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Customer needs analysis in the commercialization of LWLC Electrical Drives

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ABSTRACT

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Master's Thesis. Lappeenranta University of Technology. School of Business and Management, Innovation and Technology Management. 104 pages, 18 figures, 12 tables, and 3 appendices. Examiners: Ville Ojanen and Kalle Elfvengren	
Keywords: Customer-oriented new product development, customer needs, Quality Function Deployment, House of Quality, Voice of the Customer, commercialization	
A product's responsiveness to customer needs is one of the key success factors in new product development. The purpose of this thesis study is to identify the most relevant customer needs related to an innovative technology developed by researchers at the Lappeenranta University of Technology, and to find out the most important product attributes that create value to customers. LWLC Electrical Drive is an electrical machine architecture that is able to produce high torques at low rotational speeds in a more compact and lightweight structure. Paths to the commercialization of LWLC are explored in a Tekes funded project at LUT. This thesis was commissioned to support the commercialization project with identifying potential industrial customers and learning their needs and requirements regarding high torque electrical machines. Theoretical background for the research consists of customer-oriented new product development literature and methods of customer needs analysis. The method of Quality Function Deployment and its part House of Quality are applied in the empirical part of the study. The research process includes a web-based survey to Finnish industrial companies, and in-depth interviews with eight companies operating in two industrial segments that have been identified as potential customers to the LWLC drive. The results of the study reveal the key product attributes of LWLC that additional development should be focused on in order to create value and satisfy the identified customer needs. Part of the identified customer needs are similar in both customer industries, but some needs are specific to each application. In addition to the key development targets of LWLC, the results provide general insight to the problems and needs experienced with high torque electrical machines in industrial applications.	

TIIVISTELMÄ

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Asiakastarpeisiin vastaaminen on yksi tärkeimmistä tuotekehityksen menestystekijöistä. Tämän diplomityön tarkoitus on tunnistaa asiakastarpeita, jotka liittyvät Lappeenrannan teknillisessä yliopistossa kehitettyyn innovatiiviseen teknologiaan, sekä näitä tarpeita vastaavat tuoteominaisuudet joihin tulee keskittyä tuotteen jatkokehityksessä.

LWLC Electrical Drive on uusi kevytrakenteinen sähkökonearkkitehtuuri, joka tuottaa suuren väännön alhaisella kierrosnopeudella ilman vaihdelaatikkoa. Yliopistolla on työn kirjoituksen aikaan käynnissä Tekesin rahoittama TUTL-projekti, jossa tutkitaan LWLC-teknologian kaupallisia mahdollisuuksia. Tämä diplomityö tukee kaupallistamisprojektia tunnistamalla potentiaalisia teollisia asiakkaita sekä heidän tarpeitaan ja vaatimuksiaan, jotka liittyvät kyseisen tyyppisiin sähkömoottoreihin.

Työn teoreettinen osuus koostuu asiakaslähtöisen tuotekehityksen teorioista ja metodeista. Erityisesti paneudutaan Quality Function Deployment -menetelmään ja sen House of Quality -osaan, jota sovelletaan työn empiirisen osuuden analyysissä. Datankeruu toteutettiin kyselylomakkeella, joka lähetettiin potentiaalisille suomalaisille teollisuusasiakkaille, sekä haastattelemalla kahdeksaa suomalaista teollisuusyritystä, jotka edustavat kahta potentiaalista LWLC Electrical Driven asiakassegmenttiä.

Tutkimuksen tulokset paljastavat tuotteeseen liittyvät asiakastarpeet sekä niiden pohjalta määritetyt LWLC-moottorin tärkeimmät tuoteominaisuudet, joihin tulee panostaa resursseja jatkokehityksessä. Osa tunnistetuista asiakastarpeista esiintyy molemmilla segmenteillä, ja osa tarpeista liittyy tiettyyn sovelluskohteeseen. LWLC-tuotteen tärkeimpien kehityskohteiden lisäksi työn tulokset antavat yleisen katsauksen asiakkaiden tarpeisiin ja ongelmiin, joita on havaittu nykyisten sähkömoottoreiden käytössä teollisissa sovelluksissa.

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I want to thank the Lappeenranta University of Technology, the whole LWLC project team, and Clover Factory for giving me the opportunity to work in the commercialization project and write this thesis as part of that work. I would also like to thank my examiners, Ville Ojanen and Kalle Elfvengren, for the guidance. The companies that participated in the project and gave their valuable insight for the research deserve big thanks as well.

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Lappeenranta, August 2017

Henna Roikonen

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LIST OF ABBREVIATIONS

NPD	New Product Development
QFD	Quality Function Deployment
HOQ	House of Quality
VOC	Voice of the Customer
VOCT	Voice of the Customer Table
B2B	Business-to-Business
LWLC	Light Weight Liquid Cooled
DLC	Direct Liquid Cooled
POC	Proof of Concept
O&M	Operation and Maintenance
CAPEX	Capital Expenditure
OPEX	Operational Expenditure
kW	Kilowatt
MW	Megawatt
rpm	Revolutions Per Minute
Nm	Newtonmetre
kNm	Kilonewtonmetre
V	Volt
kg	Kilogram
t	Ton

1 INTRODUCTION

This thesis study is focused on identifying customer needs and most important product attributes related to an innovative electrical machine technology developed at Lappeenranta University of Technology. The research is carried out as a part of a commercialization project that is ongoing at the university and funded by Tekes. Identification of customer needs is done via a web-based survey and interviews with Finnish potential customer companies. The analysis of linking the customer needs with product attributes is conducted through Quality Function Deployment (QFD), which is a customer-oriented method for supporting product development. The main target is to find out which product attributes should be further developed according to the identified customer requirements.

1.1 Background for the work

The success or failure of product development is determined by several factors. According to Clausing (1994), a product's success or failure is determined by "the responsiveness to customer needs, the viability of the core concepts, the producibility of the design, the robustness of the functional quality, the economical precision of the production, the success of integration, the effective reusability, and the strategic impact". This thesis is focused on studying the product's responsiveness to customer needs.

Griffin (2013) defines customer needs as "the problems that a product or service solves and the functions it performs. They describe what products let you do, not how they do it." The benefits of integrating customer needs research into product development have been recognized for decades. As Hauser and Clausing (1988) state in their famous article *The House of Quality*, products should be designed to reflect the desires and tastes of customers. In order to fulfill this objective, the skills within an organization must be integrated – marketing team, design engineers, and manufacturing people must work closely together from the very beginning of the product development process.

Customer needs and their significance have been studied in relation to product development in numerous industrial areas. In Finland, for example Valtasaari (2000) has studied Quality Function Deployment and its applicability in mobile phone product development. Increasing international competition nowadays increases the importance of customer needs research even more. (Kärkkäinen et al. 2001).

Literature seems to be unanimous about the advantages of involving customers in product development processes. According to Alam (2005, p. 250-251), there are many benefits in integrating customers into new product development:

- **High quality products** that are consistent with customer needs.
- **Shorter market entry time**, as there is no need to make big changes in prepared concepts in the later stages of product development process.
- **Shorter customer acceptance time**, because the customers are more eager to purchase the product straight away when their opinions have been taken into account.
- **Longtime customer relationships**, when customer is included in the product development process, their trust is gained and foundation for longtime cooperation is built.

Of course, it is impossible to make all the product features right before the introduction of the new technology, even when the customer needs are investigated beforehand. The full potential of the product is educed by the next product version. But when the developers know the customers and their environments from the very beginning, it is easier and more efficient to make the demanded changes to the product. (Hyysalo 2009, p. 17)

This thesis was commissioned by a Tekes funded TUTL project "Tardamotive LWLC Electrical Drives" at the Lappeenranta University of Technology. The goal of the project is to commercialize an innovative technology developed by researchers at LUT. The said technology is a patented electrical machine architecture referred to as LWLC (Light Weight Liquid Cooled). The LWLC architecture allows a motor or generator to develop high torque at very low speeds without an additional speed reducer such as a gearbox. The architecture is based on direct liquid-cooled (DLC) tooth-coil windings and it enables substantially less massive rotor and stator structures. For simplification, the LWLC product and project are referred to as ”LWLC” and “LWLC project” in this paper.

The two-year project that begun in fall 2016 has four objectives:

1. Understanding the commercial value and identifying areas of greatest market demand.
2. Understanding specific customer challenges and needs relating to LWLC.
3. Defining the most profitable model for starting an LWLC electrical drive business.
4. Producing a Proof of Concept LWLC system and presenting it to customers.

This master’s thesis is commisioned in order to support the project in the first two objectives: understanding the commercial value and identifying areas of greatest market demand, and understanding specific customer challenges and needs relating to LWLC. The first and second objectives more precisely include the following tasks. The tasks that are related to this master’s thesis are bolded.

1. Understanding the commercial value and identifying areas of greatest market demand.
   - **Identifying potential customers and learning their business environments.**
   - **Identifying existing and coming competition and understanding the effect on LWLC viability.**
   - Investigating the supply chain, logistics, and regulatory challenges.
   - Reviewing the IP landscape and identifying prerequisites for international commercialization.

2. Understanding speficic customer challenges and needs relating to LWLC.
    - **Identifying problems faced by prominent drive manufacturers and potential end users.**
    - **Collaborating to identify the most potential solution approaches.**

In short, this thesis is focused on identifying potential customers and their needs regarding the product. The goal is to support the product development and prototype building, and to find the product attributes that meet the market needs and provide value to the customers better than competitors.

1.2 Research objectives and scope

The aim of this study is to find out the most important LWLC Electrical Drive product attributes to be further developed based on customer needs that are identified during the thesis project. The main research question and supporting sub-questions are as follows.

- How to find out the most important product attributes to be developed?
    - How to identify customer needs and requirements and respond to them with technical product characteristics?
    - What is the weight/importance of the customer demands in comparison to each other?
    - How competitors respond to the identified customer needs?

The final result of this work is a set of product characteristics that meet the identified customer needs, and their value in comparison to each other. The results may include a few different sets of product attributes, one for each different industrial segment or application. The results of this thesis will also provide latest information in general about the industry's needs and wants regarding high torque electrical motors and generators, as well as information about challenges and problems that seek new solutions.

When customer needs research is conducted in an early stage of the process of bringing a new product to market, the product development process will consume less resources in the future. This is the benefit of this research. In this study, commercialization and product development are seen as overlapping activities, that aim to introduce a new product to the market. The LWLC project aims for the commercialization of the product, but part of that process is the identification of customer needs and specifying product features based on those requirements. Introducing the product to the market is easier when it is developed according to customer needs and potential customers have been included in the process.

Theoretical focus of this study is on customer-oriented new product development, and customer needs and product characteristics identification with the Quality Function Deployment method. QFD is not utilized as a whole, only the House of Quality phase of QFD is used because it determines product attributes based on customer needs. The other phases of QFD are related to further activities that are out of the scope of this work.

Potential customers that are studied are B2B customers, the reason being that this kind of products are usually only purchased by industrial companies. The word 'company' is used in this paper to refer to an organization that develops and supplies products for its customers, although LWLC does not yet belong to a company. Theoretical part also takes into account that a new product development process involving industrial customers is a different process from involving individual consumers (Hanna et al. 1995). The target companies that are taken into consideration in the research operate on the following potential areas of application:

1) industrial crushers, shredders, and mixers
2) marine propulsion systems.

These application areas have been identified as the most potential market segments by the LWLC project team during the project thus far. The customer industries are determined according to the technical suitability and required technical features of electrical machines, including a megawatt power range and slow rotation speed, that result in high torque capabilities.

Potential customer companies operating on these market areas are also divided into three categories, because it is crucial to include the whole value chain.

1) motor and generator manufacturers
2) application manufacturers or integrators
3) end users.

Potential customers were interviewed for this thesis study in Finland, and one of the companies in Norway, but the complete market was examined globally during the project. This limitation to Finnish companies was set in order to remove geographical barriers for interviews and co-operation, and because of the temporal limitations of this thesis project in contrast to the whole commercialization project.

The product related research is focused on electrical machines with a power range of 0,5-5 megawatts. This range was set because it is approximately the ideal power range of the LWLC machines and covers a wide amount of possible industrial applications.

Other operations of the LWLC commercialization project are not addressed in this thesis. The scope of the thesis is strictly focused on the customer need assessment and determining the most important development targets of the product.

1.3 Research methods

This thesis is conducted according to both qualitative and quantitative research methods because of the amount and nature of data and the method of data collection by survey and interviews. In case of qualitative research, the data is mostly collected in the form of words, whereas quantitative research method presents data in numbers or it can be expressed as numbers. (Easterby-Smith, et al. 2008, p. 82-83) Customer studies can be either quantitative or qualitative. Quantitative research includes numerical analysis and presentation of the data, and has a good resistance to bias. Qualitative research gives understanding of problems and provides different insights and ideas. (Birn 2002; Chisnall 1995) Researchers of customer need identification commonly use qualitative techniques. Typically, this kind of study includes interviewing 10-50 customers. (Majava et al. 2014)

In case of the Quality Function Deployment, both qualitative and quantitative data about the Voice of the Customer is collected. The main data is a list of product attributes that are found out to be important to the customer. These attributes are qualitative data, but there is also numerical, quantitative data associated with each attribute. The relative importance of each attribute is expressed with numbers, as well as the satisfaction with these attributes in existing products. Generally, the attributes are determined first, and after that, they are measured. Qualitative data acquisition is usually conducted by talking to customers and observing them, whereas quantitative data is collected by surveys. (Cohen 1995, p. 254-255)

The thesis includes a comprehensive literature review that is conducted mainly from books and articles from academic journals concerning the area of the topic. The sources were searched from LUT Finna portal that has access to international research databases of academic journals, such as EBSCO, Emerald, and Springer Link. Also, some online documents were used in the research. The literature concerns models regarding customer needs analysis in the process of new product development. The theoretical background gives this thesis the conceptual framework with which the data is collected and analyzed.

In this study, both survey and interviews are used as data collection methods. Scholars (such as Brannen 1992, Robson 1995) point out that different methods often complement each other. Broadening the use of different methods can result in wider perspectives and increased reliability of the study. According to Hirsjärvi & Hurme (2015, p. 38), some studies have even been criticized for too straightforward choices of conduct that lead to narrow and weak results. Therefore, researchers should be flexible and choose a set of methods that best suit the purpose of the study – solving the research problem. (Hirsjärvi & Hurme 2015, p. 38-39)

During the data collection phase of this thesis, a web-based survey was sent to selected representatives in Finnish industrial companies that were found relevant and suitable for the purpose of this project and the LWLC product. Subject persons that were contacted were mainly business development managers, other managers, and R&D engineers. Survey questions were formed according to the conceptual framework on grounds of literature and the specific areas of interest regarding the LWLC project. The questionnaire was designed by the author and refined together with the market research team members and the supervisor.

After receiving survey responses and assessing the answers, in-depth interviews with the same contact persons from part of the companies were conducted during visits to the companies' locations during the first half of year 2017. The interviews were carried out in a semi-structured manner, and the data was processed by extracting the relevant ideas related to the topic.

The study involves also competitor product analysis. Benchmarking is used in examining competitor products. Data for the competitor product analysis is collected mainly by desktop research from product brochures and datasheets available online. Information about competitors was also received during discussions with potential customer companies.

1.4 Structure of the report

This thesis consists of three main parts: theoretical part, empirical part, and results, of which the last two are closely intertwined. Firstly, the research problem is identified and the target is set. Theoretical part includes literature review of customer oriented product development theories and Quality Function Deployment, and addresses the significance of the Voice of the Customer and management of customer needs in new product development processes.

The empirical part starts with an introduction to the project LWLC Electrical Drives and the LWLC technology. After this, the empirical part focuses on the research process including potential customer identification, and data collection with survey and interviews with potential customers. Analysis of competitor products is also included. Customer needs are identified based on the data, and related product attributes are analyzed with the House of Quality matrix of QFD. The HOQ is executed with an Excel-based HOQ template that is provided by QFD Online.

The essential results of the HOQ technique are analyzed and assessed. Based on the analysis and reflections, recommendations are made to be further utilized in the LWLC project. The following process figure (figure 1) presents the structure in the form of key steps and stages of this thesis.

