management process starting from product development phases. Reduced need of cost reductions after product launch.	
Estimation gap	Costs of new product are estimated using different methods and practices in product development. Common principles and methods are missing.	Common principles and methods defined, new product cost estimation method developed.	
Data system gap	Current cost estimation of new products relies heavily on personal expertise and knowledge. Data systems and tools are not used at full potential.	Efficient data systems support cost estimation.	
Reliability gap	Sensitivity analyses and scenarios are not used efficiently in cost estimation of new products. Confidence levels or error margins are not evaluated systematically. Validity is challenging to evaluate.	Sensitivity analyses and scenario analyses used, and error margins or confidence levels evaluated systematically. Estimates' validity and reliability are easy to assess.	
Labour cost estimation gap	Organization does not understand how organizational learning will influence on labour costs. Common principles are not defined how first labour cost estimate should be done.	Organizational learning is included in cost estimation and there are clear principles how the first labour cost estimate could be done.	
Documentation gap	Documents related to product costs are sometimes laborous to find.	Clear principles defined considering data archiving.	

Organization's current product cost management process focuses especially on operative accounting and those products that are already in production. Accounting at product development phases should be highlighted. Also, based on literature findings, it would be beneficial to shift the focus away from reactive cost management towards proactive cost management. This gap was named as product cost management gap. In the future, organization's product cost management process should be more comprehensive starting from the early phases of product development. In addition, the need of cost reduction activities after product launch should be minimized.

Estimates' reliability and validity are significantly weakened as costs are estimated using several methods, used data is gathered from various databases and neither scenario analyses nor error margins are efficiently used. Hence, there is a clear reliability gap between current and future states of product cost estimation. In the future, scenario analyses should be used and either error margins or confidence levels included in each product cost estimate. Overall, the reliability of the estimates should be better and data origin should be possible to evaluate in a more comprehensive manner. Related to data origin, also documentation gap was identified as previous product cost estimates were extremely laborous to gather and interpret. In the future, all relevant parties should be able to find needed documents and understand, which values are used in estimation and where values are gathered. In addition, product cost estimates as well as related documents should be archived more systematically.

Another gap was detected between organization's current and targeted states of usage of data systems in cost estimation of new product. This gap was named as data system gap. Organization has a large variety of data systems which could be used to support estimation, but only some of them are efficiently used. Data systems would also reduce the risk of human mistakes and organization's dependency on personal expertise and gathered knowledge.

Lastly, labour cost estimation gap was detected. This was further divided into two subproblems. First, there is a gap between current and targeted states of estimating labour cost development. Organizational learning is not considered, and labour costs are expected to remain fixed over time. The second gap is between current and targeted states of making the first labour cost estimate. Organization has not defined common principles for example considering how to evaluate required labour hours. In the future, labour cost development should be included in product cost estimation instead of expecting it to remain fixed. Also, there should be clear principles to evaluate the first labour cost estimate.

4.3 Recommendations and actions to close the caps

After defining and naming the major gaps and setting targeted future states, recommendations were given how organization could close the gaps. Actual implementation of recommended actions was not in the scope of this thesis and thus, deep evaluation and final decision were left on organization's own consideration. In this thesis, the focus was on gaps related to product cost estimation.

As already stated, organization's current product cost management process focuses especially on active products that are already in production. To close this product cost management gap, and to make the product cost management process more comprehensive and proactive, cost consideration was recommended to integrate more tightly into product development phases. In order to guarantee that cost reduction activities are not needed after product launch, target costing approach was highly recommended. More efforts could be put on setting cost targets and checkpoints during product development phases. Also, cost targets should be defined for smaller design entities. Target costing approach should be integrated efficiently into organization's existing product development processes.

Main recommendations are summarized in table below (Table 7). Different colours were used to illustrate the assessed workload and resources needed to close the gap. Workload was classified into three groups starting from those actions which need profound analysis and additional resources to first find and then implement the solution, ending up to those actions where the correction is already known, and it is easy to implement. Most of the recommendations were classified into the middle group, where the corrective action was unknown beforehand, but it was expected to be quite easy to detect as well as fast to implement.

Table 7 Recommendations and actions to close the gaps

	Needs profound analysis, corrective action unknown beforehand	
	Probably easy to find the needed corrective action and fast to implement	
	Corrective action already known, easy and fast to implement	
Gap	**Recommendations and actions to close the gap**	
Product cost management gap	More effort should be put on setting cost targets and checkpoints during product development phases. Target costs should be defined also for smaller design entities. Target costing approach should be integrated into product development processes.	
Estimation gap	New product cost estimation method was developed in order to systematize the estimation process.	
Data system gap	Recommendation to use data systems (e.g. neural networks) and tools more efficiently to support and automatize product cost estimation of new products.	
Reliability gap	Scenario analysis and evaluation of the accuracy of material cost estimate integrated into developed estimation method.	
Labour cost estimation gap	Organizational learning integrated into developed labour cost estimation method. Also, principles for making the first labour cost estimate were defined.	
Documentation gap	Recommendation to define common rules for further data archiving.	

In order to close estimation gap and labour cost estimation gap, a new estimation method was developed. The purpose of the new method was to systematize cost estimation process in new product development and define general principles. Actual development of estimation method as well as its main characteristics and functionalities are presented later in chapter five. New estimation method aimed to close the reliability gap as well. Scenario analysis was integrated into the method. Also, principles to evaluate the accuracy of material cost estimate during product development project were defined.

More efficient usage of data systems and tools were recommended to support further product cost estimation. Some of the tools could be implemented quite easily and probably without additional costs. For instance, usage of neural networks, developed by Auvinen (2016), could be considered in material cost estimation. Nonetheless, the purpose is not to replace designers by tools, but support designers to evaluate all design alternatives efficiently and without losing time neither shifting the focus away from key activities.

5 METHOD FOR PRODUCT COST DEVELOPMENT ESTIMATION

5.1 Recognized solar inverter cost drivers

Before developing the new product cost estimation method, typical cost drivers of solar inverters were evaluated. Information of costs drivers was required to understand inverters' cost behavior. Actual analysis was done by assessing previous studies and existing literature considering photovoltaic and solar inverters. In general, cost reductions can be considered as an indicator describing productivity gains and increasing returns (Strupeit 2017).

Solar inverter cost development has been strongly downward trajectory over years. Researchers have evaluated that technology advancements have been one of the most significant driver of cost reductions. According to Strupeit & Neij (2017) major product development paths have included for instance higher direct current (DC) system voltages, as well as the integration of ancillary functions into the inverter units. Also, Fraunhofer ISE (2015) has evaluated that inverter efficiencies and power densities have increased due to improved power semiconductors and new circuit topologies. At the same time, inverters have become smarter by offering several advanced monitoring and communication interfaces that can help to improve the availability and performance of PV installations (Fraunhofer ISE 2015). In addition, technology advancements have influenced on other BOS components and their costs. For instance, Comello et al. (2018) have evaluated that prices of electrical components have come down at steady pace.

On the other hand, increasing demand and expected market expansion have encouraged inverter manufacturers to innovate and look for new applications to their technologies (Willuhn 2018). For this reason, increasing demand and market expansion can be considered as drivers for technology advancements. Increasing cumulative production typically leads to scale effects. In practice, with increasing cumulative production, fixed costs can be distributed over a larger number of units when unit costs decrease. (Strupeit 2017)

High competition has increased the pressure to reduce costs and improve productivity and profitability while cost margins have declined (Strupeit 2017). At the same time, competition has created the need to differ from competitors (Willuhn 2018). On the other hand, manufacturers must be flexible and responsive to customer requirements which has led to highly customized products and large variety of configurations and extensive number of part variants (Zengin & Ada 2009). Customization can increase inverters' costs and hence, product configuration can be seen as one of the major cost drivers.

Also, organizational learning and knowledge can play a key role in innovation, not only related to technology but also to organization's practices and processes. For instance, Candelise et al. (2013) have mentioned that costs of photovoltaic systems have steadily reduced due to organizational learning and incremental improvements in manufacturing processes. Major cost drivers are summarized below (Figure 14).

