



CHALMERS

The Impact of Customer Needs on Technology Development

A case study of the usage and needs of
calculation and simulation tools for the bearing
market

*Master of Science Thesis
in the Management and Economics of Innovation Programme*

NIKLAS JOHANSSON
PONTUS DAHLENBORG

MASTER'S THESIS E 2016:092

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NIKLAS JOHANSSON
PONTUS DAHLENBORG

Tutor, Chalmers: PETER ALTMANN
Tutor, SKF: FRANCISCO SERRANO

Department of Technology Management and Economics
Division of Innovation and R&D Management
CHALMERS UNIVERSITY OF TECHNOLOGY

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NIKLAS JOHANSSON
PONTUS DAHLENBORG

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Department of Technology Management and Economics
Division of Innovation and R&D Management
Chalmers University of Technology
SE-412 96 Göteborg, Sweden
Telephone: + 46 (0)31-772 1000

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Niklas Johansson



Pontus Dahlenborg

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Abstract

The market for engineering tools for bearing calculation and simulation is changing. A combined trend of increasing computational capabilities, digitalization, and need of more advanced calculation and simulation tools have affected the way bearings are selected. Companies with products that contain bearings do not anymore have to rely solely on bearing manufacturers' expertise to select the right bearings, and a vast range of engineering tools have emerged as bearing manufacturers customers' ability to perform advanced bearing calculations in-house has increased.

Consequently, the market for engineering tools for bearing calculation and simulation is under change, and customer needs diverge as technologies evolve. Suppliers of evolving technologies need to adapt to changing conditions by e.g. develop new value propositions to satisfy new customer needs. Failure to do so might result in loss of power over customers since new entrants might take over crucial activities in the value chain. Although, companies must be aware of needs diverging to a point where attempts to fulfill these needs might lead to conflicts within value propositions. Hence, companies need to identify emerging customer segments and understand customer values in order to provide successful value propositions. These market mechanisms have been investigated through a case study of the market for engineering tools for bearing calculation and simulation.

Representatives from twelve companies have been interviewed to get an insight into present and predicted future use of engineering tools at each company. The empirical findings reveal differences between companies' current needs as well as their predictions on future engineering tool usage. The analysis resulted in three engineering tool user archetypes representing three typical engineering tool users: the indifferent user, the satisfied user, and the advanced user. The study can conclude that the three archetypes show signs of diverging further from each other due to heterogeneous needs, and propose a customer-oriented marketing strategy with careful market segmentation and customer involvement in order to meet these diverging needs. This thesis contribution to the body of literature on innovation management is a better understanding of how technologies diverge and helps managers assess future segments and how current ones are developing.

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1. Introduction

This chapter starts with the background of the study that introduces the market for engineering tools for bearing calculation and simulation to give an account for current market changes. The background also includes a presentation of theoretical arguments for the study. This is followed by the thesis' purpose and aim together with associated research questions. The chapter ends with a presentation of delimitations and the thesis disposition.

1.1 Background

The market for engineering tools for bearing calculation and simulation is changing in the light of increasing digitalization. The combined trend of increasing computational capabilities, digitalization and the need of more advanced calculation and simulation tools have affected the way bearings are selected. Companies with products that contain bearings do not anymore have to rely solely on bearing manufacturers' expertise to select the right bearings, and as the companies' ability to perform advanced bearing calculations in-house has increased, a vast range of engineering tools have emerged. This will be further elaborated upon in this chapter.

Engineering tool software for bearing calculation and simulation, and knowledge about bearings and their properties used to be part of the resources and capabilities available only to the bearing manufacturers. Tools available for customers to these companies used to be limited to paper catalogs containing basic information and formulas of how to perform simple bearing life expectancy calculations. Although, calculation software of various advanced level is nowadays common in most engineering companies. The computational demands of engineering tools for bearing calculation and simulation can be met at a successively lower cost since the computation power available at a certain price is increasing exponentially (Moore, 1975). Hence, tools with ever increasing performance and functionality can reach more and more people. The digitalization trend also gives individual people and companies the ability to gather and use knowledge at a much lower cost, in terms of e.g. price and time, than has been previously possible (Digitaliseringskommissionen, 2015). The combination of easy access to advanced tools and knowledge have made it possible for more companies to nowadays perform advanced bearing calculations and simulations in-house without relying on external expertise.

Another important aspect of the diffusion of engineering tools among bearing users is the trend among bearing manufacturers to focus on development of fundamental bearing technology (Grand View Research, 2015). Advancements in fundamental bearing technology result in better bearing performance in terms of e.g. load capacity, weight and lowered friction. As bearing performance increase, the need for more precise, i.e. advanced, calculations are required to assimilate the increased performance into the final products in which the bearings are used.

So, as technologies evolve and customer needs diverge, firms need to react and adapt to the new conditions. One possible way to adapt is to develop new value propositions to satisfy new customer needs (Desarbo et al, 2001). Companies that fail to adapt to new conditions might face difficulties when new entrants develop value propositions that better meet customers' diverging needs (Christensen, 1997). Loss of market share might also result in loss of power over customers since new entrants might take over crucial activities in the value chain (Porter, 1985). Although, customer needs might diverge to a point where companies face challenges due to an emergence of conflicting needs within the value propositions, due to e.g. customer needs that grow in contradictory directions (Malerba, 2006). An even bigger challenge face companies that lack a good way to identify these emerging customer segments

since firms competitive advantage spring from a successful value proposition, which in turn is dependent on a deep understanding of customer values (Porter, 1985). Hence, firms need a reliable way to identify emerging customer segments.