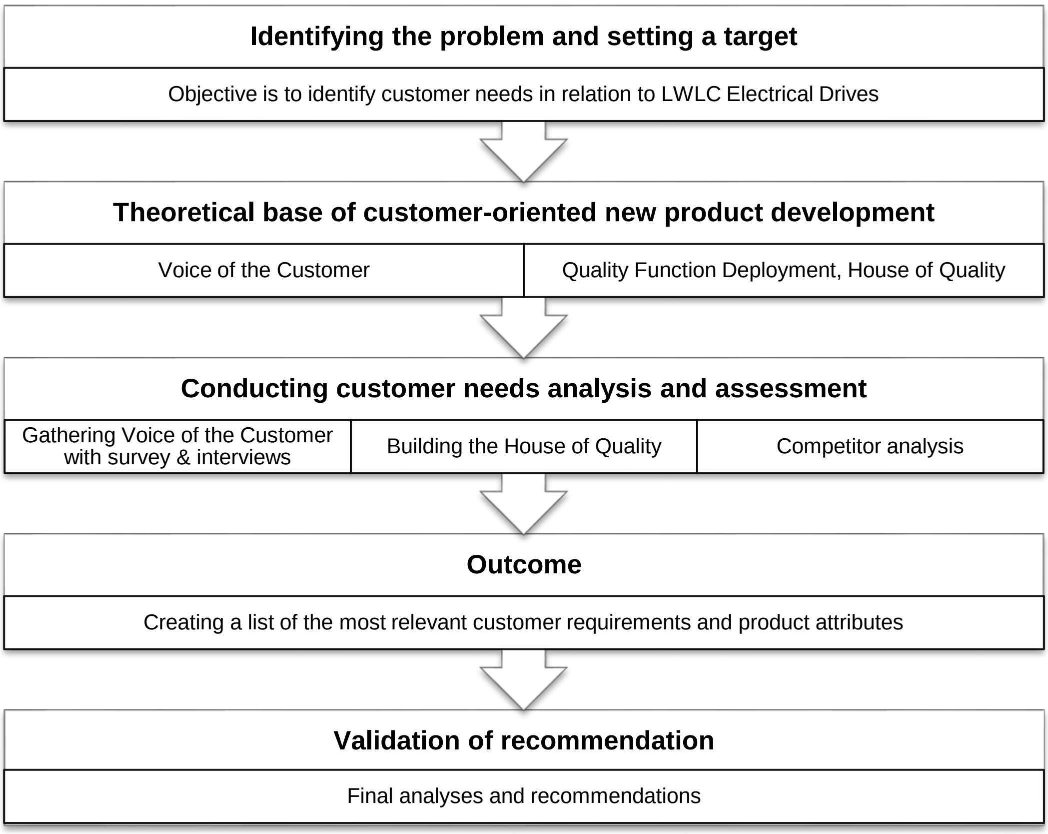

Figure 1. Key stages of the thesis project.

2 CUSTOMER-ORIENTED NEW PRODUCT DEVELOPMENT

Krishnan and Ulrich (2001) define product development as “the transformation of a market opportunity and set of assumptions about product technology into a product available for sale”. Simply put, New Product Development (NPD) is the process of bringing a new product to the market. NPD includes the activities that are conducted when a company aims to develop a product to be sold or supplied. (Maritan 2015, p. 6)

Scientific research has proposed several models for the NPD process and its phases, and many of the phases partly overlap during the process. Herstatt et al. (2006, p. 251) present a simple model for the NPD process that is divided into five major steps (figure 2).

Figure 2. Phases of New Product Development. (Herstatt et al. 2006, p. 251)

The process begins with an idea of a product that is assessed. In the second phase, the product concept and the development project are planned. Third phase is when the actual product development is done. One or more prototypes of the product are built and tested in the fourth stage, after which starts the final phase: production and launch to the market. (Herstatt et al. 2006, p. 251-253)

It is well known that customers select products based on how well the products fill their perceived needs. Therefore, product development teams have to choose product features to fulfill those needs. (Hauser et al. 2010) If products and services do not solve the customers’ problems at a competitive cost, they fail (Griffin 2013).

According to Griffin (2013), there are two paths to new product success. The first path begins with capturing a full understanding of needs related to a problem for which customers would like a better solution. Then a product is developed to solve the problem. On the other path, company develops new products that are based on new technology or have some kind of new features, and then find out if the product solves enough problems for customers to buy it at the price that the company charges. The second path is riskier but can still lead to success. (Griffin 2013)

Hyysalo (2009, p. 14-16) presents examples of successful and unsuccessful product development projects. They indicate that information related to the usage of the product is crucial in several areas. Term ‘user’ in this paper is included in the ‘customers’ that are referred to because users can be seen as the customer of the customer and their needs are included in the gathered customer needs. Impact of customer involvement is significant in these areas in Hyysalo’s examples:

- **Technical implementation**: Lack of user knowledge often leads to expensive repairs and redesign after introduction.
- **Marketing**: Marketing efforts are wasted if the product is withdrawn or delayed.
- **Business**: Usage information helps to define functioning revenue generation models and pricing, reduces risks, and helps to forecast future needs.
- **Planning maintenance and technical support**: When user needs and requirements are known, it is possible to build functioning and adequate maintenance, instructions and technical support from the beginning.
- **Users**: Users suffer the harms and expenses of badly planned products. (Hyysalo 2009, p. 16)

Customer involvement in a product development process is more and more important today in the competitive global markets. Identifying and assessing customer needs carefully helps to steer the development process and focus the development efforts to the right direction. By considering customer needs in the development process, better products can be produced that provide more benefits and value to the customer and the company itself. (Kärkkäinen et al. 2001)

Customer-oriented (or -driven, or -focused) product development is what most companies strive for, but it is a difficult and a demanding task. The essence of customer-oriented product development is that the needs of customers are considered in different phases of the product development process. Customer-oriented product development requires *customer need assessment*. Customer need assessment is a systematic operation that can be seen as a part of product development. (Kärkkäinen et al. 2001) Customer need assessment can be divided into six phases (figure 3):

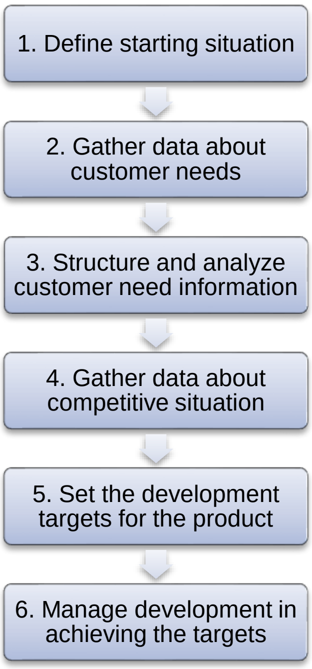

Figure 3. Phases of customer need assessment. (Kärkkäinen et al. 2001)

Customers should be involved only if the company truly wants to learn from them, and before all the product specifications are already made. Other reasons are a waste of resources. The key to obtaining customer needs is to observe the customers in context, use methods to talk to them and ask questions that they are able to answer based on facts. It is important to gather accurate information that is useful in the new product development process. (Griffin 2013) Different methods can help developers to efficiently obtain the right information from customers. Next chapter presents methods and tools that are useful in understanding customer needs in product development processes, and explains which tools are utilized in this thesis study.

2.1 Methods and tools for customer needs assessment

In order to fulfill the customer needs, companies must have a process for innovating (Lee-Mortimer 1995). The process and its phases can be supported with a set of methods and tools. Different tools help companies to systematically clarify the customer needs and ensure that they are properly considered throughout the product development process (Kärkkäinen et al. 2001).

The methods and tools that a company uses in innovation processes are an important factor in the company's innovation potential (Davidsen 2004). Using efficient quality methods and tools in commercializing products and creating innovations leads to gaining value (Cauchick Miguel 2007).

Product development should be handled as an interactive process that involves both the supplier and the customer because products have meanings that each customer individually perceives, and finding these meanings can only happen via active relations between the supplier and the customer (Lagrosen 2005). According to Ford et al. (1998), there are three levels of these relationships:

1) *Transactional relationships* – no integration between supplier and customer, and supplier's offering is not differentiated from others.
2) *Facilitative relationships* – customer wishes to acquire relatively undifferentiated products at lowest cost, but both parties are willing to invest in the relationship to increase the cost benefits of the relationship.
3) *Integrative relationships* – customer expects benefits beyond the lower costs and own revenue benefits by enhanced performance. In this relationship, the supplier is frequently working with the customer's development team.

As already stated, customers can and should be involved in the different phases of new product development. A framework by Kaulio (1998) is developed for assessing the different methods for customer involvement in the development process. It has two dimensions of customer involvement: the longitudinal and the lateral dimensions. The longitudinal dimension represents the interaction between the customer and the development process. The lateral dimension presents the depth of customer involvement in the process. Kaulio's framework is displayed in figure 4.

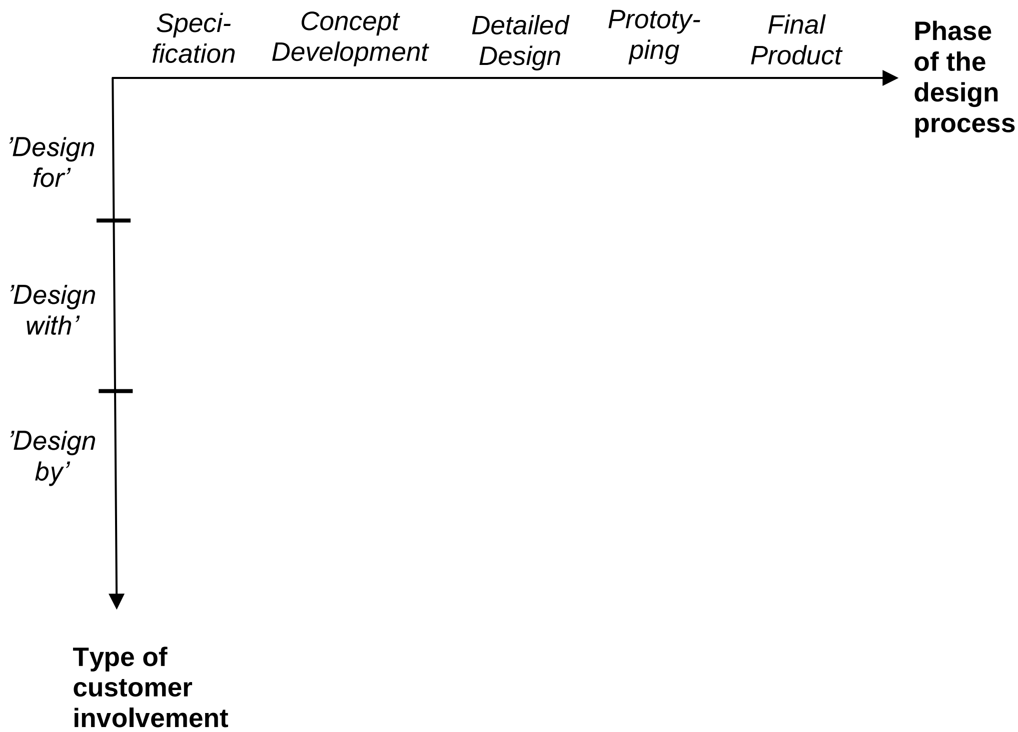

Figure 4. A framework for the analysis of methods for customer involvement in product development. (Kaulio 1998)

'Design for', 'design with', and 'design by' levels of the lateral dimension represent the depth of customer involvement in the development process. 'Design for' means that customers are not directly involved in the process, but data on the customers and models of customer behavior are used as a knowledge base for development. 'Design with' is an approach where data on customer needs and requirements is gathered from the customers and used to design and display different solutions to the customers that can then react to them. ‘Design by’ is where customers are actively involved in the development process. (Kaulio 1998)

Lagrosen (2005) has proposed an extended framework (table 1) that combines Ford et al.’s and Kaulio’s work and adds to them by suggesting methods that are suitable to be used in each level. Lagrosen gives directions on how new product development with customer involvement can be handled on the different levels on customer relationship and the development process.

Table 1. A framework for customer involvement on different levels of relationship. (Lagrosen 2005)

Level of relationship	Longitudinal customer involvement	Lateral customer involvement	Suitable methods
Transactional	Only in the early phases	Design for the customer	Surveys, focus group interviews, observation
Facilitative	In the early phases, in the testing phase and occasionally in the other phases	Design with the customer	Quality Function Deployment, Delphi method, conjoint analysis, prototype testing, beta testing, team customer visits
Integrative	In all phases	Design by the customer	Integrated product development teams including representatives of both the supplier and the customer

Quality Function Deployment (QFD) is one of the methods suggested by Lagrosen to the early phases and the testing phase of product development. QFD is “a customer-oriented approach to product innovation” (Govers 1996), that has many definitions, but the essence of it is the identification of customer needs and translating them into product specifications.

It is essential that in the first stage of any product development method, the appropriate design requirements are derived from the needs of customers. Customer requirements must be identified and product specifications formulated based on the customer requirements. QFD has proven to be well adapted for this mission when applied in a multi-disciplinary team. (Sullivan 1986, Akao 1990; Tipnis 1994)

Erixon’s (1998) experience has shown that QFD is well adapted to ensure that the right input data from the customer is derived. QFD has been studied a plenty and it has been shown to be an effective method to be involved in the product development process (Griffin 1992; Akao & Mazur 2003; Cheng 2003).

Kärkkäinen et al. (2001) have combined a set of recommendations of suitable tools for the different phases of customer needs assessment. The selection table (table 2) is based on the six phases into which they have divided the needs assessment process. Different tools can be used separately, but utilizing multiple tools of the toolset in the customer needs assessment process can be more effective.

Table 2. Selection table for tools in the different phases of the customer need assessment process. (Kärkkäinen et al. 2001)

Name of the tool	1. Define starting situation	2. Gather data about customer’s needs	3. Structure and analyze customer need data	4. Gather data about company’s competitive situation	5. Set development targets for the product	6. Manage development in achieving the targets
Need assessment outline						
Creative group interview						
Framework for 1-on-1 interviews						
Trace matric for business chains						
Voice of customer interpretation table						
Competitive position analysis						
House of Quality (QFD)						
PUGH concept selection table						
Problem source assessment						
Assessment of future competitiveness						
	Colours:					
		A solution to a problem				
		A useful tool				

Kärkkäinen et al. go deeper in the actual needs assessment process, and suggest QFD for setting development targets for the product and gathering data about competitive situation. Supporting tools, like interviews and Voice of the customer interpretation tables should be used for the gathering, structuring and analyzing of customer needs before the actual House of Quality of QFD.

This thesis uses the House of Quality matrix of QFD because the purpose is to set targets for the follow-up development of the product based on customer needs. Data on customer needs is collected via interviews and survey, and the needs are analyzed with Voice of the Customer Tables before filling in the HOQ matrix.

2.2 Which customers to involve?

Before the voice of the customer can be gathered, it has to be decided who the customer is. Often there are several market segments or customer categories. The relative importance of each category has to be decided and they must be treated accordingly. (Cohen 1995, p. 76)

Lead user theory was presented by von Hippel. Lead users of a product or service are users that face needs months or years before they become general in a marketplace. They are able to provide information and solutions to the needs because it will benefit themselves. Lead users of industrial products are usually identified more reliably than consumer products. (von Hippel 1986)

According to Xie et al. (2003), customer needs identification can be focused on:

- more to ordinary customers, if the type of product does not require high innovation speed or if the risks are difficult for the company to manage;
- more to lead users, if the context is highly competitive and innovation is the key to survival, if the speed of introduction onto the market is a critical point and if the company is able to take some risks. Information Technology and internet are examples of this second type of market.

Customers that are involved in the innovation process are usually lead users, and they provide the product development process with their own tacit and sticky information that is and often difficult to interpret (von Hippel 1986; Urban & von Hippel 1988). It is particularly important to interview the lead users of the equipment, as they have real experience and therefore might recognize needs related to the product months or years before other customers. Since they might have worked with insufficient equipment on a daily basis, they are able to articulate their needs and might have even come up with potential solutions to the perceived problems. The needs of lead users are often similar to the common needs of the market, but their understanding of the needs and possible solutions is better than regular users'. Fulfilling these needs creates competitive advantage for the company if competitors have not yet detected the same needs. (Ulrich et al. 2008, p. 58)

User knowledge, customer knowledge and market knowledge have differences (presented in table 3). User knowledge includes more detailed information about the users that is beyond market research and customer feedback, and it provides completion and brings together market and customer knowledge. The best result is a more accurate picture of customer segments and the usage of product in different contexts. (Hyysalo 2009, p. 18)

The research and analysis of this thesis addresses a combination of market knowledge, customer knowledge, and user knowledge, and the word 'customer' is generally used to describe the potential customer companies and persons that are included in the study and interviewed. Because the case product is an industrial product that is mainly bought by other equipment manufacturers that sell the machines forward, they cannot exactly be called as 'users' in the way that Hyysalo, Ulrich and von Hippel present, because the end-user is actually the customer of the customer. However, the interviewed customers were able to provide very detailed information about the machines and their usage from a technical point of view as well, that goes beyond regular customer feedback and complaints.

Table 3. Typical sources, strengths, and weaknesses of user, customer, and market knowledge. (Adapted from Hyysalo 2009, p. 19).

Type of knowledge	Market knowledge	Customer knowledge	User knowledge
What it tells about the users?	Who might buy, where and how	Who have bought, where, what complaints and praises have there been	Who, how, where and why the device is finally used
What it tells about the users' values?	Common trends and wants of the customer base	What stands up from the trends and wants of the real users	Where the users' values arise from, what are their valuations related to the product and the using environment
What it tells about what the users are doing?	General characterizations	Hints of problem situations and good features, improvement suggestions	What the usage consists of, in what kind of environments it happens, what in it is most important to the user
Where it is collected from?	Market research, competitor comparisons, group discussions, statistics	Customer feedback and complaints, discussions, partner, sellers, customer research	Research on future or current users, or co-operation with them
Biggest strength	Overview of potential buyers, common way to tell about customers	Real information about real customers	Detailed understanding of how and why users act and what they want. Combines market and customer knowledge
Typical problems or shortages	Often too general for making design decisions	Scattered, emphasizes on certain customer types, hard to analyze how things are connected to each other	Companies do not know how to acquire. User knowledge often has to be supplemented with broader surveys and market research

2.3 Motivation of the customer to participate in the development process

As stated before, customer participation in the product innovation process is an efficient way of producing products that fulfill the known or hidden customer needs and lead to customer satisfaction. The benefits for the developer are obvious. But what is the motivation of the customer that makes them willing to participate in the development process? The customer expects to obtain benefits by giving their own contribution to the process. To keep the customer interested in participating, they must receive the benefits from the product that they were expecting. (Nambisan & Baron 2009)

Lead users benefit from the advances of the product or service, so they are motivated to push innovation and perhaps participate in the innovation process themselves (von Hippel 1986). Studies have shown that the better the benefit that a user expects to gain from the product, the more they are willing to invest in the development process and provide product concept and design data (Urban & von Hippel 1988).