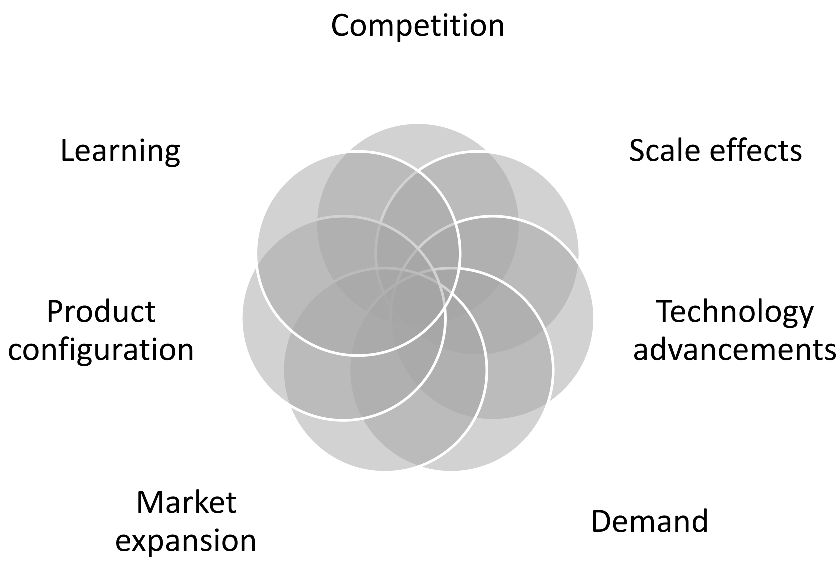

Figure 14 Main cost drivers in solar inverters

5.2 Data collection and structure

Costing data was collected from organization's ERP system and from different databases mainly in spreadsheet format. Costing data included production costs from factory as well as historical product cost estimates and components' purchasing cost history. Selection criteria for considered products were their production timespan and number of produced units. The purpose was to select such products which had been manufactured over a long period and which cumulative production volume was relatively high. This selection was done due to the observation, that with a smaller cumulative production volume, it was not possible to detect for example organizational learning. In addition, considered production timespan was limited to such period, when operation environment had remained quite similar and stable. This was done to eliminate outer factors which could distort results, such as varying overhead allocation principles and challenges related to cost comparisons. Main characteristics of products' production life cycles are presented below (Table 8).

Table 8 Main characteristics of products' production life cycles

Product	**A**	**B**	**C**	**D**	**E**
Number of produced units 0 = low 5 = high	3	5	1	1	4
Production timespan 0 = short 5 = long	5	4	1	4	5
Active product design development	Yes	No	Yes	Yes	No

Selected production cost items were material and labour costs and other direct costs. Material and labour costs were further divided into direct and indirect costs and presented per product. Indirect costs are further called overhead (OH) in this thesis.

Considered components were selected from products' bill of material (BOM) lists. BOM is a list of used components and subassemblies as well as their quantities needed to manufacture the product (Kinney & Raiborn 2009, 752). Components were selected using different criteria. All components were such that organization buys from external suppliers. Firstly, such components were selected, which comprised a significant portion of total material costs and which had been purchased in different purchase volumes over time. This was done in order to be able to evaluate the effect of purchase volume on unit cost as well as cost volatility over time. Second, such components were selected, which included as much specific raw materials as possible and which had been purchased over a relatively long period. This was done in order to be able to evaluate the raw material price fluctuation.

Lastly, old product cost estimates and product design change history were collected and assessed. Old product cost estimates were used to evaluate their accuracy as well as to collect ideas for the new estimation method. Also, shortages were tried to identify in order to ensure that the new method wouldn't run into the same problems. Documentation of historical product design changes was collected to be used in assessing and understanding the inverter cost behavior. However, old cost estimates and documentation considering product design changes were challenging to collect due to poor documentation and archiving practices. Historical cost estimates were done using several techniques and following different principles. Thus, it was difficult to evaluate estimates' reliability and validity.

5.3 Data analysis and results

After data collection, analysis was started by categorizing and plotting production costs. Actual analysis was done using both Microsoft Excel and Minitab software as tools. At first, the purpose was to identify inverter cost drivers from organization's production costs based on proposed hypotheses. Then, correlations between costs and cost drivers were assessed. Lastly, the objective was to establish parameters and attributes based on findings and use them to develop the new product cost estimation method. The structure of the analysis process is presented below (Figure 15).

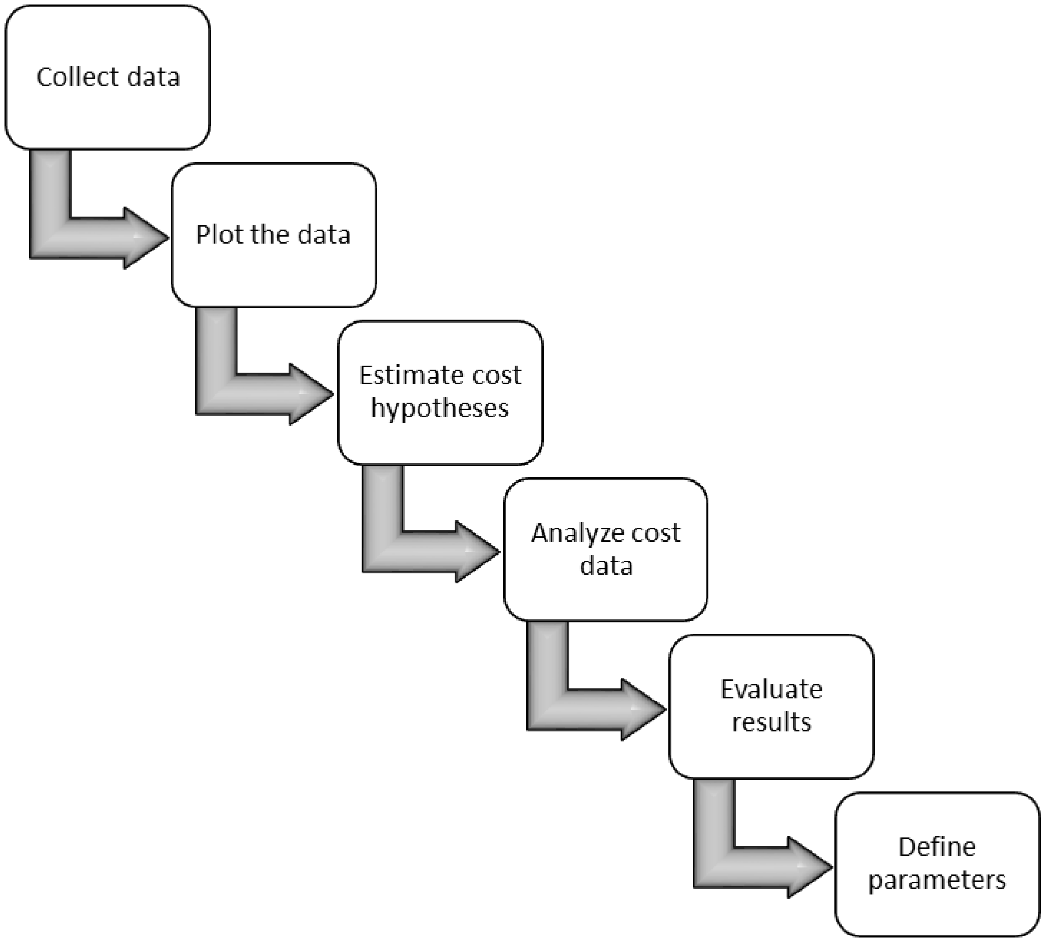

Figure 15 Cost data analysis process

First, different products and their power classes were separated. Then, each product was considered alternately. Before going further in the analysis, product configurations and variations had to unify. In practice, products are highly customized according to customer requirements which significantly influences on product cost structure. Both material and labour costs can vary and costs can even multiply due to the selected product configuration.

Configurations were unified by eliminating costs caused by them. This was done by using previous pricing tools where costs caused to organization were estimated. Nonetheless, usage of previous pricing tools as elimination method was slightly problematic as the accuracy of historical cost estimates was quite poor.

Organization hadn’t considered that some configuration selections influenced on other configurations and their costs. Also, each configuration selection influences both on material and labour costs, but now costs were estimated only as total. Hence, it had to accept that used configuration elimination might lead into small errors in the end.

After data categorization and configuration elimination, cost driver hypotheses were established. Cost driver hypotheses were defined based on literature findings, previous studies as well as organizations own expectations considering inverter cost behavior. For instance, organizational learning was expected to reduce labour costs whereas raw material price fluctuation was assessed to influence on material costs. In turn, technology advancements and product changes were expected to reflect on both material and labour costs. Hypotheses are summarized in table below (Table 9).

Table 9 Cost drivers and hypotheses

Cost driver	**Hypotheses**
Organizational learning and OpEx actions	Learning by doing and learning by volume as well as OpEx actions reduce both direct and indirect labour costs.
Purchase volume	Purchase volume influences on unit costs of components.
Product changes and technology advancements	Product design changes can reduce both material and labour costs.
SCM actions	Material costs decline due to organization’s actions in purchasing unit.
Raw material price volatility	Volatility in raw material prices reflects on material costs.
Currency rate fluctuation	Currency rate fluctuation can influence on raw material and component prices.
Product configuration	Product configuration influences both on material and labour costs.

After defining hypotheses, production costs were plotted against production timespan and cumulative production volume. First, cost data was considered on monthly basis and then on weekly basis, but averages distorts results too much. Hence, analysis was decided to conduct on one product at a time. A few outliers were detected but those were decided to exclude due to their insignificancy. Outliers were measurement errors or data errors.

After data plotting, labour costs of each product were analyzed. Labour costs were observed to decrease in proportion to production volume. A clear cause and effect relationship could be detected between labour costs and organizational learning, and hypothesis could be proved right. Value for correlation was defined using Minitab. In one product the correlation rate was -0.566. Averagely correlation rate was roughly around -0.5. From statistical perspective, -0.5 represents moderate negative relationship which means in practice, that when production volume increases, labour costs decrease.

The effect and the significance of organizational learning were quite surprising as traditionally factors such as organizational learning have been excluded from product cost development estimation. Most of the product cost estimation methods presented in previous literature have focused only on observable technical factors that can easily be identified and whose impact on product cost can be directly calculated. (Nemet 2006) Nonetheless, now the effect on labour costs was undisputed.

For instance, Elshurafa (2018) have focused on organizational learning and highlighted that more rapid annual rate of cost reductions can be observed during the early years of production or technology adaptation. Similar variation in learning rate could be observed in organization’s production data. Figure 16 represents labour cost development in one product at early phases of production life cycle.

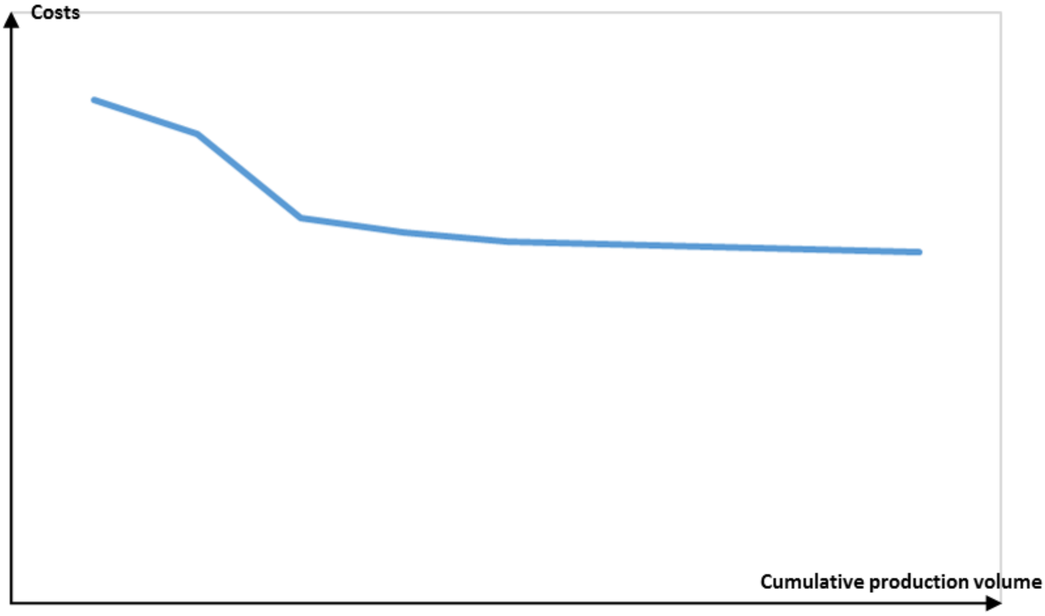

Figure 16 Labour costs development over time

Labour costs development was decided to analyze in more detail. One product was selected for further analysis. Its production timespan was divided into four periods, which were equally long together. Then, cost variance and total labour costs were compared among periods. At first, distribution analysis was conducted using Minitab. Both cost variance and the amount of total labour costs decreased during production life cycle from period one to period four. For instance, the cost variance in period one was multiple compared to period four. There were some data outliers in period three, which caused that the cost variance was bigger than in period two. Reductions in the cost variance and total labour costs can be explained by organizational learning and reduced production disturbances. In figure 17, each period is presented in the same histogram, whereas in figure 18 those are separated.

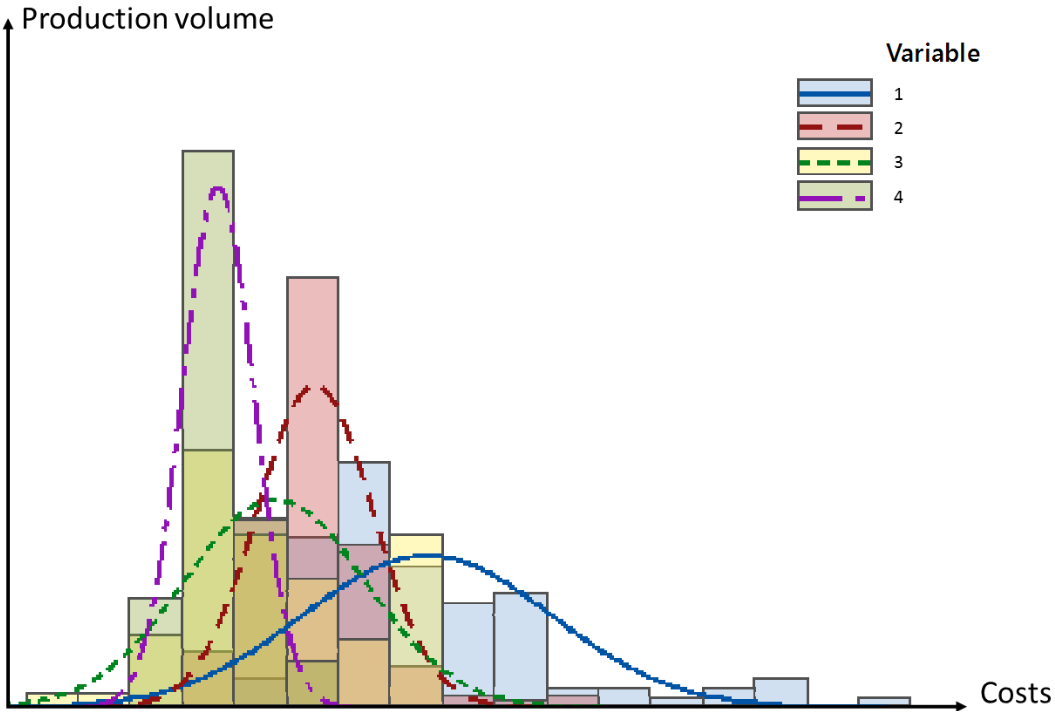

Figure 17 Labour costs and cumulated production volume in four periods

From statistical perspective, this four-period analysis could have been done using some other statistical method in order to get better results. Used method expected that data was normally distributed, which it was not by any means.