Motivation of a B2B customer is usually economic benefits or benefits that are related to the product itself. These benefits may include better quality or better product characteristics, introducing the product to use before others, extended warranties and services, rewards, discounts, and cheaper acquisition price. (Nambisan 2002; Brockhoff 2003; Franke & Shah 2003; Vargo & Lusch 2004)

2.4 Differences between industrial customers and consumer markets

There are differences between the product development and customer needs analysis processes of products directed to industrial companies and to consumer markets. Industrial companies buy products to be used in their own products that they sell forward or produce their own products with the help of purchased products. Professional people that make the purchase decisions in industrial companies consider various criteria and compare different alternatives before making the decisions. (Kärkkäinen et al. 2001)

According to Kotler (1991), industrial customers and consumer customers differ from each other, industrial markets possessing the following characteristics compared to consumer markets:

- Fewer buyers
- Larger buyers
- Several buying influences
- Professional purchasing
- Close supplier-customer relationship.

When industrial customers are considered, there are several representatives in the companies whose needs must be examined. People that have a role in the buying process may include production, product development, marketing, and business planning. The most important ones are those that R&D decisions affect the most. (Kärkkäinen et al. 2001) It is generally more difficult to gather detailed information in B2B markets because of the multiple groups of people that the products affect (Griffin 2013).

Traditional market research methods can be used to support product development, but often they are rather intended for marketing consumer products than developing industrial products. Therefore, conventional market research methods as such are not adequate for assessing the customer needs concerning industrial products. (Kärkkäinen et al. 2001)

3 QUALITY FUNCTION DEPLOYMENT

Quality Function Deployment (QFD) is a support method for product and service planning and development (Akao 1990). QFD method and its primary tool House of Quality (HOQ) (Hauser & Clausing 1988) are well-known for supporting the design of high quality products and services that result in customer satisfaction. QFD was originally developed in Japan by Dr. Yoji Akao in 1966, but the method has been applied by companies all over the world since. (Akao & Mazur 2003)

The early applications of QFD include shipbuilding, electronics, automobiles, electronics, and software (Chan & Wu 2002a). For instance, Ford and General Motors have used it. House of Quality was generated at Mitsubishi's Kobe shipyard site, and Toyota contributed the development of QFD significantly. (Hauser & Clausing 1988) Many manufacturing industries have applied QFD since its development. Service sector has adapted QFD as well; for example, government and health care sectors have used QFD. Nowadays, there hardly is an industry that QFD has not been introduced to. (Chan & Wu 2002a)

3.1 Definition and purpose

QFD is a customer oriented method that translates the requests of customers into design and quality targets (Maritan 2015). QFD brings together the voice of the customer and the voice of the engineer/specialist to integrate the wants of the customer with existing organizational know-how (King 1995, p. ix).

Day (1993, p. 9) describes the key points of QFD as follows:

- Planning process
- Utilizes customer requirements
- Important information can be gathered with the matrix framework
- Allows to prioritize important information
- Result is the development targets that are based on customer demands and lead to improved customer satisfaction

A number of definitions for QFD have been offered in literature. Ford Motor Company has proposed a couple definitions for QFD, the following being the starting point and a broader definition in 1987:

> "A system for translating customer requirements into appropriate company requirements at each stage (of the product development cycle) from research and product development to engineering and manufacturing to marketing/sales and distribution."

Later in 1992, another definition by Ford:

> "A planning tool that identifies the significant few items on which to focus time, product improvement efforts and other resources"
> (Ginn & Zairi 2005)

QFD has two purposes: to assure that customer needs are deployed throughout the design, build and delivery of a new product or service, and to improve the process of development itself. (Akao 2003) Therefore its goals are improved customer satisfaction, organizational integration of customer needs, and improved profitability (Griffin 1992). QFD provides a structured way to assure product quality and customer satisfaction while maintaining a sustainable competitive advantage (Akao 1990).

How does it help in practice? What questions does it help to answer? According to Vuori (1995), questions seeking answers with QFD related to the functional characteristics of the product are as follows.

1) What?
    - Which functional features must be developed?
    - What are the strengths of the product?

2) How?
    - What technical features should be developed to maximize customer satisfaction?
    - In order to maximize the safe use of the product, which measurable product features' technical quality have to be invested in? (Vuori 1995)

QFD is said to answer the question "how to transform customer needs into product characteristics", but Vuori (1995) argues that this is actually not always true because it is the design team's task. Instead it can be also said to answer the question "What significance do customer needs give to the development of product characteristics?"

3.2 Customer satisfaction – The Kano Three Arrow model

Customer satisfaction is the ultimate goal of product development, and it can be achieved by considering what customers want and need. Kano's three arrow model is a useful model associated with QFD for describing customer satisfaction as it relates to product characteristics. The model was developed by Professor Noriaki Kano in the 1980's. (King 1995, p. 1) According to the model, there are three distinct categories of quality that customers experience in a product:

1. *Expected quality,* which people take for granted until it is missing. These product characteristics are also known as *dissatisfiers, must-be* or *basic*.
2. *One-dimensional quality*, which makes people happy when they have it and unhappy when they do not. Also known as *satisfiers*, or *straight-line* characteristics.
3. *Exciting quality*, which customers do not expect, but which brings excitement when they are surprised with it. Also known as *delighters* or *attractive* qualities. (King 1995, p. 1; Cohen 1995, p. 36)

These three types can be explained through the three-arrow model below in Figure 5. The vertical axis is the level of customer satisfaction from low to high. The horizontal axis represents the extent to which the customer requirements are fulfilled. (King 1995, p. 1)

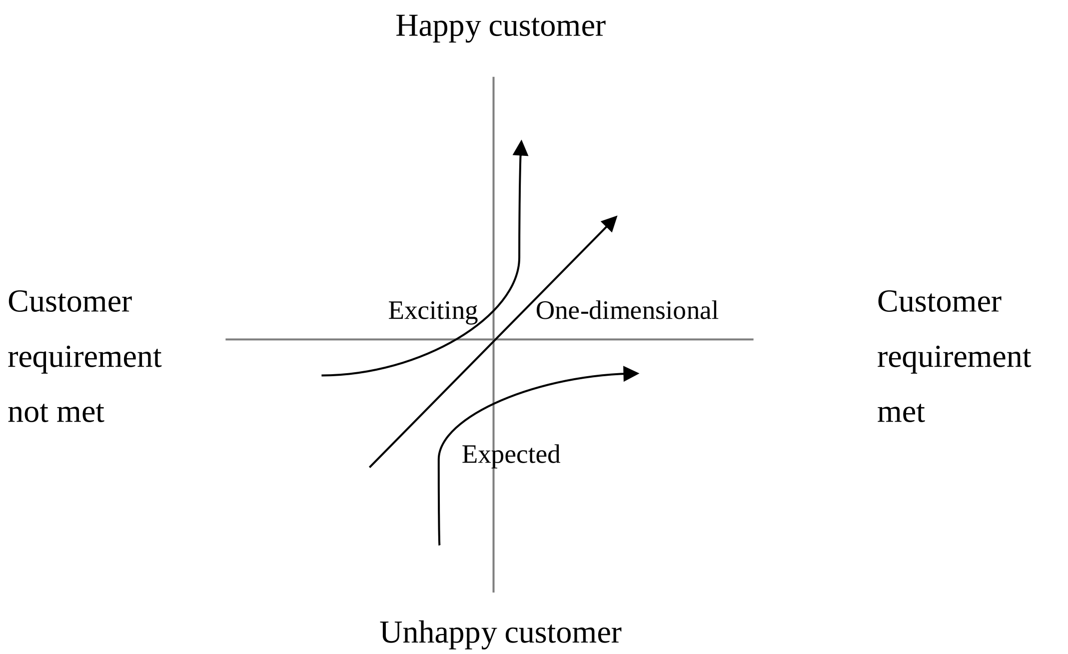

Figure 5. Kano Three-Arrow Model. (Kano et al. 1984)

If the customer requirements are not met, the customer is unhappy. This is represented by the arrow ‘expected quality’. In this case, if the needs are met, it is not a big deal to the customer because it is something that he/she expects, and it does not affect the satisfaction significantly. However, if the expected quality is not met, meaning the product has flaws, the customer can be dissatisfied. Examples of dissatisfiers are scratches on the surface of a product, broken parts, or missing features that equivalent products routinely have. (King 1995, p. 1; Cohen 1995, p. 36-37)

The arrow of one-dimensional quality presents that if the product performs well, the customer is satisfied, and on the other hand if the performance is bad, the customer is dissatisfied. These *satisfiers* are something that customers want and ask for in the products. Examples are lower cost, higher reliability, and increased capacity. These qualities are usually easy to measure, and often become benchmarks used for comparative analysis. (King 1995, p. 2; Cohen 1995, p. 38)

The arrow representing exciting quality, or *delighters*, shows that if the product makes a customer's life better, it may particularly delight them. These features are pleasant surprises to the customer. On the other hand, if these delighting features are not there, customers are not dissatisfied because they do not know what they are missing. Each delighter is unique, and there are not as instructive examples as with the other qualities. The needs that are fulfilled with the *delighters* can be called 'latent' or 'hidden' needs. Customers do not expect these qualities, and usually cannot tell about them when they are asked about their needs. These can be sometimes linked to the customer's perceptions of technological limitations. Some examples of these exciting qualities have previously been car drink holders, or even entire products that created new markets, such as Sony Walkman or Post-it Notes. (King 1995, p. 2; Cohen 1995, p. 38-39)

According to Cohen (1995, p. 41), Kano's model has two major lessons. Firstly, all satisfaction qualities are not equal. Some of them are more important to the customer than others, and they can be important in different ways. Expected qualities do not affect the satisfaction when they are met, but if they are not met, it significantly dissatisfies the customer. The second lesson is that it is not adequate to base the product quality strategy on customer complaints and removing the dissatisfiers. An active strategy, breaking old patterns and finding new creative ways to fulfill the customers' needs and to exceed their expectations, results in satisfied customers.

3.3 QFD process

A comprehensive QFD process consists of one or more matrices that are constructed to guide the product development process throughout. It guides the development team through the conceptualization, creation, and realization process of a new product in a structured way that relates customer needs via product specifications to parts specifications and to production process, and thus to production planning (Govers 1996).

House of Quality (HOQ) is the first of the QFD matrices, and the most used. It consists of several sections that include the customer needs and technical product attributes that meet those needs. (Cohen 1995, p. 11). In this thesis, only the HOQ matrix is applied in the case study, but the other possible matrices should still be briefly introduced for understanding the whole concept of Quality Function Development process. HOQ and its phases are examined more closely in the chapter 4, and it is applied in the empirical part of this paper.

In addition to HOQ, QFD can be constructed to include the later stages of the development process (Cohen 1995, p. 13). Configuration of these additional matrices is presented in figure 6, that shows interrelated matrices carrying information from one matrix to another. There can be several of these matrices in a comprehensive QFD process.

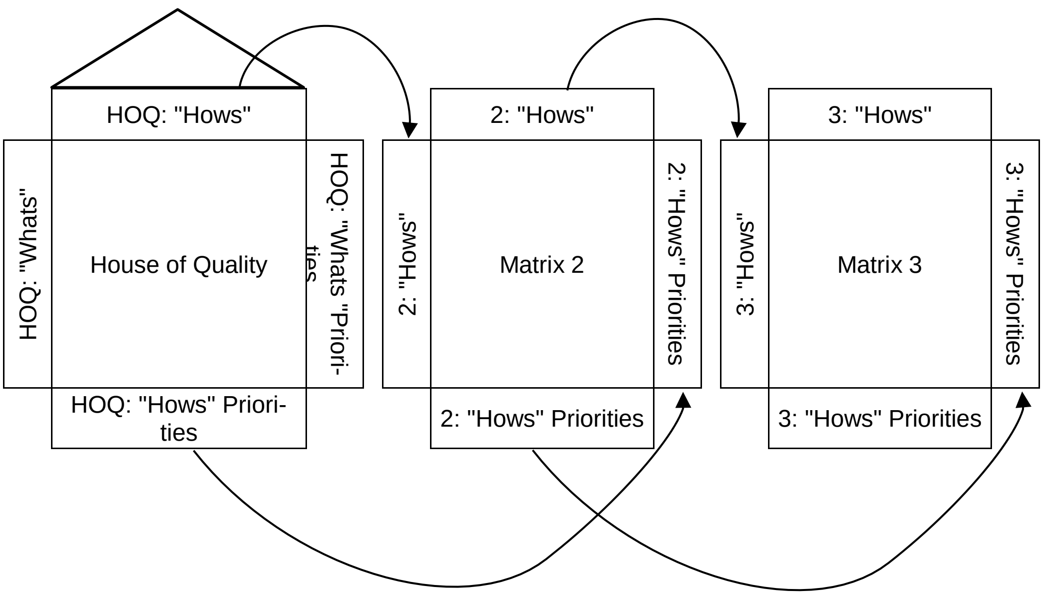

Figure 6. QFD matrices. (Cohen 1995, p. 14)

“Whats” describes the objects that need to be achieved, in HOQ it is most often the customer needs. “Hows” are responses to “Whats”, possible ways to achieve them, such as technical features of the product. “Whats” and “Hows” are then prioritized, which leads to getting the main results of the HOQ process. (Cohen 1995, p. 13-15) Moving to other phases, the “Hows” of one phase become the “Whats” of the next phase, continuing the product development process until manufacturing (Hauser & Clausing 1988).

Various models of the entire QFD development process have been suggested. Most common model has four matrices that cover the whole development process: House of Quality, Parts Deployment, Process Planning, and Production Planning (Hauser & Clausing 1988; Sullivan 1986; Day 1993; Cohen 1995; Govers 1996). This four-phase model is displayed in figure 7.

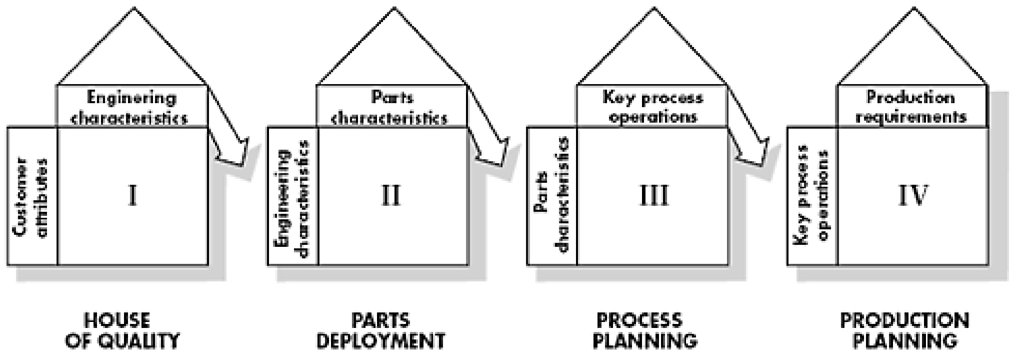

Figure 7. Linked QFD matrices through the process to manufacturing. (Clausing & Hauser 1988)

In practice, the HOQ is often the only matrix used when development teams implement QFD (Cohen 1995, p. 309). This is the case in this thesis project as well, as the thesis is associated with the customer need identification and product feature determination phase of the process, and not the further technical design activities or production process planning operations.

The only phase where designers have direct contact with customers is the initial needs analysis and specifications phase. However, even though QFD's later phases do not explicitly support customer involvement, it does not mean that customer involvement is not recommended in the later phases at all. QFD just offers a support for structuring and representing customer requirements information, and linking them with design characteristics. (Kaulio 1998)

3.4 Strengths and weaknesses of QFD

Some organizations see QFD controversial to some extent because it can involve a lot of effort and time, and even tedium. Early applications involved hundreds of customer needs and product features, which made the process heavy. Fortunately, nowadays there is software and shortcuts available. (Hauser et al. 2010) Now it is even recommended to limit the number of attributes to make the matrix manageable (Kärkkäinen et al. 2004, p. 83). Some other issues of QFD have been generalization of the opinions of multiple decision makers, large amounts of subjective data, burden of a large dimensional comparison, and uncertainty and ambiguity in human decision making (Lee & Lin 2011).

Olewnik & Lewis (2007) have criticized the QFD's ability to provide quantitative design information and suggest that developers should be careful with placing importance on the results in decision making. According to their experiment, quantitative conclusions are potentially flawed because it is difficult or impossible for the developers to assess the true relationship between the customer demands and the product attributes, and that the choice of quantitative scale does not affect the relative weights of the results.