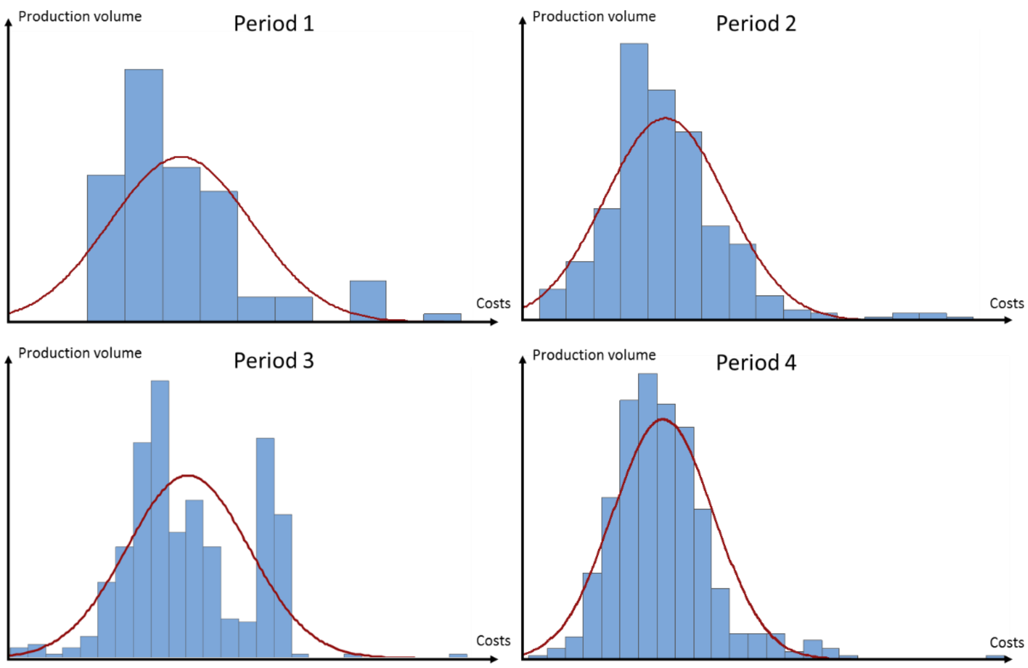

Figure 18 Labour cost histograms

Another noteworthy observation was, that some product configuration selections increased labour costs. Product B was selected for further analysis (Figure 19 & Figure 20). Cost effect was evaluated by plotting labour costs against cumulative production volume alternately both including and excluding costs caused from specific options. Labour costs almost doubled when options were included in consideration.

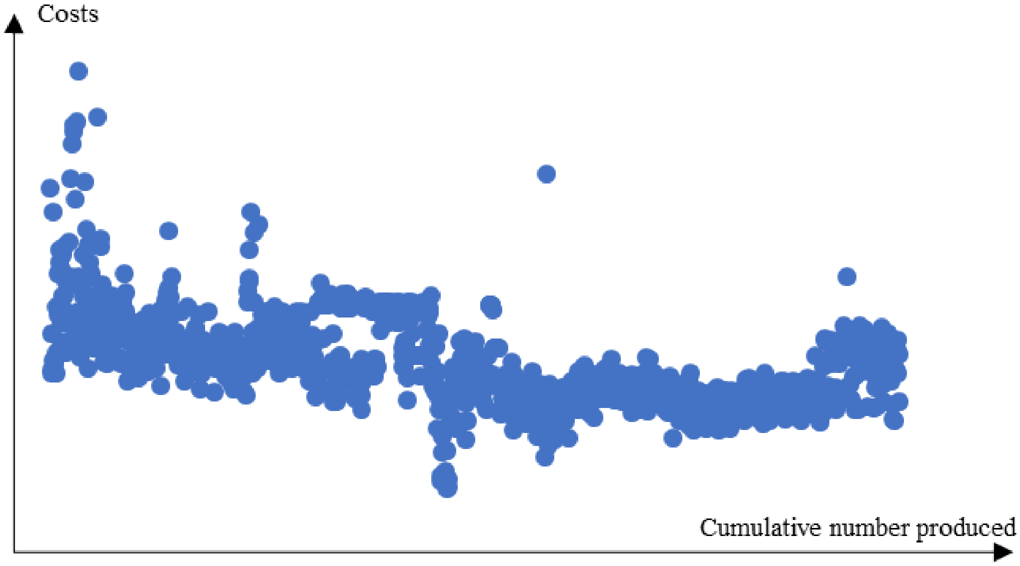

Figure 19 Labour costs in product B without specific options

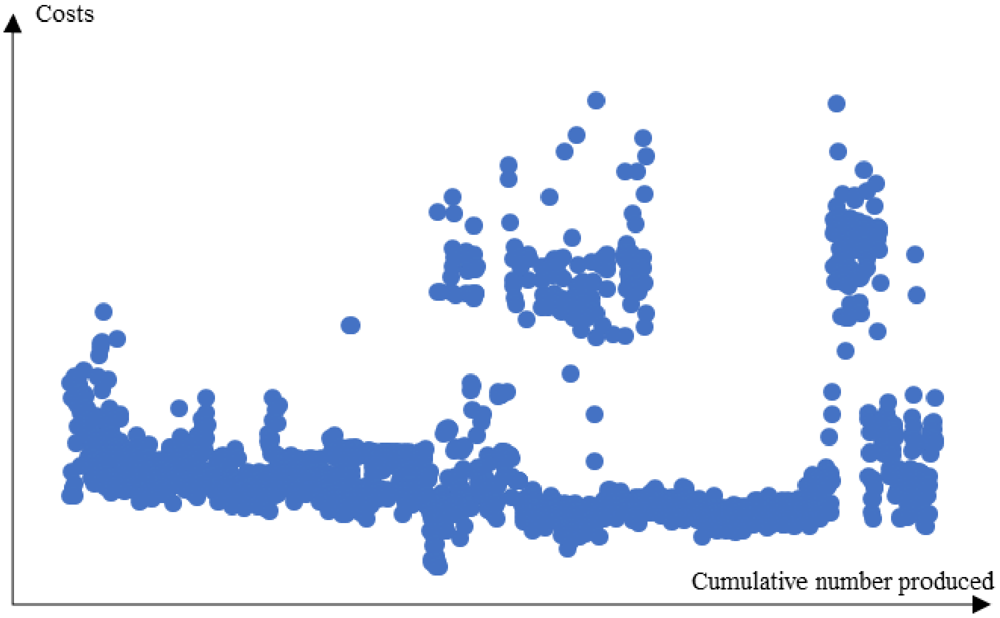

Figure 20 Labour costs in product B with specific options

After analyzing labour costs, material costs were considered. A few products were selected for analysis. At first, material costs of each product were plotted against production timespan and cumulative production volume. Material costs per unit in product A (Figure 21) and product B (Figure 22) are presented below.

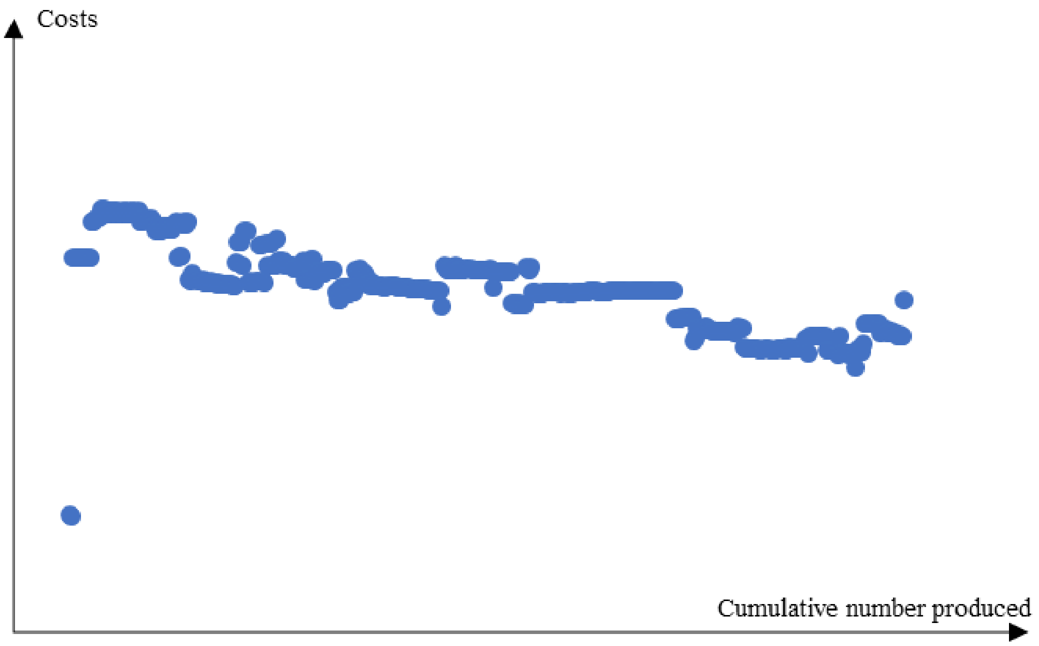

Figure 21 Material cost development in product A

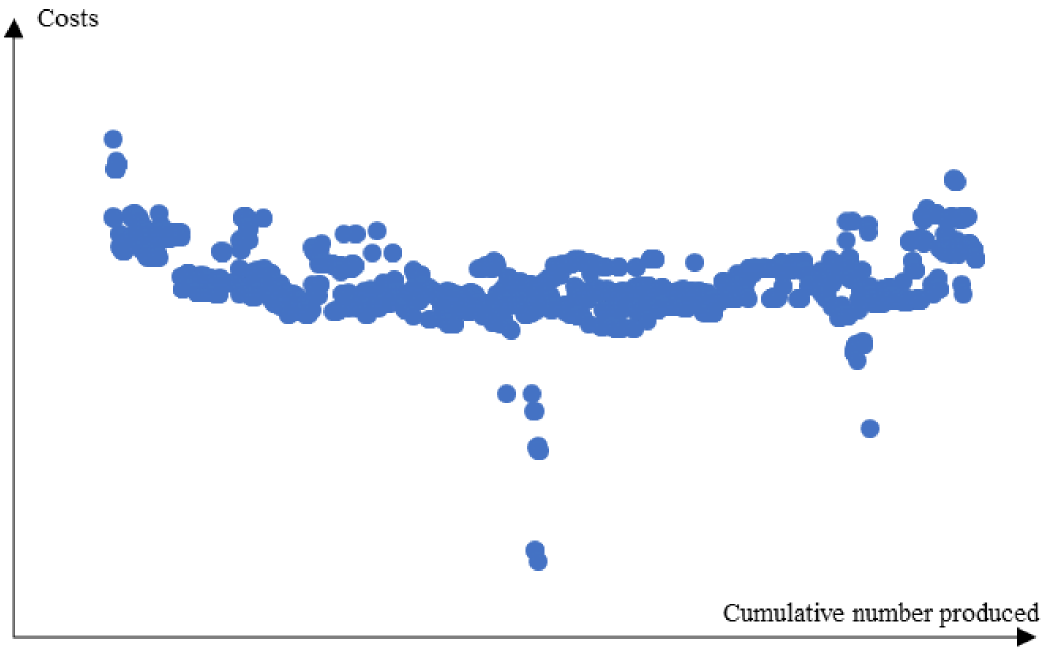

Figure 22 Material cost development in product B

In product A (Figure 21), product design has been under continuous development and material costs have declined at steady pace. In product B (Figure 22), development actions have been stopped quite soon after product launch. After stopping development actions, material costs have remained almost fixed. Analysis stated that organization's product design changes and other cost reduction actions in purchasing unit are tightly bound together.

Historical product design changes were tried to identify, and their cost effects evaluate. Changes were much more difficult to detect than thought beforehand due to the long delays between organization's design change decisions and actual implementation in production. Delays can be explained by several factors in organization's supply chain. For instance, order backlog and existing material stock effect on how fast new designs are implemented in manufacturing. Nonetheless, the total cost effect of technology advancements was now quite small because analysis focused on one product type at a time. In practice, organization's products form product generations and probably more significant cost effects could have been observed by comparing generations together.

After considering product design changes, explanations for other material cost declines were started to seek and evaluate. Raw material price fluctuation was analyzed by assessing several components. Components' purchasing cost history was plotted against time and compared to raw material price indexes. No radical volatility could be observed which can be explained for instance by contract prices.

Lastly, cause and effect relationship between purchasing volume and components' costs was analyzed. This was done by dividing purchase order costs by the amount of purchased items in order to calculate unit cost. Results were plotted against time and correlation rate evaluated using Minitab. A wide range of results were get which made it impossible to establish any simple generalization. Results can be explained by different purchase contracts and negotiated prices with suppliers but not directly dependent on volume. In turn, currency rate fluctuation was decided to exclude because organization's purchase orders were mainly in euros from the eurozone.

As a result, it can be stated that multiple factors cause cost incurrence and cause and effect relationships were much more difficult to detect than thought. Labour costs developed in clear proportion to cumulative production volume but material costs seemed to remain quite constant without active product design changes. Main results from analysis are presented below in table 10.

Table 10 Results from analysis and data for further estimation

Cost driver	Results and data for further estimation
Organizational learning and OpEx actions	Learning happens in clear proportion to cumulative production volume. Cost decrease can be expressed in percentages and define between specific cumulative production volume points. Percentages are at their biggest in the beginning of production and decline thereafter.
Purchase volume	Clear cause and effect relationship could not be defined. Purchase volume was excluded from further consideration.
Product changes and technology advancements	Product design changes and technology advancements reduce material and labour costs.
SCM actions	SCM actions happen together with product design changes.
Raw material price volatility	Clear cause and effect relationship could not be defined. Raw material price volatility was excluded from further consideration.
Currency rate fluctuation	Organization purchases mainly in euros in eurozone. Thus, the effect of currency rate fluctuation is negligible. Currency rate fluctuation was excluded from further consideration.
Product configuration	Product configuration can significantly influence on material and labour costs.

5.4 Further product cost estimation

To improve organization's future product cost estimation and to systematize estimation principles, new product cost estimation method was established. In the beginning of this thesis project, the purpose was to develop purely parametric cost estimation method to be used after the first cost estimate is done. This idea was abandoned due to the complex cost behavior and problems related to definition of clear parameters. In addition, during analysis phase, it was understood that organization's practices related to making the first product cost estimate had to improve as well. Hence, the scope of the new method was expanded. As a result, a hybrid product cost estimation method was built.

The purpose of the new product cost estimation method was twofold - to support in the making of the first product cost estimate and to help in evaluating the cost development throughout production life cycle. Developed estimation method combined and utilized elements from learning curves, parametric cost estimation and case-based reasoning. Main users for developed method were expected to be project managers during their product development projects.

Development of the new estimation method was started from the expectation, that organization's product costs are generated according to following formula:

$$C_{product} = C_m + C_l + C_w \tag{1}$$

whereas C_m material costs

C_l labour costs

C_w warranty provision

Material costs were expected to generate according to formula:

$$C_m = C_{dm} + C_{om} \tag{2}$$

whereas	C_{dm}	direct material costs
	C_{om}	material overhead
		(fixed % of fixed material costs)

Labour costs were expected to generate according to formula:

$$C_l = C_{dl} + C_{op} \tag{3}$$

whereas	C_{dl}	direct labour costs
	C_{op}	production overhead
		(fixed % of fixed labour costs)

Warranty provision was expected to remain fixed over the whole estimation period due to its complexity and time-consuming evaluation.

Labour cost estimation was considered first. This was started by developing method to estimate labour hours in order to be able to calculate direct labour costs. Several hypotheses were evaluated but lastly correlation between number of assembled components and spent labour hours was assessed. The idea was applied from the study by Ben-Arieh & Qian (2003) where they evaluated different cost driver activities during manufacturing process.

Now, evaluation was done using three products and their labour costs and BOMs. Direct labour costs were divided by the number of total assembled components. Number of assembled components were calculated from BOMs using as simple product configuration as possible in each product. Subassemblies were considered as they were only one component. Then, number of labour hours were defined by dividing direct labour costs by existing hour price. Calculation showed, that positive correlation existed between labour hours and number of assembled components. Hypothesis was proved right that the more assembled components, the more labour hours required. Also, comparison stated that cost-component-ratio remained quite constant among these products. Number of components and cost-component-ratios are presented below with dummy values (Table 11).

Table 11 Cost-component-ratio in three products

	Product 1	Product 2	Product 3	Average
Number of components	6	5	3	
Ratio	11	7	8	**9**

Defined cost-component-ratio was then used as determinant for required labour hours. Calculation was built in excel so, that by entering the estimated number of components, required labour hours were calculated automatically using average cost-component-ratio. Results from previous products were left in the excel to help in estimation. After defining labour hours, estimator was asked to give the current hour price for labour. Based on labour hours and current hour price, method could calculate direct labour costs. Mandatory input fields were marked on red and blocked from nonsense values in order to guarantee the efficient operation of the method. Estimation method is presented below (Figure 23).