Regardless the controversy, QFD has been showed to have a number of benefits. Hauser et al. (2010) have combined the key benefits of using QFD in the product development process as follows:

- It makes it possible for teams to prioritize development activities in a systematic and analytical way that puts the customer first (vs. the political free-for-all that depends on which customer, salesman or officer has the loudest voice and most power).
- It takes advantage of cross-functionality in a way that is orderly and truly participative and enlists the support of all major functions within the organization toward a common view.
- It provides an "audit trail" which reminds new and old project members of why certain decisions were made in the past.
- It often results in an unexpected prioritization that is different from the conventional wisdom held by the company and participants before engaging in QFD, widening the team's thinking as to which activities are the most important in creating a successful product or service.
- It improves communication among the product development team members. (Hauser et al. 2010)

4 HOUSE OF QUALITY

House of Quality is the basic design tool and the first phase of QFD. HOQ links customer needs to the technical responses that meet the needs. It is the fundamental phase of QFD where the voice of the customer is identified and linked to the voice of the development team. (Chan & Wu 2002b)

Products should be designed to meet customer's tastes and desires – this belief is the foundation of the House of Quality. To achieve this, marketing people, design engineers, and manufacturing staff have to work closely together ever since an idea of a product is first generated. Quality Function Deployment coordinates different skills in an organization. House of Quality works as a map for interfunctional planning and communications. (Clausing & Hauser 1988)

Several versions of the House of Quality have been portrayed by scholars. There is also variation in the terminology used for the parts of HOQ, and various terms may be used interchangeably (Cohen 1995, p. 13). Figure 8 presents a version of HOQ by Kärkkäinen et al. (2004, p. 77). It includes the main building blocks of HOQ, which are constructed in the following order:

1. Customer needs
2. Competitor analysis
3. Product attributes
4. Interaction of product attributes
5. Interdependencies between customer needs and product attributes
6. Prioritizing product attributes
7. Preliminary specifications.

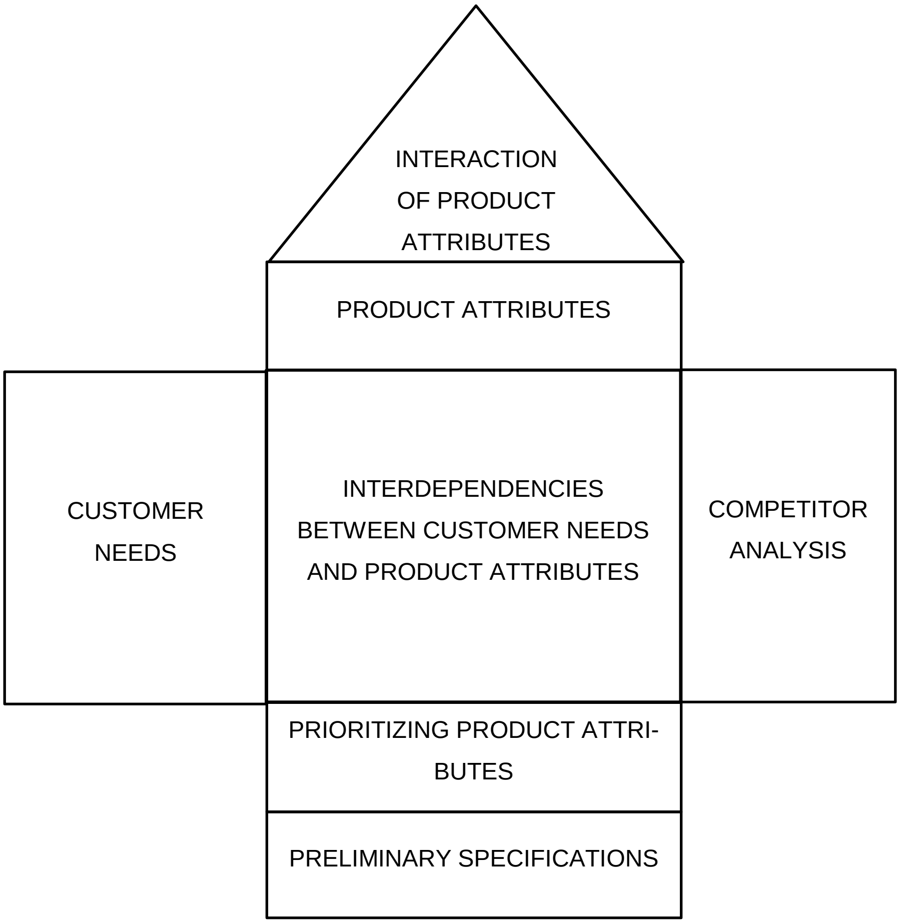

Figure 8. Structure of the House of Quality matrix of QFD. (Kärkkäinen et al. 2004, p. 77)

Building a HOQ starts with identifying the customers and gathering their needs and requirements concerning the product. Customer needs can be categorized into groups of attributes that concern the same, more general feature, and then the attributes are weighed by importance to the customer. Then, competitors and their performance is evaluated in the matrix. Third part includes the identification of technical attributes of the product that match the customer needs, and the impacts of the technical product attributes to one another are defined on the top of the house. Then the relationships between product attributes and customer demands are filled in the middle of the matrix. The product attributes are prioritized based on the need priorities and the relationships between the needs and product attributes. (Clausing & Hauser 1988; Kärkkäinen et al. 2004, p. 77; Chan & Wu 2002b)

Dividing the process to phases help guide the participants work their way through HOQ. The phases define distinct activities that should be performed in sequence to make the process as efficient as possible. Cohen (1995, p. 210) presents four phases of HOQ process, numbered 0-3:

- (Pre-)Phase 0: Plan
- Phase 1: Gather the Voice of The Customer
- Phase 2: Build the House of Quality
- Phase 3: Analyze and Interpret the Results. (Cohen 1995, p. 210)

Hauser and Clausing (1988) summarize the key benefit of HOQ like this: “The principal benefit of house of quality is in-house. It gets people thinking in the right directions and thinking together. For most U.S. companies, this alone amounts to a quiet revolution.”

4.1 Voice of the Customer

The Voice of the Customer (VOC) is a component of QFD that includes the operations of identifying customer needs, structuring them, and prioritizing them. VOC is a product development technique that gives a detailed set of customers’ wants and needs that are organized into a hierarchical structure and prioritized according to the relative importance and satisfaction with current alternatives. (Griffin & Hauser 1993; Hauser et al. 2010)

Voice of the Customer technique is able to expose both general customer needs and very detailed customer needs (Griffin & Hauser 1993; Zaltman & Coulter 1995). VOC includes both qualitative and quantitative market research regarding current and potential customers. Gathering the Voice of the Customer for QFD includes two prominent, separate activities:

1. Gathering the qualitative data.
2. Quantifying the data. (Cohen 1995 p. 294)

VOC is based on reality and customers' real experiences and situations, so it does not have customers imagining things they do not know anything about. VOC unveils the needs and wants by asking indirect questions rather than directly asking "What do you want?" Questions are asked from the customer from a functional orientation, which leads to finding out the product features that solve the problems. Multiple situations and contexts can be addressed where the customer has faced problems to acquire a deep and broad set of details about the needs. (Griffin 2013)

Successful product design requires effective communication. Incorporating the Voice of the Customer through a systematic process such as QFD into the new product development process proactively and early on is more efficient and effective than to redesign the product after an unsuccessful launch. (Griffin & Hauser 1993)

4.1.1 Gathering the Voice of the Customer

Customer needs identification is mainly a qualitative research operation. A typical study includes 10-30 customers that are interviewed. (Griffin & Hauser 1993) Besides interviews, there are also other methods for gathering customer needs that development teams can choose to use depending on the information requirements, budget, schedule, and other needs of the project. Other methods include brainstorming, statistical market research methods, market surveys, focus groups, warranty claims, different scenario analyses, Opera and Delphi methods, and Affinity Diagram. (Kaulio, 1998; King 1995; Kärkkäinen et. al., 2001; Lagrosen, 2005).

Interviews and survey techniques were chosen to be applied in this study, so these methods are examined closer later in this chapter. Interviews were chosen because they allow obtaining a large amount of in-depth information about the customers' wants and needs. In interviews, several different product use situations can be examined in a short period of time (Griffin 2013). Also, according to Griffin, research has shown that in-depth one-on-one interviews are more cost effective than focus groups. Survey was used to gather technical requirements and initial information about customer needs and problems before arranging the interviews. Moreover, the survey helped to determine which customers would be the most beneficial to interview, and gave directions on the topics that should be covered more deeply in the interview framework.

Raw data, the non-filtered sentences that are gathered from customers with the selected interaction methods, represents the VOC. After gathering this Voice of the Customer data, it can be analyzed by placing it into a Voice of the Customer Table (VOCT) (Mazur 1996). There are different ways to set up this table, but Maritan (2015, p. 57) presents a simple model shown in Table 4 below.

Table 4. Voice of the Customer table. (Maritan 2015, p. 57)

Who is the interviewee	**Where interview is conducted**	**When interview is conducted**	**What customer notes**	**Why customer says this sentence**	**How the problem could be solved**

The table can contain distinct sections for each customer with the relative context of use. Maritan (2015, p. 57) suggests that the customers' sentences must not be screened, so if there are lexical mistakes, common sayings or strong expressions, they should be included to express the emotion and passion that is behind the statement.

Interacting with customers always involves some level of risk. The development team should plan the interactions carefully so that both the company and the customer will benefit from the interaction. It is more likely that the customer wants to work with the company in the future if they see benefits for themselves. In B2B markets the benefit to the customer can be for example a better understanding of their own end customers. (Griffin 2013)

Information gathering from customers has some pitfalls to avoid. One is the mistake of selling the company's products, which uses time and may reduce the customers' willingness to participate. The interviews are for learning facts, even if there is a salesperson in the team. Another pitfall is talking to too few customers. Third mistake is to ignore the obtained results. The results have to be systematically utilized so that effort and money are not wasted. When development team members are involved in the customer interactions themselves, they are more likely to use the data. (Griffin 2013)

Surveys

Surveys are one method for collecting information about customer needs and requirements. The construction of a survey questionnaire is a key element and it should be well-written and manageable. Web-based questionnaire is a popular way to conduct survey research. E-mail and internet links can be used to direct respondents to the survey that is constructed on some website that hosts surveys. (Nardi 2014, p. 71-73)

Open-ended questions are a good way to get to know what people think because they have to write it out. Open-ended questions may give a plenty of data, and content analysis has to be done to these written statements, so that the key ideas and phrases can be extracted. However, respondents rarely want to answer many open-ended questions, so closed-ended questions are an efficient way to gather information in a survey as well. Closed-ended questions are quick and easy but can limit the answers. (Nardi 2014, p. 78)

In this study, a survey was used as an initial method for investigating potential customers and their needs and detailed technical requirements regarding megawatt-range electrical machines.

Interviews

Interview process begins with defining objectives and formulating questions based on the objectives. When interviewees are selected and contacted, the preparation for interviews begins. After the most important part, conducting the interviews, the results have to be documented. (Kärkkäinen et al. 2004, p. 51) Interview process steps are illustrated in figure 9.

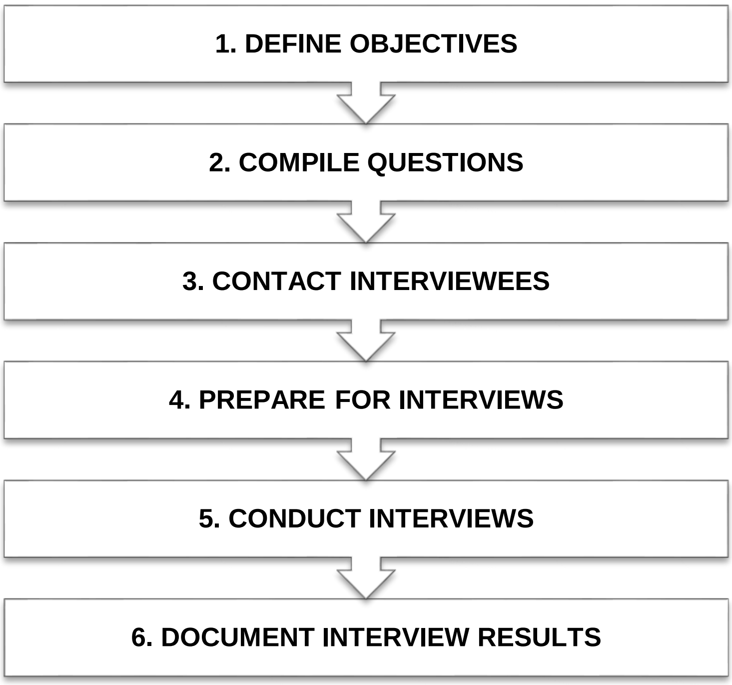

Figure 9. Progression of the “One-on-one interview”. (Kärkkäinen et al. 2004, p. 51)

Griffin (2013) states that the product development team gets a better understanding of the customers’ detailed needs if the team conducts the customer interviews personally, as opposed to outsourcing the interviews to a market research group. It is important to remember that gathering customer needs should be a two-way conversation instead of ‘grilling’ the customer. (Griffin 2013)

Interviewees should be screened and selected early before the interview and motivated when they are contacted for the first time. They should have broad perspectives on the topics so that they are able to provide reliable answers, and they should have the power of decision making. Another principal factor is that the confidentiality of the interview must be emphasized to the interviewee. (Kärkkäinen et al. 2004, p. 53-54)

The interview should begin with easier questions, like the background of the interviewee, and move towards more complicated questions. Trust is built during the interview, therefore the interviewee is more likely to give good answers to the difficult questions if the easy questions are asked first. (Jacob & Furgerson 2012) Kärkkäinen et al. (2004, p. 52-53) suggest a specific framework for interview questions when the aim is to identify customer needs. The framework consists of six sections focusing on different aspects.

I. Background information on the interviewee.
II. Description of the interviewee’s operational environment.
III. Assessing the selection of the present product and the selection criteria.
IV. Evaluating customer satisfaction with the present product.
V. Specifying customer needs and requirements on a new product.
VI. Description of issues related to the product selection in future.

Recording the answers carefully either by writing them down in full sentences or taping the interview is essential. Documentation and writing notes on the same day or on the following day at the latest is an important part that enables executing further measures. (Kärkkäinen et al. 2004, p. 55)

Contextual Inquiry

Contextual Inquiry is a variation of the one-on-one interview. The same principles apply also to Contextual Inquiry, but the difference is that the customer is observed at site, in the context of their activities. (Cohen 1995, p. 272) The planning outlines of one-on-one interviews apply for Contextual Inquiry as well (Cohen 1995, p. 280). The nature of Contextual Inquiry and the relationship of the interviewer and the interviewee is very interactive. Therefore, it is called *inquiry* instead of *interview*. (Cohen 1995, p. 272)

Another main point behind Contextual Inquiry is sharing. Sharing the customer's experience allows obtaining the fullest possible understanding of the customer's needs, as opposed to just observing. Although sharing as a word may sound quite intense, it practically means a professional relationship with the target of providing the product developer with design data. It includes observation at the site of the customer, and discussion with the customer, in order to understand the customer's experience of the activity to the fullest. (Cohen 1995, p. 275)

The difference between interview and inquiry is that in inquiry there is not much difference in the roles of the developer and the customer. In a way, the inquiry is a joint search for information and partnership. The developer has special knowledge of the product and the technology regarding the product, and the customer has special knowledge of his/her job and how the product fits in. (Cohen 1995, p. 279) Figure 10 below pictures the overlap of the shared knowledge of the developer and the customer.

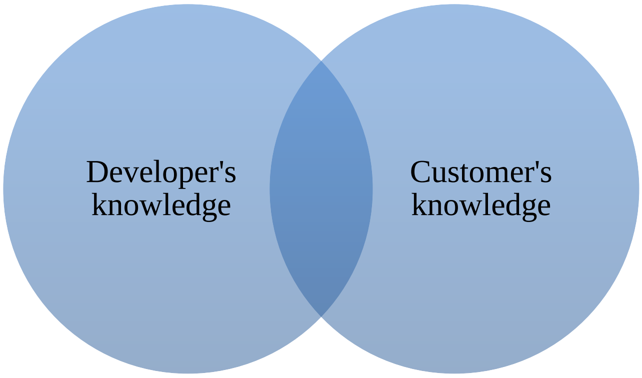

Figure 10. Developer/Customer partnership. (Cohen 1995, p. 279)

Contextual Inquiry provides the benefit of direct observation, experiencing things concretely and receiving concrete data. When things are experienced concretely, more information is learned than what could possibly just be written down. (Cohen 1995, p. 274) This method was utilized in the data gathering process of this thesis. By seeing the companies and their machines (in production or in use) with the team’s own eyes, it was easier to learn and understand the customers’ actual needs and views concerning their electrical machines.

How many interviews?

How many interviews should be conducted? Kvale (1996, p. 102) has stated that in qualitative studies the number of interviewees often tends to be too small or too large. Too few responds cannot provide sufficient statistical generalizations, and too many cannot lead to profound interpretations. Nowadays a usual number seems to be 15 interviewees. (Hirsjärvi & Hurme 2015, p. 58)

According to the experience of Xie et al. (2003), from 10 to 15 interviews are enough to collect a huge quantity of information. According to Griffin and Hauser (1993), 20–30 interviews for each homogeneous segment of customers are enough to determine 90–95 % of possible product requirements.

Regardless the original plan about the number of interviews, the interviews can be carried on until it is noted that the same matters are brought up interview after interview. This phenomenon is called saturation. When it happens, it is a reason to interpret that there is enough material to be able to draw conclusions and accomplish theoretically significant research results (Tuomi & Sarajärvi 2002, p. 89; Hirsjärvi et al. 2009, p. 182; Eskola & Suoranta 2014, p. 63).