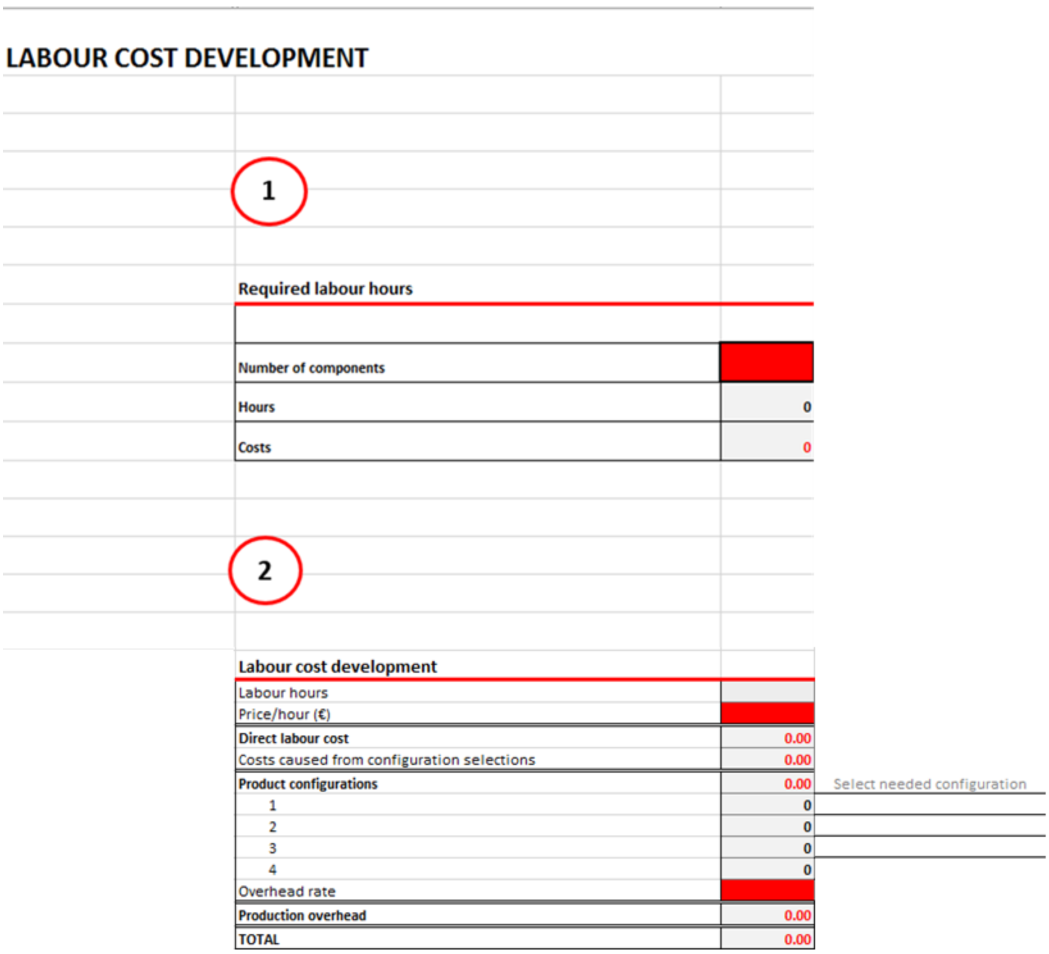

Figure 23 Labour cost estimation method

After defining direct labour costs, production overhead was included in calculation. Production overhead rate were expected to remain fixed over the whole estimation period. Calculation was developed so, that by adding the existing production overhead ratio in percentages, labour overhead costs were calculated automatically by multiplying direct costs by this given ratio. Hence, method could calculate total labour costs to the bottom line.

Lastly, possibility to include costs caused from specific product configurations was integrated into the estimation method. Those configurations, now expressed as 1, 2, 3 and 4, were observed to influence especially on labour costs. Calculation was developed so, that when estimator added X to the field of needed product configuration, method included costs in calculation. This was done using IF-functions, where X added predetermined costs and blank returned 0.

After calculating the first labour cost estimate, method for labour cost development estimation was established. Learning curve method was utilized. Average labour cost decreases were defined as percentages between specific cumulative production volume points. Percentages were defined by comparing three products and their labour cost development and decline rates together. Decrease rates were observed to be faster in the beginning of production and slow down thereafter. Estimated labour cost development is presented below (Figure 24).

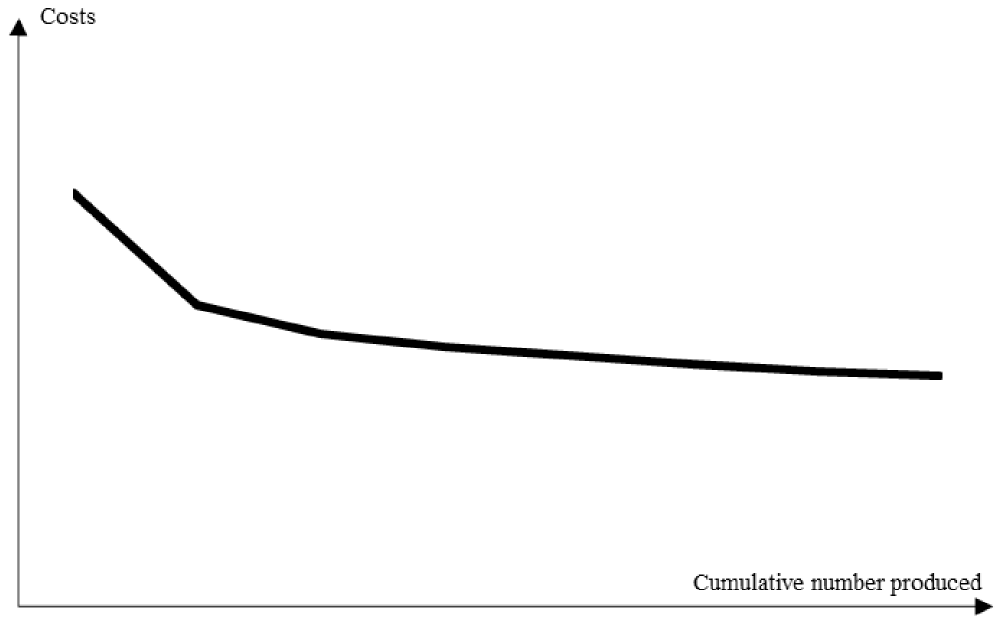

Figure 24 Estimated labour cost development

After labour costs, material cost estimation was considered. This was started by evaluating how the first material cost estimate could be done. As material costs' behavior was observed to be much vaguer compared to labour costs as simple estimation method could not be developed. It was decided to focus especially on to support estimator in the assessment of the accuracy of material cost estimate and evaluation of how preliminary product design sharpen into actual design. Thus, excel template was created.

Excel template was developed based on the observation that specific material groups and their cost proportions remain quite constant among different products. Thus, direct material costs could be estimated roughly by comparing costs and designs from previous products. Five major material groups were selected and named. Now, those are called as Group 1, Group 2, Group 3, Group 4 and Group 5. Later in this thesis, classification is named as product breakdown structure (PBS). The purpose of the estimation method was to evaluate the costs of each material group by using known cost proportions. For instance, when knowing that total product cost is 5000 and cost proportion of Group 1 is 20 %, costs can be evaluated to be around 1000. Classification is presented below (Figure 25).

MATERIAL COSTS

PBS	EUR	% of costs
Group 1	1000	20%
Group 2	1000	20%
Group 3	1000	20%
Group 4	1000	20%
Group 5	1000	20%
DIRECT MATERIAL COSTS	5000	100%

Figure 25 Product breakdown structure and direct material costs

Direct material costs were classified into four groups – actual costs, based on agreements, based on offers and estimated from scratch. The fundamental idea was to assess the proportion of each cost group on each material category at each production life cycle phase. In general, actual costs refer to those design structures and components which are already used in other products and which costs are known. Based on agreements refer to those prices that are already agreed with suppliers. Based on offers refers to those components which costs can be evaluated based on preliminary quotations from suppliers. In turn, estimated from scratch refers to those components and design structures, which costs are evaluated using several estimation methods and the accuracy can be relatively low. In practice, actual costs and based on agreements can be considered as accurate costs. Production ramp down phase was now excluded and only concept phase, design phase, production ramp up and production phase were considered. Template is presented below (Figure 26).