4.1.2 Structuring customer needs

Once the gathered VOC data is processed for example with the help of Voice of the Customer Table, and all customer needs are listed, the needs can be structured. There usually is a number of needs, so it is useful to arrange them in a hierarchical format. There are several tools that can be applied when categorizing the customer demands in the QFD process. Examples of these are Affinity Diagram, Tree Diagram, Matrix Diagram, and Priorization Matrix. (Cohen 1995, p. 87-91)

Affinity Diagram is a tool for organizing qualitative information that builds a hierarchy of the data. The data can be for example ideas, opinions, and issues. The ideas used in an affinity diagram can come from internal sources (brainstormed by development team) or external sources (facts that the team has obtained). (Cohen 1995, p. 47; King 1995, p. 45)

Tree Diagram is also a hierarchical structuring tool that is commonly used with QFD. It is often used after Affinity Diagram. It is built from top down and uses logic to map out the paths to accomplishing a goal, like a customer need. (Cohen 1995, p. 57; King 1995, p. 46)

4.1.3 Weighing customer needs

Once the customer needs are listed in the customer needs matrix of HOQ, they have to be weighed. Weights are put into the HOQ matrix next to the customer needs. The weight describes the importance of a feature in comparison with other listed features. Weightings are determined based on the knowledge of the product development team members and their experience with customers, or they are asked directly from the customer on surveys. (Hauser & Clausing 1988)

Weights that are determined by the product development team may be inaccurate. They might also lead the product development process in a non-customer-oriented way. Statistical methods, on the other hand, are based on weights that are determined by the customers themselves. For example, a survey is an ideal way to obtain the evaluations. This is a very customer-oriented approach, but it has to be taken into account that different customers appreciate different features, and it can be troublesome to find a happy medium in a mass of different opinions. (Hauser & Clausing 1988; Day 1993, p. 55)

Weights are often determined as percent, when all the features combined total 100 percent. Weights can also be expressed as numbers 1-9; 1 meaning low importance and 9 meaning high importance, or on a five-point scale from 1-5, where 1 = not at all important to the customer and 5 = of highest importance to the customer. (Hauser & Clausing 1988; Day 1993, p. 55; Cohen 1995, p. 94)

4.2 Competitor product analysis

The essential goal of competitor analysis is to find ways to create competitive advantage and improve the status of a company compared to competitors (Välimaa et al. 1994, p. 35). In case of this study, there is not yet a company whose status to maintain, therefore the objective is to find competitive advantage that enables the initial establishment of a profitable business.

HOQ includes comparison of the product and competitors' similar products in terms of the performance on customer needs. First thing is identifying the competitors that manufactures similar products. Then the products are evaluated based on their performance. The performance is rated on a numerical scale. (Chan & Wu 2002b).

Analysis of competitor products can also be sufficiently conducted on the basis of product brochures. For example, a technical product such as industrial gears, can be compared to each other with two key figures: kW/kg and mk/kW. Brochures provide the information about the power and weight of the product. Information about price has to be investigated from the customers in the market or by purchasing the competitor product, when the price is found out and the product can be examined and tested. (Välimaa et al. 1994, p. 36)

Competitors can also be included in a customer need questionnaire that is sent to customers. This way, the customers provide information about the competitors from their own perspective. Pros and cons about the competitors probably transpire. The customers' view can support the own competitor analysis.

4.3 Determining product attributes

Once the important customer needs are identified, product attributes are determined based on the customer needs. Product attributes should be measurable and have a direct effect on customer perceptions. For example, the 'weight of a door' is an attribute that the customer will feel, but the 'thickness of sheet metal' is a part characteristic that the customer does not perceive directly, and therefore goes beyond the HOQ phase of QFD. (Hauser & Clausing 1988) Examples of the measures associated with the product attributes are for example voltage in volts, time in minutes, length in feet, and so on (Chan & Wu 2002b).

The aim of HOQ is to find the most important attributes that should be the focus of the product development efforts. According to Kärkkäinen et al. (2004, p. 82), the phase of determining product attributes includes the following steps:

- Determine the product attributes that meet the customer needs.
- Eliminate part of the attributes if needed.
- Determine the most important interdependencies between customer needs and product attributes.

- Evaluate the rationality of the matrix.
- Determine development priorities for product attributes.

The development team lists the product attributes, or engineering characteristics, that have an effect on one or more of the customer needs. The development directions of each attribute are also determined. The engineers decide if they want to reduce, increase, or close a product attribute, for example they might hope to reduce 'required energy'. If there is a standard product attribute that has no relationship with a customer need, it may either be redundant to the list, or a customer need is missed. On the other hand, one product attribute can affect more than one customer need. (Hauser & Clausing 1988)

Number of product attributes should be as small as possible. Filling and understanding the QFD matrix becomes difficult and time-consuming if there are too many attributes included. Too many attributes impair the clarity of the matrix. It is suggested that there should be 1-2 product attributes per customer need, and that the appropriate number of product attributes is 1.5 times the number of customer needs in the matrix. (Kärkkäinen et al. 2004, p. 83; Day 1993, p. 70)

4.4 Interaction of product attributes

Interaction of product attributes, or the Technical Correlation matrix, is the roof of the house. It presents which product attributes are interrelated and how strongly, which can be determined by engineering analysis and experience. This section is usually the least used part of QFD, but it may help to find important insights. The development team usually finds that changing some product attribute affects the other. The roof shows which technical areas need communication and which do not. (Cohen 1995, p. 152-154; Chan & Wu 2002b)

There are usually five degrees of technical impacts: strong positive impact, moderate positive impact, no impact, moderate negative impact, and strong negative impact. Symbols are usually used to represent the impacts. (Cohen 1995, p. 152-153;

Chan & Wu 2002b) Cohen states that the direction of the correlation should be indicated, although the symbols do not carry any directional connotation. For example, increased BTU rating of an air conditioner in a car could raise the automobile weight, but increased automobile weight does not necessarily affect the air conditioner's BTU rating. (Cohen 1995, p. 155)

4.5 Relationships between customer needs and product attributes

The body of the house includes the relationships between the customer needs and the product attributes. In other words, it presents which product attributes affect which customer needs, and how much each product attribute affects each customer need. These evaluations are usually made based on the team's expertise and experience. (Hauser & Clausing 1988)

There are usually four possibilities in the relationship levels between product attributes and customer needs: no relationship/not linked, possible relationship/possibly linked, moderate relationship/moderately linked, and strong relationship/strongly linked (Chan & Wu 2002b; Cohen 1995, p. 140). The words 'link' and 'relationship' are used alternatively in this context. Cohen (1995, p. 140) defines the different strengths of the relationships as follows:

1. *Not linked*: changes in the amount of degree of product attribute does not change the customer satisfaction performance of the need.
2. *Possibly linked*: relatively large changes in the amount of product attribute has little or no change in the customer satisfaction performance of the need.
3. *Moderately linked*: relatively large changes in the amount of product attribute noticeably but not majorly changes the customer satisfaction performance of the need.
4. *Strongly linked*: relatively small changes in the amount of product attribute significantly changes the customer satisfaction performance of the need. (Cohen 1995, p. 140)

Symbols or numbers are used in the matrix cells to describe the strength of the relationships (Hauser & Clausing 1988). Table 5 below presents the most common symbols and numerical values that are used to portray the relationships. There is no actual scientific basis for the choices of the symbols and numbers; they are simply a way to express the relationships. (Cohen 1995, p. 144) The most used scales are the symbols, and the (0, 1, 3, 9), because it assigns greater weight to the strong relationship which is important in the product development process. (Chan & Wu 2002b).

Table 5. Relationship symbols and numbers. (Cohen 1995, p. 141)

Symbol	**Meaning**	**Most common Numerical Value**	**Other Values**
	Not linked	0	
△	Possibly linked	1	
○	Moderately linked	3	
◎	Strongly linked	9	10, 7, 5

4.6 Prioritizing product attributes

After the relationships are determined, the key result of the QFD, the relative importance of product attributes is calculated next. These priorities of product attributes are placed below the relationship matrix. (Cohen 1995, p. 144-145)

The relative importance rating of a product attribute is a comprehensive measure that indicates how much the product attribute is related to all the customer needs. The relative importance ratings are usually calculated with the following simple formula, where HOW is a product attribute, and WHAT is a customer need. (Chan & Wu 2002b)

Relative importance of a HOW =

$$\sum_{WHAT} [final\ importance\ rating\ of\ WHAT \\ * relationship\ value\ between\ WHAT\ and\ the\ HOW] \tag{1}$$

The total priority of a product attribute is the sum of all the relationship values with the importance ratings of all customer needs. The priorities represent the contribution of the product attributes to the overall customer satisfaction. The most important product attributes have the biggest contribution to the customer satisfaction, and therefore it is important that the product successes in implementing these attributes. (Cohen 1995, p. 145)

4.7 Preliminary targets

Once the product attributes are prioritized and the competition is benchmarked, it is time to set targets for the key product attributes. Performance targets are not the same as design specifications. Target for a product attribute is the level of performance that is believed to be competitive compared to competitor products. The targets should nevertheless be reachable for the technical resources of the company. Target setting is based on the business know-how and technical expertise of the team. (Cohen 1995, p. 166-167; Chan & Wu 2002b)

Difficulty factors for the targets can also be determined. The difficulty to achieve a target can be high or low, based on how aggressive or conservative the target is. The difficulties are presented with numerical scales similar to the scales used in previous steps. (Chan & Wu 2002b)

5 CASE: LWLC ELECTRICAL DRIVES

The empirical part of this paper starts here. First, the LWLC Electrical Drives commercialization project and the technology itself are briefly introduced. The purpose is to find the most important product features to be developed based on customer needs assessment and House of Quality analysis.

5.1 LWLC Electrical Drives commercialization project

LWLC is a proprietary electrical machine architecture developed at Lappeenranta University of Technology. At the moment of writing the thesis, a Tekes funded TUTL project (TUTL = Tutkimusideoista uutta tietoa ja liiketoimintaa = New business from research ideas) project is ongoing at the university. The two-year project aims to research the market potential and appropriate commercialization paths for LWLC, and includes building a Proof of Concept (POC) prototype of the machine.

Part of the research of the project, and the focus of this thesis, is the identification of potential customers and learning about their needs and requirements in relation to this kind of high-torque machines. It is examined how LWLC meets these needs, and more importantly – how it could do so even better.

5.2 Brief description of the LWLC architecture

The LWLC architecture is based on liquid-cooled tooth-coil windings that are combined with unique and substantially less massive rotor and stator structures. The architecture makes it possible to produce compact and lightweight electrical machine drives that offer high torque at low speeds without a gearbox. The solution has several patents pertaining to the LWLC and DLC (Direct Liquid Cooled) technologies owned by Lappeenranta University of Technology. LWLC based electrical drives are smaller, more efficient, more reliable and more cost-effective than conventional drives that include gearboxes or have a large diameter. LWLC is best suited to a particular power range, which is in the range of megawatts.

Proprietary DLC windings (figure 11) are the key feature of LWLC architecture. They more than double cooling performance in comparison to traditional cooling methods. Cooling liquid flows through the tooth-coil construction of the DLC windings and removes heat in direct contact with the conductors. This superior thermal management approach enables to produce high torque with smaller machines than before.

Figure 11. Example photo of the DLC tooth-coil winding – the key feature of the LWLC architecture.

The second key feature is the lightweight structure (figure 12). Stator and rotor wheel structures are made of stacked steel elements, which allows large and durable structures to be built without welding and the fatigue problems often associated with it.

Figure 12. LWLC motor with the lightweight wheel structure.

The POC prototype that is being built is a 500 kW machine that produces 100 kNm of torque at 50 rpm. Figure 13 below presents the physical size of the POC and how it could look like with casing in place.

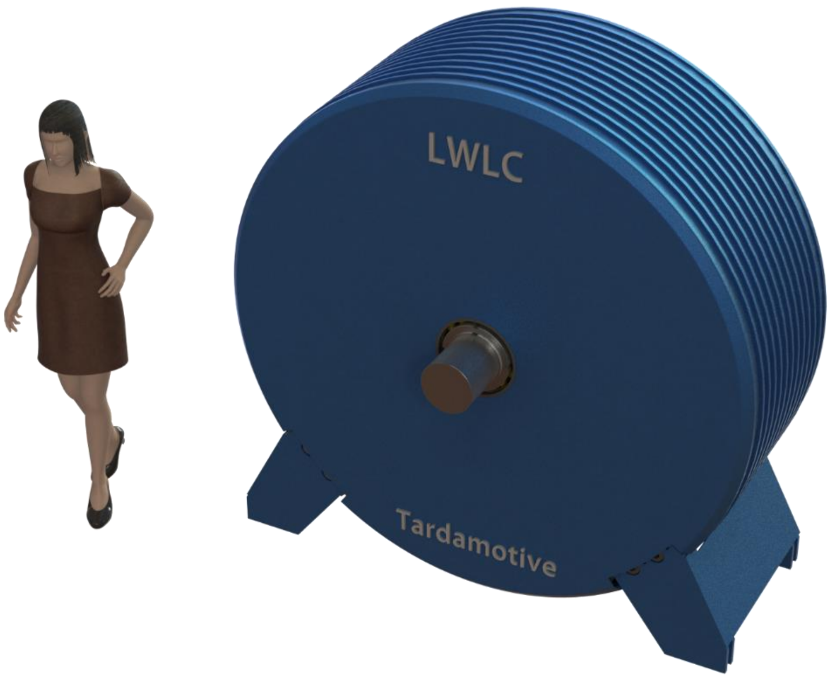

Figure 13. Model of the LWLC 500 kW Proof of Concept prototype.

5.3 Potential industrial applications

LWLC would be an ideal solution for high-power applications that require high torque and low speed. A number of suitable industrial areas of application for LWLC machines have been recognized. Potential applications include:

1) industrial mixers, shredders, and crushers
2) wind turbine generators
3) elevators and escalators
4) marine propulsion auxiliary systems
5) rolling mills
6) mine hoists
7) cement fabrication machines.

This list of applications was used as the basis for identifying potential customers and customer segments in the research process of this thesis.

6 RESEARCH PROCESS

Gathering the Voice of the Customer began by identifying potential industrial customers in Finland. Identified potential customer companies were contacted in a four-step process by the LWLC commercialization team members, of which one was the author of this thesis. The process included the following steps:

1. Cold calling, round I: presenting the LWLC project and initially assessing the company's needs and requirements associated with electrical machines used in high torque and slow speed applications.
2. Survey: Sending a questionnaire and analyzing the individual responses of each company.
3. Cold calling, round II: introducing targeted questions concerning individual technical specifications that were drawn from the survey responses.
4. Interview: Conducting company visits in order to present the LWLC project in person, learn about the operational environment, and to gain more detailed information about the needs and requirements.

Initial aim was to contact and interview as many companies as possible during the thesis project. Company contacting began by phone. The companies were asked about their products and usage of motors and generators of approximately 500 kW and up. The purpose of the first contact round by phone was to approach them regarding the LWLC project for the first time, to awake their interest towards the project, and to find out more about their products and suitability of the LWLC machines.

Another important purpose was to inform them about this master's thesis and ask about their willingness to take part in a survey that would be sent to them shortly after the phone discussion. This was later found out to be a highly advantageous approach because the number of survey responses turned out to be satisfying; 12 out of the 16 of companies that were asked gave their response to the questionnaire.

It can be noted that a phone call to a subject person before sending him/her a questionnaire increases his/her motivation to respond to the survey. Also Cohen (1995, p. 281) notes that preliminary phone conversations have been proven to get the interviewees in the right state of mind for the participation.

Table 6. List of companies contacted during the project.

Company	Company group	LWLC application	Cold calling	Survey response	Interview
Company A	Integrator	Shredders	x	x	x
Company B	End user	Ball mills	x	x	x
Company C	Integrator	Chippers	x	x	x
Company D	Integrator	Crushers	x	x	x
Company E	Integrator	Mixers	x	x	x
Company F	Integrator (engineer)	Ship propulsion	x	x	x
Company G	Integrator	Ship propulsion	x	x	x
Company H	Integrator	Mixers	x	x	x
Company I	Integrator	Ship propulsion	x	x	-
Company J	Integrator	Crushers	x	x	-
Company K	Integrator (engineer)	Ship propulsion	x	x	-
Company L	Manufacturer	Motors	x	x	-
Company M	Manufacturer	Motors	x	-	-
Company N	Integrator	Ship propulsion	x	-	-
Company O	Integrator	Cranes	x	-	-
Company P	Integrator	Elevators	x	-	-

Table 6 above presents the companies that were contacted, and their participation in the different steps of the project. Total of 16 Finnish companies were contacted and sent the survey, total of 12 replied to the survey, and 8 were visited and interviewed at their facilities. Four companies did not give a survey response; two of them notified by phone that their products are not suitable to be included in this project and therefore it would not be beneficial to answer the survey.

After considering the survey answers, the most interesting companies were contacted again by phone and asked if they were interested in meeting the LWLC team and being interviewed. Visits to 8 companies' facilities were arranged and interviews with representatives were conducted during the spring 2016. For one of the meetings, the LWLC team traveled to Norway to visit a Finnish company's local office. Rest of the meetings happened in Finland.

6.1 Identifying potential customers in Finland

Potential market segments were analyzed by examining the overall market segments as well as the individual companies operating in each segment. At the beginning, as many customers as practical were considered, of which the most potential and reachable were contacted in the research project.

Potentially interesting companies in the market were researched mainly on the internet, in addition to the team members' existing knowledge. Companies were searched based on three categories: manufacturers of motors and generators, manufacturers that use large high torque motors or generators in their products, and final end users of these products.

Approximately 20 Finnish companies were initially recognized that operated in the potential LWLC application areas and could therefore be potential customers to the LWLC solution. These companies were contacted by phone and email in regard to the LWLC project.

In addition to collecting customer needs, one of the goals of the project was also to find actual potential customers or cooperation partners with whom the commercialization process could be taken even further after the customer needs research phase and this thesis. Companies were researched globally, but at first the focus was on contacting Finnish companies. This geographical delimitation to Finland was set in order to minimize barriers for initial co-operation in commercializing the LWLC solution. This thesis and its results only address the Finnish companies also because of the temporal limitation of the thesis project. International companies will be contacted later in commercialization project for the full market potential to be explored.

6.2 Survey

The second phase of the company contacting process was sending the contact persons a questionnaire regarding electric machines in the approximate power range of 0,5-5 megawatts. The questionnaire included qualitative questions, but also quantitative values were asked for technical specifications and their importance. In the questionnaire, the companies were asked about their current experience with electrical motors and generators, problems and challenges they have had with the machines, specific technical specifications that they need from these machines in their applications, and other needs and requirements that they have regarding this kind of products. Questionnaire is presented as an appendix.

The questionnaire was divided into four parts. The first part provided a brief introduction to the LWLC technology and the commercialization project, including two questions about the respondent's company and position. The second part was focused on the respondent's current experience with electrical machines, whereas the third part purely consisted of questions about the certain technical specifications that the company's applications have for motors or generators. The last and final part of the questionnaire contained open questions where other needs and requirements, ideas or questions could be freely expressed. In the final part, the respondents were asked about their willingness to co-operate with the LWLC team to develop an ideal solution for their application, and lastly, an open field was left for other free comments and feedback.

As mentioned earlier, the survey received a satisfying number of responses, the response rate being 75 %. Data from the survey responses was processed by extracting the given technical specifications and other expressed needs and requirements, as well as problems that the respondents had had with current electrical machines. Customer needs were derived from the survey answers and put together in Voice of the Customer tables.

Separating customer needs and technical specifications can be problematic when QFD analysis is conducted. Questions about detailed technical requirements of each company’s product formed a part of the survey. The detailed, numerical technical specifications of each equipment given by each company cannot be included in the HOQ analysis and are not further addressed in this thesis, despite being crucial to the LWLC project. Those results however help guide the LWLC development with specifying technical features, and can be used when the LWLC product portfolio is constructed and different standardized versions of the machine are decided.

At this point it is too early to define the collection of standard specifications because the research data is not yet adequate for that purpose. Detailed technical requirements are separate for each customer and application, and they go beyond the needs related to the product that may be hidden behind. Also, each technical specification of an LWLC motor or generator may not even end up being the same as the given specifications of the current machines, because of the different technical capabilities of LWLC. For example, LWLC machines are able produce the required torque with less power compared to current technologies. Another reason for leaving out the detailed technical specifications from the analysis is the purpose to maintain the anonymity of each company.

6.3 Company visits and interviews

Interviews were conducted with 8 companies between January and June of 2017. Interviews were integrated with visits at the companies’ facilities. Four project team members attended the meetings: the project manager, an engineer, a commercial specialist, and the author of this thesis.

6.3.1 Conducting the meetings and collecting the VOC data

Interview data was collected by meeting with total of 29 representatives from 8 companies. At each meeting, there were 2-6 company representatives present, most of them working in R&D or business development departments as engineers or managers.

The interviewees' names or exact job titles are not specified in this paper in order to maintain anonymity. These persons were chosen according to their area of responsibility and knowledge regarding motors and applications in the company. For the LWLC commercialization project, it was essential that the contact persons had good technical knowledge about the applications and end customer requirements in order to provide reliable expert knowledge about their demands for the product. Another important criterion was their ability to make decisions in the company. Decision-making capability was important for future co-operation reasons and it also supported the aim to get real information on the company's needs.

Company visits were arranged during 4.1.-21.6.2017. The visits consisted of discussions, and when possible, a tour in the company's production facilities where the research team was able to see the actual products in manufacturing. One visit also included a trip to a separate waste treatment plant where the team was able to observe a shredder in operation.

Several technical product requirements were already addressed in the survey that was sent to the contact persons prior to the face-to-face meetings, so the main goal was to gain more in-depth information and reasons behind those requirements, as well as to understand their business environment in general and other needs related to the products.

Duration of the meetings was about 1-2 hours. Some of the companies were more interested in the LWLC concept and gave more elaborate answers and participated in the discussion more enthusiastically than others, hence some of the meetings were longer than others. Generally, both parties were interested about the opposite side and the compatibility and adjustability of LWLC to the target company's equipment.

The discussions were recorded, except for 2 companies that did not want recording, because they felt that it would affect too much on what they would be able to say during the meeting. However, they did not prohibit taking notes during the discussion, so the important issues were documented by the author of the thesis.

As said, the LWLC team visited 8 potential customer companies and pursued to gather as much information as possible of the product needs of each company. Table 7 below summarizes the company visits; the visited company, interviewed persons, date, and the duration of the recording or the visit in the cases that did not have recording.

Table 7. Conducted company visits.

Company	**Interviewees**	**Date**	**Duration**
Company A	- Technological Manager - Product Development Manager - 2 Engineers	4.1.2017	1:48:36
Company B	- Production Manager - Engineer	12.1.2017	1:05:26
Company C	- 2 R&D Managers - Engineer	17.1.217	1:59:01
Company D	- Manager - 5 Engineers	18.1.2017	no recording, meeting approximately 1,5 h
Company E	- Department VP - Sales Manager - 2 Product Managers	9.2.2017	no recording, meeting approximately 2 h
Company F	- Team Leader - Project Engineer	14.2.2017	00:57:25
Company G	- 2 Business Development Managers - General Manager - Sales Manager	16.3.2017	01:22:03
Company H	- Founder & Technical Manager - Head of the Business Line - Sales & Marketing Manager	21.6.2017	00:59:45

6.3.2 Framework for discussion

In order to collect relevant information for the LWLC project and this thesis study, a contextual framework of themes to discuss at the meetings was constructed prior to the meetings. Thematic framework was used to support the discussion, even though the situation could not be described as a one-on-one interview in a traditional sense, but more as an open discussion between 6-10 people. The discussion was steered according to the themes when necessary.

The framework was constructed based on the interview framework suggested by Kärkkäinen et al. (2004, p. 52), and modified to suit the objectives of this research and cover the essential issues, while being simple enough to allow efficient use of time. The framework was chosen to cover four topics: company's operational environment, currently used products and the selection process, demands on a new product, and future development. Questions are presented below.

I. The company's operational environment
   a. Who are your main customers?
   b. What are the most important issues for you customers?
   c. What issues are important in your business and what unique selling points do you use in marketing your products?
II. Description of the selection of the present product
   a. Do you purchase the motors/generators alone or the whole drive system?
   b. From which company do you purchase them?
   c. What criteria do you have for making the choice? What are the most important criteria?
   d. Participants in making the choice?
III. Demands on a new product
   a. What would be an ideal solution for your needs without any restrictive factors?
   b. What would be the specifications of the electrical machine?
   c. Do you have development ideas regarding electrical machines?
IV. Future development
   a. What development projects do you have?
   b. Would you be interested in working with the LWLC team to develop a solution for your needs?

6.3.3 Processing the interview data

Material collected from the company visits (recordings and notes), was processed as soon as possible after the meetings. The recordings were transcribed during the next day or few days. The transcription was made almost word-for-word, though excluding parts of the discussion that were completely irrelevant to the topic of this study because they could not provide any extra value to the research.

Transcribed material was further analyzed, by starting with extracting the important statements related to the themes of interest. The main target of the research was to find out about the companies' needs and requirements regarding electrical machines. Customer needs were identified by interpreting the companies' statements.

Voice of the Customer Table was used as a framework for putting together what the customers noted and the related needs. After collecting this information from the interviews, attained data was placed into the VOCT. These complete VOCTs for each interview are not presented in this paper because of the number of tables and large amount of data included.

6.4 Voice of the Customer from the survey and interviews

The only way to obtain a full set of customer needs is to understand the needs of several customers in detail, so that each customer contributes a piece of the information (Griffin 2013). Data acquisition phase resulted in a decent amount of qualitative raw data that had to be processed and analyzed to form a clearer picture of the complete need set that is combined from the discussions with all contacted customers. Voice of the Customer Table was used for this purpose.

Part of the customer needs in this case are more generally related to electrical motors, and others are specifically related to LWLC. The LWLC technology was introduced to the companies prior to the survey and interviews, so they had formed perceptions regarding LWLC and asked many questions which revealed some of their more specific needs. It should be regarded that the goal is not to invent a new product but to improve an existing product concept.

Analysis of the transcripts of interviews was a time-consuming process. The statements that represented customer needs had to be extracted. Hundreds of phrases had to be examined, of which many addressed the same issues or needs. Many phrases included technical requirements, product attributes, and other issues that are not actually customer needs. Although being important to the topic, the other notes are not relevant in the HOQ study, only the customer needs.

Many of the identified customer needs appeared in several interviews. The needs are only listed once despite hearing them many times from different customers. When a customer need is identified in an interview, it does not need to be repeated (Cohen 1995, p. 286). The relative importance of the need to all other needs is determined later, and the incidence of each need can be considered when the needs are prioritized.

Results of customer needs assessment showed differences in the needs of different segments. Therefore, the analysis is divided into two segments: shredders, crushers, and mixers as one segment, and marine propulsion systems as the other segment. Table 8 includes the list of identified customer needs of both customer segments. The list of needs is not in order of importance or otherwise organized in this table. Mainly they are in the order of appearance during the VOC gathering process.

Table 8. Identified customer needs.

Identified customer needs	
Shredders, crushers, and mixers	**Marine propulsion systems**
Low price Low operation and maintenance costs Reliability Follows directives and regulations Fulfills technical requirements Mechanically strong Works in different temperature and humidity conditions Sealed from dust and dirt Small size Durability High torque Variable speed Easy maintenance Several voltage options for different end customers High starting torque Same size as standard AC motors Fits inside a container Small diameter Lightweight Able to provide 3x torque at times Robust structure Lifetime of tens of years Efficient High availability Tolerates pressure peaks Direction of rotation can be changed Efficient and reliable cooling Tolerates immediate shocks and stops Eliminates vibration Low power consumption Can be assembled in an angle Safe Easy to adjust Can be assembled horizontally As modular as possible	High efficiency Competitive price Technical suitability Easy installation Small size Multiple power options Variable speed Several voltage options Approved by the marine classification societies High torque Cooling water temperature can be changed Can be placed horizontally Overtorque Reliable Lightweight Runs with partial load Service available Lifetime of tens of years Variety of sizes available

Shredders, crushers, and mixers segment has more identified customer needs, probably because of the larger number of companies involved in the research process. This segment might also have more variety in the products than marine propulsion systems and therefore have more variety in the needs as well.

Survey results revealed that price, and operation and maintenance (O&M) costs are one of the most important features in the product to the shredder/crusher/mixer segment. Some of the reasons for giving price the highest importance were “Price is the most important point when we sell chippers”, “Asian customers are quite price conscious”, and “Competitive situation is tough”. Two out of four marine companies ranked the importance of price high, but did not give further explanations. One marine company gave price moderate importance, reason being “for designers and shipyards bigger packages are favored when there are less integration "challenges"”. Meaning that the price of a single motor is not that important because the whole drive systems are purchased as big packages.

One respondent ranked the importance of O&M costs higher than the purchase price and explained: “Most important issue is operational saving comparing to old technology”. Another respondent described the importance of O&M costs to be moderate: “They are important but business is still very CAPEX oriented and plant availability comes second. After that OPEX costs.” In the quote, CAPEX refers to capital expenditure, and OPEX to operational expenditure. This respondent thereby regarded purchase price more important than operational costs. What is interesting in these responses is that both respondents manufacture mixers. It can be only noted that both CAPEX and OPEX costs are important to customers, and both must be carefully considered.

6.5 Competitor analysis

HOQ matrix includes competitor product analysis. This chapter addresses motor and generator manufacturers and the products that can be seen as competitors to LWLC machines. Competitor products are assessed based on brochures and datasheets available on the competitors’ websites. Brochures and datasheets cover a wide range of essential information on the product’s technical details and other features, as well as the most important selling points that the company uses to market the product. Analysis and assessment is conducted mostly based on technical characteristics of the products. Technical features such as power, speed, and torque are compared with the size and weight of the motor.

A challenging part of the analysis in this case was finding the most relevant competitors that can provide similar results as the LWLC technology. There are multiple manufacturers that produce traditional higher rpm motors that produce high torques when coupled to a gearbox, or massive slow speed and high-torque motors. Large high-torque motors are usually highly customized products that are ordered for specific applications. Detailed information about these custom products is not usually available, so this analysis only takes into account the standardized products that have brochures available.

6.5.1 Electric motor and generator manufacturers

Current competitors of LWLC machines are companies that produce large high torque and low speed motors, or medium and high-speed motors that are coupled to a gearbox to provide the desired high torque and low speed. These electric motors include permanent magnet motors, induction motors, synchronous motors, asynchronous motors, and other types of electric motors.

This competitor analysis only considers companies that produce motors with a power range of several hundred kilowatts and up. There are also several other companies that manufacture permanent magnet motors and other electrical motors in the smaller power range, but they cannot be considered as competitors to the LWLC technology, which has a sweet spot in the range of megawatts and a 500 kW prototype in the making. Of course, these companies producing smaller machines can become serious competitors in the future if they start producing bigger motors.

Some of the biggest players in the electric motor market today are ABB, GE, and Siemens. Two most commonly used motor and generator manufacturers among the interviewed customer companies were ABB and Siemens, third popular manufacturer being VEM. Other manufacturers mentioned by the interviewed customers include GE, Oswald, The Switch, Hoyer, Helmke, Alconza, and Marelli Motori.

Some of the most interesting direct competitors, companies in the market that produce high torque motors with low speed, include The Switch, Oswald, and Baumüller. Baumüller's machines however are somewhat smaller than LWLC or the other direct competitors, but it is still a relevant competitor in the slightly smaller range. Other companies that manufacture large electric machines include Leroy Somer, Rockwell Automation, Teco Westinghouse, Brook Crompton, Toshiba, and Cummins. Most of the potential competitors are presented below in figure 14.

Figure 14. Competing motor and generator manufacturers.

6.5.2 Competitor products

In addition to analyzing who the most important competitors are, the competitor products must be looked at more closely. Here are presented four products that can be seen as important competitors to LWLC.

The Switch designs and manufactures permanent magnet machines for wind power and marine industries. Below (figure 15) is presented an example of one of their permanent magnet synchronous machines designed for marine applications. This machine is an alternative for someone that needs a high torque, low speed permanent magnet machine. The downside is its massive size and weight, that also bring costs.

PMM 500-5800 kW
Speed range: 0-600 rpm
Max. continuous torque: 73-290 kNm
Voltage: 450/500/690 V
Machine weight with shaft and bearings: 13.3-24.1 t
Height: 2431, width: 2730, length: 2542-3460

Figure 15. The Switch's permanent magnet machine PMM 500-5800 kW. (The Switch 2016)

German Oswald Elektromotoren Gmbh designs and produces customized electric motors between 10 and 2500 kW (figure 16). The product portfolio includes torque motors, synchronous motors, asynchronous motors, generators, linear motors, and induction coils. (Oswald Elektromotoren Gmbh 2013a) Oswald's torque motors and generators are very relevant competitors to the LWLC machines because of their similar torque capabilities. However, just like all of the current solutions, they are larger in size and weight than LWLC.

TF Torque Motors

Power: 5-4500 kW

Speed range: up to 3000 rpm

S1 Torque: 100-250 000 Nm

Voltage: 300-500 V, 690 V

Weight: 50-15500 kg

Figure 16. Oswald's high torque – low speed, permanent magnet direct drive. (Oswald Elektromotoren Gmbh 2013b)

Siemens is one of the biggest players in the market and therefore it is a tough competitor to LWLC. Siemens has product lines of high-torque motors that are widely used in various industries. The SIMOTICS HT-direct high torque motor (figure 17) provides high torques at low speeds directly at the driven machine, and its typical applications include paper industry as roller and press drive, marine industry as propeller drive, mining industry for mill drives, steel industry, plastics industry, crane industry, and sugar industry for sugar centrifuges. (Siemens 2017) It is a competitor in several markets that LWLC attempts to enter, but the product does not provide as high torque as LWLC. It is a competitor when customers have a need for a high torque motor of a little smaller scale.

SIMOTICS HT-direct high-torque motors

Power: 200-2080 kW

Torque: 6000-42 000 Nm

Speed: 200, 300, 400, 500, 600, 800 rpm

Voltage: 400, 460, 690 V

Figure 17. Siemens' SIMOTICS HT Series HT-direct motor. (Siemens 2017)

ABB, as one of the biggest motor manufacturers in the world, also has high torque permanent magnet machines in their portfolio (figure 18). These machines are also designed to eliminate the need of speed reduction equipment such as a gearbox. (ABB 2017) ABB's standard permanent magnet motors have also lower torque capabilities in this scale.

ABB Permanent magnet motors

Power: 17-2500 kW

Torque: 1000-50 000 Nm

Speed: 0-600 rpm

Voltage: 400 to 690 V

Standard IEC frame sizes 280-580

Figure 18. ABB's permanent magnet motor. (ABB 2017)

6.5.3 Customers' selection criteria related to the manufacturer

According to the interviewed customer companies, the most important reasons behind the selection of the manufacturer are usually price and technical requirements of the machine. Other important selection criteria include the reliability of the manufacturer, worldwide presence and availability, as well as the overall competitiveness of the manufacturer.

Many customers use standard motors that are commonly available through numerous large and smaller suppliers, and in that case the price is usually the most distinct determining factor. In other cases, there may also be very specific orders and special equipment with specific requirements, that requires special motors. In that case, technical features of the electrical machine may be more important than price. Some of the smaller suppliers only manufacture special motors for some distinct niche market, and in that case, this is what determines the selection.