ESTIMATION TRACKING

PBS	Actual	Based on agreements	Based on offers	Estimated from scratch
	CONCEPT PHASE			
Group 1	10%	10%	20%	60%
Group 2	10%	10%	20%	60%
Group 3	10%	10%	20%	60%
Group 4	10%	10%	20%	60%
Group 5	10%	10%	20%	60%
	10%	10%	20%	60%
Average % of accurate costs	*20%*			
	DESIGN PHASE			
	Actual	Based on agreements	Based on offers	Estimated from scratch
Group 1	20%	20%	20%	40%
Group 2	20%	20%	20%	40%
Group 3	20%	20%	20%	40%
Group 4	20%	20%	20%	40%
Group 5	20%	20%	20%	40%
	20%	20%	20%	40%
Average % of accurate costs	*40%*			
	RAMP UP			
	Actual	Based on agreements	Based on offers	Estimated from scratch
Group 1	50%	30%	10%	10%
Group 2	50%	30%	10%	10%
Group 3	50%	30%	10%	10%
Group 4	50%	30%	10%	10%
Group 5	50%	30%	10%	10%
	50%	30%	10%	10%
Average % of accurate costs	*80%*			
	PRODUCTION			
	Actual	Based on agreements	Based on offers	Estimated from scratch
Group 1	100%	0%	0%	0%
Group 2	100%	0%	0%	0%
Group 3	100%	0%	0%	0%
Group 4	100%	0%	0%	0%
Group 5	100%	0%	0%	0%
	100%	0%	0%	0%
Average % of accurate costs	*100%*			

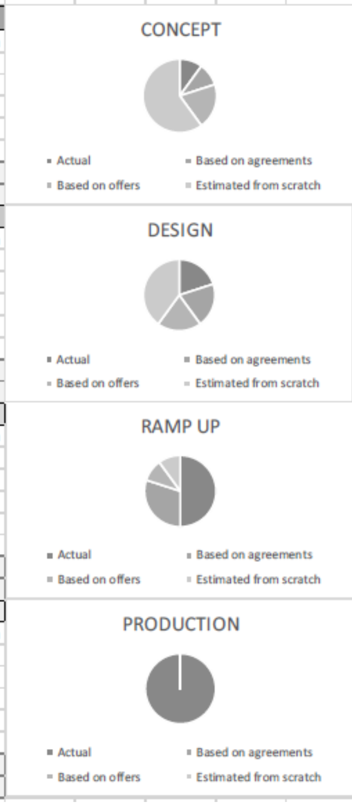

Figure 26 Material cost estimation follow up

In concept phase organization creates a preliminary product specification which means the definition of general product outlines and targets. For instance, is product used indoor or outdoor and how much output power should be reached are considered. In concept phase the accuracy of material cost estimate as well as PBS are typically relatively low. Preliminary specification is sharpened into design specification when product reaches design phase. At the same time, the accuracy of product cost estimate and PBS improve. Design specification is further sharpened into product specification in production phase. In practice, this means that product specification is finally defined and agreed. At the same time, the proportion of actual costs reaches 100 % and the proportion of estimated from scratch 0 %.

After defining the principles of PBS approach and how to assess the accuracy of direct material cost estimate, total material cost development was considered. Material overhead rate was expected to remain fixed percentage of direct material costs over the whole estimation period. Calculation was developed so, that estimator was asked to give the existing material overhead rate in percentages. Input field was marked on red. Then, production overhead was calculated automatically by multiplying direct costs by this given rate. Calculation template is presented below (Figure 27).

Material overhead rate			
Material overhead			0
Material total			0

Figure 27 Material overhead calculation

In analysis phase, material cost development was observed to remain quite stable in case no major changes were done to product design. This observation was used to establish the estimation curve for total material costs development (Figure 28). Slight material cost decline was defined in percentages between specific cumulative production volume points. Points were determined using data from two products.

Figure 28 Estimated material cost development

Lastly, labour and material cost estimates were brought together into one total cost – estimate. Also, warranty provision was now added into calculation. Lastly, simple scenario analysis was integrated into total cost estimate. The fundamental idea was to ensure that organization would include scenario analysis to its estimation in order to improve the reliability of the estimates. Scenario analysis was developed so, that 100 % was defined to describe the normal state. By changing the percentage, estimator could evaluate how radically costs will change. In practice, 120 % in material change field describes situation where material costs increase 20 % from the normal state. On the contrary, 80 % in material change describes situation, where material costs decrease 20 % from normal state.

5.5 Evaluation of the method and future development

Developed hybrid product cost estimation method expects that operation environment will not change during the production life cycle. For instance, overhead ratios are now expected to remain constant. In practice, this never happens, and especially solar inverter business has been constantly under several changes. Method cannot adapt to changes and hence its accuracy can fluctuate in case calculation principles vary.

Method is optimal for such products which strongly resemble previous products. Similarities were used to define required labour hours and to evaluate product material cost structure. Those can significantly vary if product design changes. Also, it was expected that product design stays similar throughout the production life cycle even though organization's product cost history has stated that design changes are probably done after reasonable amount of time. To minimize these shortages, estimation timespan was decided to keep relatively short. Short timespan reduces estimation mistakes caused from ignoring factors such as changes in operation environment and product design.

Method expects that organizational learning will always result in cost reductions and learning parameter is positive in every case. However, learning parameter could be negative as well. It is possible, that organization invests money in training or machines to make the production more safety or efficient. This can cause that labour costs increase momentarily or even permanently and the shape of the learning curve changes. Hence, method's accuracy can fail if radical changes are done to the production practices or used tools.

Another shortage is that method could not be tested enough during this thesis project. Method was developed using historical cost data which was not totally faultless. Testing would have required that there would have been a new product which production life cycle could have been followed always from the product development to the end of the production. This would have required much more time. Hence, method should be evaluated carefully when it is used for the first time to new products and then developed based on observed shortages and feedback.

In order to improve the accuracy of labour hour estimate, more parameters should be established. Product complexity should be evaluated in a more comprehensive manner as the number of assembled components is not the only denominator by any means. One interesting aspect for further study would be, how many connection points exist in product or how many screws are used. This would require more profound understanding about components and product structure as well as cause and effect relationships between design alternatives and product complexity. In addition, possibilities to change input values, such as labour hour price and production overhead rate during estimation, would improve the utility of the method.

Developed material cost estimate method is relatively primitive. It relies strongly on past products and expects that PBS remains similar over time. Also, used product database in PBS comparison is quite small. One aspect for further study would be, how case-based reasoning could be used in a more comprehensive manner. This would require more data and more versatile material categorisation. More attention could be paid on estimating costs of unknown design structures. Also, possibilities to change material input values during estimation would improve the method.

Also, another interesting aspect for further study would be, how warranty provision and its development could be estimated. Now it was expected to remain fixed due to its complexity and time-consuming evaluation. Its effect should not be underrated because the cost effect can be significant. Warranty provision should develop in proportion to the age of the product as well as used technology.

6 CONCLUSION

6.1 Answers to research questions

The purpose of this thesis was twofold – to analyze how product cost development can be estimated already at the early stages of product development and to evaluate how organization could improve its product cost management practices. Theoretical framework was conducted as a literature review by examining product costs, product cost management and product cost development as concepts. Also, different product cost estimation methods and their classifications were presented. Research material for theoretical section was gathered from existing literature and previous studies.

Three research questions were identified. At first, it was evaluated what are the main cost drivers of solar inverters. Previous studies and existing literature have highlighted the importance of competition, volume and scale effects as well as technology advancements. Based on analysis of organization's past production cost data, especially organizational learning, product configuration and product design changes were underlined. Importance of organizational learning was quite surprising as existing studies have totally excluded its effect. Now, its appearance as cost driver was undisputed. Cost data analysis stated that material cost decline and cost reduction activities in purchasing unit were tightly bound to product design changes. Also, the relationship between product configuration and product costs was obvious and some options even multiplied costs.