Sometimes the motors can be supplied by the same company that manufactures the equipment that uses the motor. This can be a determinative factor. For example, for a shipbuilder, an equipment manufacturer may provide the whole set; a propulsor/pump + electric motor, and if not, the motors are bought separately from a separate supplier.

Often the end customer determines the motor manufacturer, or at least determines the specifications based on which the selection is made. Sometimes the end-customer has specific restrictions for the motor brand that is used in their equipment. Usually the electric motor is purchased by the integrator, but sometimes the end user makes both the selection and the purchase themselves.

Considering the previous fact, it is important to market LWLC machines to various companies that are in different parts of the value chain, like integrators and end-users. Also, the motor that is initially integrated to a crusher for example, may be bought by the integrator at that time, but if the motor breaks down or is chosen to be replaced during the crusher’s lifetime, the one making the purchase decision regarding a new motor is the end-user.

7 CONSTRUCTING THE HOUSE OF QUALITY

As Cohen (1995, p. 210) presents, QFD is a phased process:

1. Gather the Voice of The Customer
2. Build the House of Quality
3. Analyze and interpret the results.

Gathering the Voice of the Customer was described in the previous chapter, so this chapter is dedicated to building the House of Quality. The VOC is the base which the other parts of the house are built on. Two HOQs are built in this study; one for each industrial customer segment that was investigated in the research. The division into two separate HOQs is made because of the differing needs of the two segments.

For the construction of the house, a HOQ template provided by QFD Online (2007) is used. The Excel based template has the traditional structure of HOQ, and it has built in all the formulas for calculating the priorities of the product attributes. The template is downloadable for free, and it is a helpful and simple tool for construction of HOQ as it provides formula protection and data validation. The constructed HOQ matrices are in the appendices of this paper.

7.1 Customer needs and priorities

The most important customer needs were derived from the statements of customers interpreted with the help of the VOCT. Needs that were closely related were combined as one need. The number of needs included in this analysis is restricted to 10 to keep the construction of the HOQ in manageable measures. Therefore, many lower priority needs are excluded from the HOQ. The customer needs were collected from two customer segments, so the HOQ has to be customized for these segments. Therefore, each HOQ includes the needs that are seen critical for success in the particular market segment. The customer needs included in the HOQ are presented in table 9, as well as the priority ratings of each need.

The priorities of the needs are assessed based on perceived importance to the customers. Assessment of the priority is affected by how often and how emphatically each need was mentioned by the companies during the discussions or in the survey. It is assumed that the more times each need came up, the more important it is to the customer. The needs that were mentioned by several customers receive a higher importance rate compared to needs that relate to fewer customers only. Numbered scale of 1-5 is used to assess the importance from low to high.

Table 9. Customer needs priority table.

	Customer need	**Priority**
Marine propulsion systems	Small size	5
	High efficiency	5
	Reliability	5
	Variable speed	3
	Various voltage options	4
	Can be placed horizontally	2
	Competitive price	4
	Long lifetime (tens of years)	3
	Approved by marine classification societies	5
Shredders, crushers, and mixers	High efficiency	5
	Robust, tolerates vibrations and shocks	5
	Reliability	4
	Low price & operating costs	5
	Follows standards and regulations	5
	Compact size	2
	Variable speed	3
	Protected from dust	4
	Various voltage options	4
	Can be placed at different angles	2

7.2 Determining product attributes

Product characteristics are determined to respond to the customer demands. Each customer demand has 1-2 matching product attributes. Product attributes are the features of the product that directly affect each customer need. Table 10 lists the product attributes that were determined to respond to the customer needs.

Table 10. Customer needs and product attributes.

	Customer need ”WHAT”	**Product attribute ”HOW”**
Marine propulsion systems	Small size	Dimensions Weight
	High efficiency	Operating efficiency
	Reliability	Probability of failure Cooling system
	Variable speed	Rotation speed range
	Various voltage options	Voltage
	Can be placed horizontally	Possible inclinations
	Competitive price	Sales price
	Long lifetime (tens of years)	Expected lifetime
	Approved by marine classification societies	Obeys marine regulations
Shredders, crushers, and mixers	High efficiency	Operational efficiency
	Robust, tolerates vibrations and shocks	Mechanical structure Vibration damping
	Reliability	Probability of failure Cooling system
	Low price	Sales price
	Compact size	Dimensions Weight
	Variable speed	Rotation speed range
	Protected from dust	Protection class
	Various voltage options	Voltage
	Can be placed at different angles	Possible inclinations
	Fulfills standards like ATEX and IEC	Obeys standards and regulations

If the QFD was taken beyond the HOQ, each customer attribute would be transformed into more specific, secondary engineering characteristics and parts analysis.

7.3 Competitor assessment

Competitor products that were selected to the customer analysis include Siemens's SIMOTICS high-torque motors, Oswald's torque motors, and The Switch's permanent magnet motors. The analysis is done by comparing the product information that is provided by the companies in product brochures and datasheets, and partly based on the customers' statements about previous problems with motors.

The competitors are placed on the right side of the matrix and their performances in responding to each customer need are assessed on a scale of 1 to 5. The analysis creates a graph that shows how well each competitor performs. Based on the assessment it seems that the competitors are quite even, and the biggest benefit of LWLC is the smaller size and reliability. Unfortunately, price could not be properly compared because of the lack of information about the prices of these competitor products.

Accurate comparison of the competitors is challenging to do without extensive investigation or real-life testing. Information regarding all identified customer needs cannot be found on the brochures or datasheets. Technical information, such as available voltage options and speed ranges, is easy to find and compare, but when it comes to real-life experience of the reliability or toleration of vibration or shocks, for example, it becomes harder to find information. Price is another thing that is impossible to find without purchasing the machine oneself.

7.4 Correlation matrix

Not much effort is put to the correlation matrix that presents the interrelations between product attributes in this case study. The main benefit of the roof of the HOQ is that it shows which organizations or individuals in the product development team should communicate with each other (Cohen 1995, p. 159). The engineering team at this point of LWLC development is very small, and the persons are already working closely together. Therefore, it is not necessary for the project to define the correlations in this study, but the roof was however filled.

Some of the attributes have direct impact on each other. For example, the size of the machine obviously affects the price so that the bigger the machine, the more expensive it is. This means that there is a negative correlation.

Correlation symbols that are used in the HOQ template are:

++	Strong positive correlation
+	Positive correlation
–	Negative correlation

7.5 Relationship between customer needs and product attributes

Relationships between the product attributes and customer needs are a crucial factor in building the house and getting accurate results. Filling in the correlation matrix is one of most laborious parts of HOQ. The symbols that are used to portray the relationships in the HOQ template:

Θ	Strong relationship	9
O	Moderate relationship	3
▲	Weak relationship	1

Tables 11 and 12 include the relationship assessment of the customer needs and product attributes in the HOQ matrices for each segment. This is a crucial part of the construction because the relationships are one of the factors that are used to calculate the most important result, the relative importance of each attribute.

Table 11. Relationships between customer needs and product attributes (marine).

Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / **Demanded Quality** (a.k.a. "Customer Requirements" or "Whats")	Dimensions	Weight	Operating efficiency	Cooling system	Probability of failure	Rotation speed range	Voltage	Possible inclinations	Sales price	Expected lifetime	Obeys marine regulations
Small size (low shaft height)	⊝	O							O		
High efficiency			⊝	O	▲						O
Reliability			▲	O	⊝		▲			O	O
Variable speed						⊝					
Various voltage options							⊝				
Can be placed horizontally	O	▲						⊝			
Competitive price	▲	▲	▲						⊝	▲	
Long lifetime			▲		O					⊝	
Approved by marine classification societies											⊝

Table 12. Relationships between customer needs and product attributes (shredder/crusher/mixer).

Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / **Demanded Quality** (a.k.a. "Customer Requirements" or "Whats")	Dimensions	Weight	Operating efficiency	Vibration damping	Probability of failure	Rotation speed range	Voltage	Possible inclinations	Sales price	Mechanical structure	Obeys standards and regulations	Cooling system	Protection class
Robust, tolerates vibrations and shocks	▲	▲		⊝	O				▲	O			
High efficiency			⊝						▲		O		
Reliability			▲	O	⊝		▲			O	⊝	⊝	⊝
Variable speed						⊝							
Various voltage options							⊝		▲				
Can be placed at different angles	O	▲						⊝		▲			
Low price	▲	▲	O						⊝				
Compact size	⊝	O						▲		O			
Protected from dust											O		⊝
Follows standards and regulations											⊝		O

7.6 Relative importance of the product attributes

When the relationships are determined, the HOQ calculates the importance/weight of each attribute based on the importance of customer needs, and the relationship between the customer needs and the product attributes. The results reveal the product attributes with the highest relative weight. Tables 11 and 12 show the weights and relative weights that were calculated in the HOQ.

Table 11. Weights of product attributes in the marine segment.

Product attributes	Dimensions	Weight	Operating efficiency	Cooling system	Probability of failure	Rotation speed range	Voltage	Possible inclinations	Sales price	Expected lifetime	Obeys marine regulations
Weight / Importance	157,1	60,0	160,0	77,1	142,9	77,1	114,3	51,4	145,7	122,9	205,7
Relative weight	12,0	4,6	12,2	5,9	10,9	5,9	8,7	3,9	11,1	9,3	15,7

The five most important product attributes of the motor in marine propulsion applications in order of importance are as follows:

1. Obeys marine regulations
2. Operating efficiency
3. Dimensions
4. Sales price
5. Probability of failure

Table 12. Weights of product attributes in the shredder/crusher/mixer segment.

Product attributes	Dimensions	Weight	Operating efficiency	Vibration damping	Probability of failure	Rotation speed range	Voltage	Possible inclinations	Sales price	Mechanical structure	Obeys standards and regulations	Cooling system	Protection class
Weight / Im-portance	87,2	46,2	164,1	146,2	130,8	69,2	102,6	51,3	151,3	89,7	276,9	92,3	223,1
Relative weight	5,3	2,8	10,1	9,0	8,0	4,2	6,3	3,1	9,3	5,5	17,0	5,7	13,7

Based on the HOQ analysis of this sector, the five most important attributes of the machine in the shredders, crushers, and mixers segment are:

1. Obeys standards and regulations
2. Protection class
3. Operating efficiency
4. Sales price
5. Vibration damping

These are the key result of the HOQ; the targets that effort should be put on when the product is further developed and improved. More detailed technical specifications for these product attributes have to be defined so that the product attributes can give the best performance results that meet the customer needs and provide value to the customer and end user.

The complete HOQ matrices of both segments are placed in the appendices of this paper.

8 ANALYSIS OF RESULTS AND REFLECTION

This chapter summarizes and analyzes the results of the study. Reflection is conducted in respect to the findings and the utilized theoretical frameworks. In addition to addressing the key results and recommendations, this chapter also assesses the results and points out the limitations of the study.

8.1 Most important product attributes to be developed

The key result of the HOQ study is the list of most important product attributes that attention should be paid to in the continuing product development and specification operations in order to create more value to the customers. The development of these product characteristics is the key target in creating value to customers and successfully commercializing LWLC. The key product attributes in the analyzed segments include obeying standards and regulations related to the application, operating efficiency, dimensions, sales price, protection class, probability of failure, and vibration damping.

Efficiency and price are essential development targets for both application segments, and probably for other segments as well. However, the two analyzed segments had differences in the most important customer needs, so the set product attributes that respond to the needs is also a little different for each industry. The most important application specific needs in the shredder/crusher/mixer segment are protection from vibration and dust. In marine segment, the size of the machine, and reliability are very important product features.

Price of the product is commonly a crucial factor in a product, but also technical requirements are essential. Especially in niche markets and in case of customized solutions, technical requirements are often even more important than price. Many of the interviewed customers stated that LWLC would be attractive if the price of the machine is about the same as the price of the current motor + gearbox combo.

Electrical machines of this size range are usually highly specific and customized solutions. Therefore, a certain set of product specifications that fit every customer is impossible to determine. There are of course more general features that satisfy a wide range of customers, and standards that the machine has to fulfill, for example the IEC standards related to efficiency, and ATEX directive that concerns equipment that is used in an environment with an explosive atmosphere.

There are matters that cannot be standardized in the machine, such as the individual needs of every customer, that may concern for example the mounting of the machine, special space requirements, or the position that the machine is assembled to; some of the applications would need it assembled vertically, horizontally, or even inclined at a certain angle.

8.2 LWLC's advantages and disadvantages compared to competitors

As far as Kano's Three Arrow Model is considered, most of the LWLC features are *satisfiers*, but it also has features that can be described as *delighters*. It introduces technology that provides benefits the customers find as pleasant surprises. LWLC may not provide completely unique outcomes as an electrical drive, but it does it in a more advantageous way because of the unique architecture. LWLC provides the same features of high torque and slow speed in a notably smaller size than conventional permanent magnet machines. Moreover, it does it without an additional speed reducing device. Many of the interviewed potential customers stated that LWLC is something that could solve problems that they have had. Some customers had been wanting to find a direct-drive motor that performs in a certain way with smaller size and lower price. Customers had not seen it possible to find such a machine. This has to do with the customer's perceptions of technological limitations.

LWLC has competitive advantages compared to all the other permanent magnet machine manufacturers in the market today. Technical characteristics form the majority of advantages. First being the fact that the need for a gearbox to produce high torque and low speed is eliminated. Second is that LWLC's torque per active material is higher than anyone else's because of the compact structure. Competing products that are able to produce high torque directly without a gearbox, are much more massive in size and weight.

Cost is a prominent factor in this case. Permanent magnet machines, especially big ones, are very expensive, and most of the cost comes from the building materials, mostly the permanent magnets and copper. When the construction is large, the raw material costs also rise up to high numbers.

LWLC's biggest challenge compared to competitors is its newness and the fact that it is a completely new company that is trying to enter the market and introduce new technology. The perceived reliability of the manufacturer and brand value are something that LWLC lacks compared to competitors for the time being. Customers are conservative and resistant to purchase new technologies from unknown companies that have not been around for long and gained a good reputation. Therefore, it is essential that LWLC acquires pilot projects with partners that can start to prove the advantages of the technology, and gain references and interest among the industry.

8.3 Differences in perceptions of separate segments and interviewees

Many of the identified customer needs are similar in both industrial segments, but some differences in the demands can be of course noted because the segments are quite different, even though similar electrical motors fit both industries' needs. Many of the differences are related to the outside environment where the machine is used. Differences in the perceptions of different interviewees and individual companies were also observed.

8.3.1 Different industrial segments

One of the main differences in the needs of marine propulsion segment, and shredder/crusher/mixer segment, is the size of the machine. Marine vessels have strict limitations in the space where the systems are assembled. The engine rooms do not allow for very high machines. The height of the space is very limited, so the large diameter of direct-drive motors is a problem. LWLC gives the same torque with a smaller diameter than other direct-drive machines. Also, when needed, LWLC structure can be modified to be longer with a smaller diameter. Shredders and mixers have some limitations regarding the size of the motor, but there usually is some flexibility. Reasons for size limitations in these machines are related to maintenance reasons, transportation, or the structural features and size of the machine itself.

Another crucial point that the marine segment was considered about, was the reliability of the cooling of the machine. At sea, if the cooling system breaks and the motor cannot be run on a partial load for a long time, there is a problem. Of course, a functioning cooling system in a motor is crucial for the other industries as well, but in marine segment there is more at stake. In LWLC's case, the cooling pump is practically the component that is more likely to break than the integrated cooling system itself. This risk can be handled by having several backup pumps on board.

The most important demands exclusive to shredders and crushers are robustness and dust resistance. Shredding or crushing of material, rock for example, produces excessive amounts of dust. This can clearly be seen on the end-user sites, despite the presence of dust removing units. Motor casing has to be solid and tightly sealed in order to prevent dust from getting into the structures of the motor and causing problems with its functionality. This factor is not as crucial inside ships.

One of the most interesting observations is a slight difference in the view of the importance of cost between the two segments. The segment of shredders, crushers, and mixers mentioned the importance of price slightly more often than the marine segment. This can perhaps be explained by a few reasons. Shipbuilding as an industry is larger, and costs of building a ship are significantly higher than a single shredding machine. Part of the interviewed crusher/shredder manufacturers sell the products separately, and part of them offer turnkey solutions. According to the interviewed companies, motors used in ships are normally purchased as a part of the whole drive system. Being just one component in a large configuration of multiple equipment, the price of a single electrical motor is not as a significant factor. Technical superiority is seen as a more important matter.

Outside temperature of the environment where the machines operate was mentioned during a couple interviews, though it was not included in the key customer needs in the HOQ analysis. In maritime conditions, temperature can sometimes be as low as -50 degrees Celsius. Shredders and crushers often operate in outside temperatures despite being inside industrial facilities. In Finland, during the wintertime the temperature can be -30 degrees Celsius. On the contrary, in the countries on the Equator, temperatures can rise up to +50. So, the machine must be able to operate in very different temperature conditions. Temperature of operating environment should not be a problem with LWLC, as the cooling liquid temperature can be adjusted.

8.3.2 Different interviewees

When it comes to the differences in the opinions of separate interviewees, the key difference is certainly in the perceptions of engineers versus managers, especially business development managers. Engineers were mostly concerned about technical issues, and were excellent at providing information regarding the technical demands for the product. However, the LWLC team faced most skepticism from some of the interviewed engineers. From a business point of view, engineers seemed to be more attached to the current solutions, and not always were that enthusiastic about the new technology. This is somewhat surprising. Reason for this may be that the engineers would have to do some extra product development work in order to fit the LWLC technology into the machines. Another reason for their lack of interest might be that they would not necessarily be able to make decisions in the company about acquiring new technologies.

Business development managers were the most interested and enthusiastic about participating in the development project. They could instantly see the benefits that LWLC could bring to the table, such as reduced costs and improved efficiency.

Their job is to develop the company and strive for better results, and they are not afraid of change. Also, their ability to make decisions in the company probably affects the level of interest for new technologies because they can make the decision about acquiring a new technology. Managers were also able to provide information about needs and wants regarding the product. One of the key points from their perspective is cost, and if they are offered a chance to reduce costs in manufacturing or operation and maintenance in long-term, they seem to be clearly interested, even if the initial investment costs would not be notably lower. Business development managers are not concerned about possible short-term costs or difficulties in modifying the products if there are recognized long-term benefits for the business.

8.4 Assessment of the results

According to Griffin (2013), customers are not able to provide reliable information about products with which they are not personally familiar or have not experienced. Therefore, customers are not familiar with new technologies that have not yet been commercialized. This means also that the information they provide regarding a new concept or prototype may not be reliable. This problem concerns especially radical new-to-the-world products. (Griffin 2013) LWLC is a new technology that has not yet been commercialized, and thus fits Griffin’s concern. However, LWLC is an electrical motor, which is not a completely new or radical concept. The innovative key features of LWLC are unfamiliar to the customers, which could be perceived in the interviews. Thus, there might be some level of unreliability in the customer’s perceptions regarding the product.

However, most of the identified customer needs were drawn from the customers’ experiences with current electrical machines. According to Griffin (2013), customers provide reliable information on things that they are familiar with and products that they currently use. They can express the problems and strengths of the current products. In the future when LWLC is used by the customers, they will be able to provide more accurate needs that are directly pointed to the LWLC architecture.

One constraint in the study was the limited number of interviewed customer companies, and the fact that they operated only within two industrial segments. The number of identified needs was higher in the segment that had more companies. This indicates that the more customers are interviewed, the more needs can be identified. However, saturation in the identified needs appears at some point.

In addition to the two segments, several other potential applications of LWLC have been recognized as well. Analyzing the needs of these other segments would give a wider view of the important product attributes. As it was noticed in the study, the two analyzed segments had differences in their needs.

Precise number of interviews was not determined in the beginning of the study. The plan was to conduct interviews with as many companies as the project team was able to reach in Finland during the spring 2017. Initially the ideal number of companies was roughed to be around 10-15. One thing that can be noted is that during each meeting with a company, there were several interviewees present. Saturation in the interview answers was noted because same issues were repeated during several discussions. Perhaps there would have not been much gain in interviewing more companies in the same segment. Also, there was a limitation in the number of interesting Finnish companies to reach out to.

Another constraint that turned out during the study was the fact that the discussions with companies did not consider generators. As the LWLC technology can be used as a motor or a generator, it would have been beneficial to gather customer needs specific to generators as well.

Despite the limited number of interviewed companies, the observations within the companies of each segment were highly consistent, and saturation in the results was perceived. Because of this fact, it can be stated that the results give a satisfactory outlook to the shredder/crusher/mixer segment’s and marine segment’s needs and requirements concerning high-torque electrical motors.

Construction of the HOQ includes operations that are somewhat subjective. Accuracy of the determined weights of the customer needs and their relationship with product attributes is a factor that affects the results of the analysis, and must therefore be considered as a possible fault in the study. The real importance of each need varies between different customers, and depends on the person or persons that assesses the importance and determine the weights. Therefore, it must be acknowledged that there can be uncertainty in the quantitative conclusions.

It is interesting to see in the results that one product can satisfy such different industrial applications with some level of modification. Not only are the results beneficial to the development and commercialization of the LWLC product, but also give a general insight to the problems that the two industries have been facing with current drive solutions. Also, the study gives an idea of the industries' future development directions, which in both cases include moving towards fully electrical solutions.

8.5 Further operations and recommendations

The House of Quality analysis suggests the most important key factors in the product that are determined by the customer needs and their priority. The most important product attributes in the analyzed customer segments include obeying standards and regulations related to the application, operating efficiency, dimensions, sales price, protection class, probability of failure, and vibration damping. These features should be focused on in the further product development to provide value to customers and fulfill their needs. In shredder and crusher applications, the most important application specific needs are protection from vibration and dust. Marine segment's most crucial needs include the size of the machine and reliability. Efficiency and price are crucial for both industries.

This study provides information regarding the customer needs in two potential application segments, but there is room for further improvements in the customer needs analysis and product development. To further develop the LWLC machine to meet the needs of a wider range of potential customers, more potential customer companies in other segments should be reached and interviewed as well. Other potential applications that have been recognized include wind turbine generators, elevators and escalators, rolling mills, and mine hoists. Needs analysis on these segments should be carried out. QFD was found to be a useful tool in this thesis for determining systematically the most important customer needs and development targets of the product.

Attention has to be paid to the collective needs of each customer segment, as well as the individual needs of each customer. Building the LWLC product portfolio is a major step that happens once the Proof of Concept prototype is ready and operating. As the team proceeds forward from the prototype, there is a learning curve that will result in some level of standardization for different applications, and some level of customizability.

The conducted interviews with potential customers showed that there is considerable interest towards the LWLC technology in the market, and one of the most important results of the project thus far is the finding that real customers and the need in the market for this kind of machines exist. Not only being excited about the product itself, several interviewed companies are highly interested in co-operation and starting a pilot project with the LWLC team. Some design work and drawings have already been done by the LWLC developers to the interested companies according to their individual needs. Such collaboration should be continued with these companies, and with other companies as well.

The next step after the prototype is the pilot projects that will hopefully prove the functionality of the LWLC technology in real industrial applications. Continuing the development according to the needs of individual customers, and building long-lasting relationships with customers this way from the beginning is invaluable in the development process and supports the establishment of a successful business. Customers should be treated more as partners that equally participate in the product development process.

9 SUMMARY

Literature states that careful customer needs analysis leads to more competitive products that meet the needs of customers and provide them more value. Companies are striving for customer-orientation in their new product development processes to gain benefits for themselves and for the customer.

The research of this thesis was focused on identifying customer needs related to LWLC Electrical Drive, which is a proprietary electrical machine architecture developed at the Lappeenranta University of Technology. This thesis work was conducted as part of the LWLC Electrical Drives commercialization project to support it with customer needs analysis.

The goal was to find the most important product attributes that contribute to customer satisfaction. Customer needs related to the LWLC Electrical Drive were identified and assessed based on survey responses and interviews with eight Finnish companies operating in two potential market segments of LWLC. Product attributes that respond to the identified customer needs were determined and analyzed with the help of the House of Quality matrix tool, that is a part of the Quality Function Deployment method. Based on the analysis, the attributes with highest relative importance include obeying standards and regulations related to the application, operating efficiency, dimensions, sales price, protection class, probability of failure, and vibration damping. The results of this research help the development team to focus future efforts to these key attributes of the product.

In LWLC's case, the final impact of the results on the successfulness of the product will be seen in the future when the commercialization process is completed. At least the results provide insight to the most important development targets of the product specifically related to the two examined application areas, and provide information about the customers' problems and needs related to high torque motors used in industrial equipment.

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APPENDIX 1. QUESTIONNAIRE

Questionnaire regarding electric motors and generators up to 5 MW

You are invited to participate in a Master's thesis study that supports the development of a new electrical machine architecture. The study is being conducted by Henna Roikonen, a candidate for Master of Science in Industrial Engineering and Management at the Lappeenranta University of Technology.

Part of an innovative new technology development by LUT Energy Systems, LWLC is a proprietary machine architecture based on direct liquid-cooled tooth-coil windings and a substantially less massive structure. The new architecture makes it possible to produce a compact and lightweight electrical machine that offers high torque at slow speeds without a gearbox.

Your responses to the survey questions will give us valuable information about your industry's wants and needs. Our goal is to develop a better solution for your electrical machine requirements.

On the following pages, you will be asked about motors and generators up to 5 megawatts. There are four sections addressing your current experience with electric motors and generators, your specification wants and needs, and other issues that you think are relevant. We encourage you to share with us any of your thoughts, wishes, and ideas regarding electrical machinery. Completion of this survey will likely take 10 minutes of your time. Your individual answers will remain anonymous.

If you have questions about the survey or the project, please contact Henna Roikonen by email at henna.roikonen@lut.fi.

Thank you very much for your time and support.

Please answer the questions given below.

Background information

1. Your company

2. Your position

   CEO
   Business Development
   R&D Engineer
   Marketing & Sales
   Purchasing
   Other:

Current experience with electric motors/generators

3. Are you currently manufacturing, retailing or using 1-5 MW electric motors or generators? If this range of 1-5 MW is not suitable for your products, what is the appropriate range for you?

(continues)

4. Do your applications require high torque and low rotation speed? If yes, which applications?

5. How do you select your electrical machine manufacturer? Which manufacturers do you use?

6. Have you had problems with existing electrical machine products? If so, what kind?
In different situations, e.g., installation, transport, adjustment, usage, replacement of parts, maintenance, with the gearbox or cooling?

What would be an ideal solution?

In this section, please consider a typical application where an electric motor or generator (up to 5 MW) with high torque and low rotation speed is being used.

Please give an ideal value for the following product specifications of the motor/generator.

You are also asked to assess the importance of each specification you gave on a scale of 1, 3 and 9, where:
1 = Low importance
3 = Moderate importance
9 = High importance.

Please give reasons for your answers.

The application that your answers are
related to: ______________________

Nominal power (1/10)

8. Nominal power?
Please write the ideal value or range in MW.

9. How important is the specific nominal power?
1 = Low importance, 3 = Moderate importance, 9 = High importance
Mark only one oval per row.
Importance 1 3 9

10. Why?

Rated speed (2/10)

Rotation speed after the gearbox or in the axle. In a solution where gearbox is not needed.

11. Rated speed?
Please write the ideal value or range in RPM.

12. How important is the specific rated speed?
1 = Low importance, 3 = Moderate importance, 9 = High importance
Mark only one oval per row.

(continues)

Importance 1 3 9

13. Why?

Rated torque (3/10)

14. Rated torque?
Please write the ideal value or range in Nm.

15. How important is the specific rated torque?
1 = Low importance, 3 = Moderate importance, 9 = High importance
Mark only one oval per row.
Importance 1 3 9

16. Why?

Voltage (4/10)

17. Voltage?
Please write the ideal value or range in V.

18. How important is this specific voltage?
1 = Low importance, 3 = Moderate importance, 9 = High importance
Mark only one oval per row.
Importance 1 3 9

19. Why?

Current (5/10)

20. Current?
Please write the ideal value or range in A.

21. How important is a specific current?
1 = Low importance, 3 = Moderate importance, 9 = High importance
Mark only one oval per row.
Importance 1 3 9

22. Why?

Operational efficiency (6/10)

23. Operational efficiency?
Please write the ideal value or range in % for efficiency under normal operating conditions.

24. How important is operational efficiency?
1 = Low importance, 3 = Moderate importance, 9 = High importance
Mark only one oval per row.
Importance 1 3 9

25. Why?

Dimensions (7/10)

26. Dimensions (length, width, height, and shaft height)?
Please write the ideal value or range in mm.

27. How important is size?
1 = Low importance, 3 = Moderate importance, 9 = High importance
Mark only one oval per row.
Importance 1 3 9

28. Why?

Maximum weight (8/10)

29. Maximum weight?
Please write the ideal value or range in kg.

30. How important is weight?
1 = Low importance, 3 = Moderate importance, 9 = High importance
Mark only one oval per row.
Importance 1 3 9

31. Why?

Operation and maintenance costs (9/10)

32. How important are operation and maintenance costs?
1 = Low importance, 3 = Moderate importance, 9 = High importance
Mark only one oval per row.
Importance 1 3 9

33. Why?

Price (10/10)

34. For an application with the above specifications, what would you expect to pay for the electrical machine? The converter?
Please write the ideal value or range in total €
or €/MW.

35. How important is price?
1 = Low importance, 3 = Moderate importance, 9 = High importance
Mark only one oval per row.
Importance 1 3 9

36. Why?

Free comments

37. What other requirements do you have for an electric motor or generator?

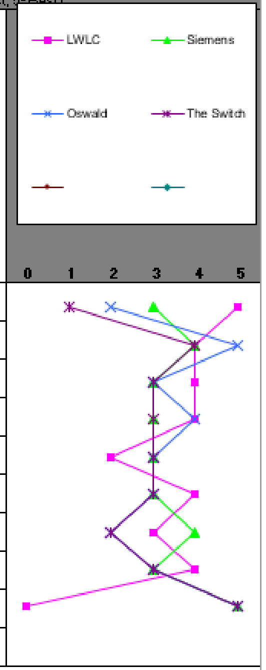
38. Would you be interested in working with us to develop an ideal solution for your application? If yes, what is your application?

39. Free comments/feedback

Thank you very much for your answers.

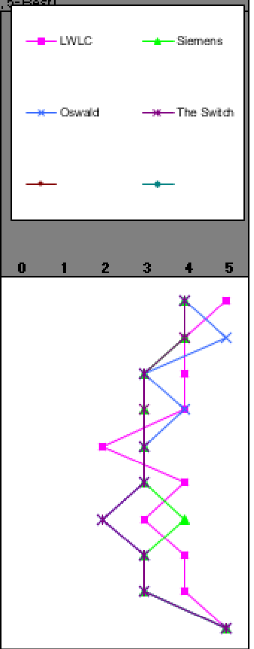
APPENDIX 2. QFD MATRIX 1 (MARINE SEGMENT)

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Dimensions	Weight	Operating efficiency	Cooling system	Probability of failure	Rotation speed range	Voltage	Possible inclinations	Sales price	Expected lifetime	Obeys marine regulations					LWLC	Siemens	Oswald	The Switch
				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Competitive Analysis (0=Worst, 5=Best)			
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	x	x	▲	x	▼	x	▲	x	▼	▲	▲								
1	9	14,3	5,0	Small size (low shaft height)	Θ	O							O							5	3	2	1
2	9	14,3	5,0	High efficiency			Θ	O	▲						O					4	4	5	4
3	9	11,4	4,0	Reliability			▲	O	Θ		▲			O	O					4	3	3	3
4	9	8,6	3,0	Variable speed						Θ										4	3	4	3
5	9	11,4	4,0	Various voltage options							Θ									2	3	3	3
6	9	5,7	2,0	Can be placed horizontally	O	▲						Θ								4	3	3	3
7	9	11,4	4,0	Competitive price	▲	▲	▲						Θ	▲						3	4	2	2
8	9	8,6	3,0	Long lifetime			▲		O					Θ						4	3	3	3
9	9	14,3	5,0	Approved by marine classification societies											Θ					0	5	5	5
10																							
				Target or Limit Value	According to power	According to power	>95 %	As small as possible	As small as possible	0-400 rpm	400/690 V	Any	As low as possible	20 years	100 % compliance	DLC							
				Difficulty (0=Easy to Accomplish, 10=Extremely	1	1	5	1	5	1	3	1	6	2	5								
				Max Relationship Value in Column	9	3	9	3	9	9	9	9	9	9	9								
				Weight / Importance	157,1	60,0	160,0	77,1	142,9	77,1	114,3	51,4	145,7	122,9	205,7								
				Relative Weight	12,0	4,6	12,2	5,9	10,9	5,9	8,7	3,9	11,1	9,3	15,7								



APPENDIX 3. QFD MATRIX 2 (SHREDDER/CRUSHER/MIXER SEGMENT)

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Competitive Analysis (0=Worst, 5=Best)					
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	x	x	▲	▲	▼	x	▲	x	▼	x	▲	x	▲								
				Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Dimensions	Weight	Operating efficiency	Vibration damping	Probability of failure	Rotation speed range	Voltage	Possible inclinations	Sales price	Mechanical structure	Obeys standards and regulations	Cooling system	Protection class			LWLC	Siemens	Oswald	The Switch		
1	9	12,8	5,0	Robust, tolerates vibrations and shocks	▲	▲		Θ	○				▲	○						5	4	4	4		
2	9	12,8	5,0	High efficiency			Θ						▲		○					4	4	5	4		
3	9	10,3	4,0	Reliability			▲	○	Θ		▲			○	Θ	Θ	Θ			4	3	3	3		
4	9	7,7	3,0	Variable speed						Θ										4	3	4	3		
5	9	10,3	4,0	Various voltage options							Θ		▲							2	3	3	3		
6	9	5,1	2,0	Can be placed at different angles	○	▲						Θ		▲						4	3	3	3		
7	9	12,8	5,0	Low price	▲	▲	○						Θ							3	4	2	2		
8	9	5,1	2,0	Compact size	Θ	○						▲		○						4	3	3	3		
9	9	10,3	4,0	Protected from dust											○		Θ			4	3	3	3		
10	9	12,8	5,0	Follows standards and regulations											Θ		○			5	5	5	5		
				Target or Limit Value	According to power	According to power	>95 %	Excellent	As small as possible	0-400 rpm	400/690 V	Any	As low as possible	LWLC structure	100 % compliance	DLC	IP55								
				Difficulty (0=Easy to Accomplish, 10=Extremely	1	1	5	5	5	1	3	1	6	1	5	1	5								
				Max Relationship Value in Column	9	3	9	9	9	9	9	9	9	3	9	9	9								
				Weight / Importance	87,2	46,2	164,1	146,2	130,8	69,2	102,6	51,3	151,3	89,7	276,9	92,3	223,1								
				Relative Weight	5,3	2,8	10,1	9,0	8,0	4,2	6,3	3,1	9,3	5,5	17,0	5,7	13,7								



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