Second, answer for research question, what should be considered in organization to ensure more efficient product cost management, was presented. Organization's current state of product cost management and estimation were evaluated using gap analysis as a tool. The fundamental idea in gap analysis was to define current and targeted states, name gaps between states and define needed actions to close the gaps.

Organization's current product cost management process focuses mainly on operative accounting and those products that are already in production. In turn, there are shortages when it comes to the cost estimation of new products at the early phases of production life cycle. Product cost estimation process is not systematic enough for organization's current needs and common principles and tools are missing. For instance, organization has not considered the relationship between labour costs and organizational learning as labour costs are expected to remain fixed. Scenario analysis and evaluation of confidence levels are not used efficiently which weakens the accuracy of estimates. Also, current cost estimation of new products relies heavily on personal knowledge and gathered expertise. Existing data systems are not used efficiently to support estimation.

Organization was recommended to shift its focus on proactive product cost management instead of reactive cost management actions. Organization's product cost management process should be more comprehensive starting from the early phases of product development. This could lead to larger profits and enable organization to use its resources more efficiently. Importance of target costing approach was especially highlighted and proposed to be implemented in product development processes. Main findings from gap analysis as well as recommendations are presented below (Table 12).

Table 12 Summary of gap analysis

Recommendations and ipmrovement actions	Recommendation to integrate more proactive product cost management approach and target costing in product development phases. Cost targets should be defined also for smaller design entities. Organization's current product cost management process concentrates mainly on active products and operative accounting.
	Estimation method was developed to standardize organization's product cost estimation process and to support in the making of the first product cost estimate in new product development. Standardization and common principles are needed to improve cost estimation in new product development.
	Simple scenario analysis was integrated into developed product cost estimation method. Principles how to evaluate the accuracy of material cost estimate were defined. Scenario analyses and confidence levels are not used efficiently and there is a clear gap related to estimates' validity and reliability.
	Organizational learning integrated into labour cost development estimation. Effect of organizational learning is not understood and considered systematically in cost estimation of new products.
	Recommendation to use more data systems such as neural networks to support in cost estimation of new products. Current cost estimation of new products relies heavily on personal expertise and knowledge.
	Recommendation to agree common principles for data archiving in order to reduce the time needed to search documents. Cost data is laborous to gather.

Gaps related to product cost estimation, was closed while answering to the third research question, how future product cost development can be modeled and estimated. Theoretical background was created by examining existing product cost estimation methods and categorizing them into qualitative and quantitative methods. Previous studies stated, that various methods have been developed over time all aiming to estimate product costs in a more accurate and efficient manner. Still, there is a crucial need to improve existing methods and make them more suitable for modern needs.

It was not surprising, that suitable method for organization's future product cost estimation could not be found among existing methods. Thus, a hybrid product cost estimation method was developed. The purpose of the new hybrid estimation method was to systematize organization's cost estimation process and to unify estimation principles in product development. Hybrid estimation method was developed based on organization's production cost data and combining elements from parametric estimation, learning curves and case-based reasoning. Analysis of past production cost data stated that organization's labour costs followed clear learning curve, and there was a moderate positive correlation between required labour hours and number of assembled components. Material costs did not behave as expected and proposed parameters could not be used. Nonetheless, product breakdown structure was observed to remain quite similar among different products which was used to establish material cost estimation principles.

It is undisputed that accurate product cost estimation is needed already at the early phases of product development. Knowing the product costs is lifeblood for each business. Still, estimation is extremely complex due to the unexpected and nonlinear behavior of costs as well as large variety of existing uncertainties. Even the best estimation method can give only assumptions of the future. The fundamental challenge in product cost estimation in product development phases is, how to consider product costs efficiently without shifting the attention away from organization's key activities. In order to tackle these challenges, this study highlighted the importance of target costing approach and usage of efficient data systems.

6.2 Validity and reliability of the study

Reliability and validity measure the quality of the study. Study is reliable, if obtained results can be replicated by using the same research design again. Validity refers to the accuracy of the analysis, suitability of the used measurements and generalizability of the achieved results. (Saunders et al. 2016) In this thesis, literature review was conducted by evaluating previous studies and existing literature considering product costs, product cost management and product cost estimation. Data was gathered from several databases and using various keywords. A wide range of references were used, and the emphasis was especially on the latest available research on the topic. It can be claimed, that this study succeeded to construct a reliable theoretical framework.

After theoretical section, empirical research was conducted. Data was gathered from interviews and organization's ERP system and databases. The number of interviewees were relatively small. Still, quite comprehensive view on organization's current practices could be established because interviewees were from central positions and they were familiar with considered issue. Gathered data mass for cost data analysis was large and actual analysis was done avoiding usage of average values. This ensured reliable results. However, other statistical methods and tools could have been used in order to improve the quality of the analysis. Now, it was expected that the cost data was normally distributed which it was not by any means.

Due to the used case study strategy, findings and results cannot be generalized extensively (Saunders et al. 2016). Results can be utilized only in the current operational environment and products. Nonetheless, only organization's challenges were in the scope of this thesis and thus it can be claimed that this study succeeded to reach its targets and provide answers for the research questions. Also, this study managed to give realistic recommendations for the organization how to improve product cost management and estimation practices.

6.3 Aspects for further study

One interesting aspect for further study in the organization would be how the amount of warranty provision should change in proportion to the age of the product or used technology. In this thesis, warranty provision was expected to remain fixed due to its complexity and time-consuming evaluation. Also, life cycle consideration could be widened to the whole product life cycle. Now, life cycle phases such as maintenance and disposal were totally excluded.

Another aspect for further study could be, how technology advancements occur in the whole product generation. In this thesis, the focus was on specific product types and their cost development over time. It would be interesting to compare which one is more beneficial in economic perspective – a new product development or small design changes to existing product generations. Also, negative organizational learning could be considered. Most of the previous studies have expected that organizational learning is always positive and results in cost reductions in every case. It would be interesting to assess how negative learning generates and how significant its effect can be in the modern manufacturing environment.

Developed hybrid product cost estimation method requires further development as well. Future study could focus especially on to sharpen labour and material cost estimates. For instance, more parameters could be established considering product complexity to support in labour cost estimation. Also, further material cost analysis could reveal material category-dependent correlations. In addition, possibilities to change input values such as overhead rates according to changes in operational environment and production would improve the method and make it possible to expand the estimation timespan.

7 SUMMARY

The purpose of this thesis was to study how product cost development can be estimated already at the early phases of product development. Also, another aim was to evaluate how organization could improve its product cost management practices. Study consisted of theoretical and empirical sections and complied with case study strategy combining both quantitative and qualitative research methods. Also, design sciences approach was used in empirical section to establish product cost estimation method and to give recommendations how organization could improve its current state. The study was limited to product costs during production life cycle, and especially on labour and material. Costs caused from product development project, marketing, sales and associated risks were excluded.

Theoretical framework was conducted as a literature review concentrating on product costs, product cost management and product cost estimation. Focus was especially on cost classifications, different cost estimation methods and cost management principles. Also, major cost drivers of solar inverters were evaluated. After theoretical section, empirical research was conducted. Gap analysis was used to evaluate organization's current product cost management process and product cost estimation practises. Also, past production costs were analyzed. The main purpose was to recognize the major gaps between organization's current and targeted states of product cost management and estimation and understand inverter cost behaviour.

As a result, recommendations were given how organization could improve its current state and new product cost estimation method was developed. Organization was recommended to integrate target costing approach in its product development processes and to use data systems more efficiently to support cost estimation of new products. Hybrid product cost estimation method was developed to systematize estimation at the early phases of product development. Hybrid method was selected due to costs' complex behaviour and detected shortages related to existing methods. Method combined elements from parametric cost estimation, learning curves and case-based reasoning.

The main finding of this study and related cost analysis was that cost behaviour can be unpredictable and unique estimation parameters are difficult to establish. Constantly changing business environment makes cost estimation even more difficult and increases the amount of uncertainties. Still, accurate product cost estimation is needed already at the early phases of product development. Recognizing the major cost drivers is essential for estimation. In contrast to solar inverter cost drivers highlighted in previous studies, product configuration, organizational learning and product design changes were especially outlined in this thesis.

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