This thesis illustrates the challenges to meet diverging customer needs by incumbent firms by using the case of engineering tools as an example. This case is suitable since the industry meet changing customer demands and the industry leaders, the incumbent global bearing manufacturers, have reacted to this trend in different ways. Today, bearing manufacturers offer their customers engineering tools with very different functionality and complexity levels. At the same time, bearing manufacturers face competition from both their current customers' in-house developed engineering tools and third party providers of engineering software. These software are also believed to have an impact of what bearing manufacturer customers select. The complexity, availability and quality of these software vary massively, which might indicate an uncertainty of current customer needs and/or a great variation in customer needs. Hence, there is a need to determine how emerging customer needs diverge and what future customer segments this might result in.

1.2 Purpose and Aim

The purpose of this master's thesis is to map engineering tools usage and needs for bearing calculations and analyze how certain user needs affect the requirements of new engineering tools. This will be done through an empirically driven study with the aim to gain further understanding of the changing needs and usage of engineering tools.

1.3 Research Questions

In order to fulfill the purpose of this thesis, the usage of engineering tools among companies developing products containing bearings needs to be mapped. This leads to this thesis first research question:

- How are engineering tools for bearing calculations and simulations used today?

This information is important for this thesis purpose since it will enable the authors to categorize collected data into customer profiles. The customer profiles combined with empirical findings on customers' projections on future engineering tool usage will answer this thesis' second research question:

- How do present and future needs affect the requirements of new engineering tools?

This study has been conducted with support from the engineering tools department at SKF, a Swedish bearing manufacturer. In the light of bearing manufacturers expanding their business offers to include more service-like products such as engineering tools, efforts are at the present being made at SKF to position the company in this changing environment. Hence, a case study has been made in collaboration with SKF in order to find relevant companies to investigate in different industries and sizes with the purpose to answer the research questions.

1.4 Delimitations

This study is limited to engineering tools usage associated with calculation, simulation and decision support for bearing applications. Due to constraints in time and reach, a limited number of engineering tool users in a limited number of industries have been investigated.

1.5 Disposition of the Report

First, an introduction is given to the thesis that includes the background for the study to give an understanding of why this study has been conducted, which is followed by a presentation of the study's purpose and aim together with related research questions.

The second part constitutes of a literature study that comprises of theories on e.g. user-driven innovation. The literature study has been conducted in order to give an understanding of the research context and to use in the empirical data analysis.

The methodology used in the study is described in the next segment and include a presentation and discussion of how empirical data have been collected and analyzed.

In the fourth segment, the industry context is presented including the roller bearing market and engineering tool providers as well as known engineering tools used for bearing calculation and simulation.

The case study is presented in the fifth segment. It is composed of empirical data from interviews with companies regarding their use of engineering tools for bearing calculation and simulation.

The next chapter consists of the empirical data analysis. The companies are analyzed based on three dimensions that are considered important when addressing the usage of engineering tools. Eleven clusters of companies are then created and analyzed based on the three dimensions. The clusters combined with the individual companies' future needs are condensed into three customer archetypes.

The study's penultimate part consist of a discussion of the empirical findings together with literature from the literature study. The identified customer archetypes and other empirical findings will be discussed using a theoretical lens in order to investigate how customer needs affect the development of future engineering tools. The discussion is used to answer the purpose of the study.

The thesis will end with concluding remarks that contain practical implications and suggestions for future research.

2. Literature study

The literature study is presented in this chapter with the purpose to present important theoretical aspects used in the study. First is an introduction to the topic of innovation, the effect of customer needs on innovation, and industry evolution, all on an overall industry level which is required to understand the second part. The second part present literature on firm level on how to deal with demand pull and heterogeneous customer needs and how it affects innovation. The third part touch upon innovation characteristics and how old knowledge can create unforeseen new technology and products. This is followed by how innovations can be used to create value for customers and how to deliver value to a heterogeneous market.

Technology innovation and the effect of customer needs on innovation

Researchers have argued that there are at least two sources of innovation and technology development. One source is innovation derived from customer demand, which is referred to as *demand pull* (Schmooklaer, 1966; von Hippel, 1988). *Technology push* is another source of innovation, and is innovation driven by e.g. internal capabilities (Cohen and Levinthal, 1989) or macro level factors such as technological trajectories, e.g. the “technology s-curve” (Dosi, 1982; Foster, 1988). There is extensive research on the topic of innovation, with early contributions from Schumpeter (1934; 1950) who linked innovation to industry life cycles. Demand pull and technology push will be presented further in the following paragraphs.

Demand pull can be derived from industry and technology life cycles, even though much of the early work have been from a technology push point of view. One important aspect of the early stages of an industry life cycles is the emergence of a dominant design (Clark, 1985). A dominant design emerges as a result of the combined forces of technological advancements and customer demand. Abernathy and Utterback (1978) argue that the innovation focus shift from technology and product innovation to incremental design as the industry matures. Also Klepper (1996) argues that the innovation focus shift during the industry life cycle from product innovation to process innovation, although the innovation climate differs between industries. There is more literature in the borderline between the technology push and demand pull views on innovation. Cohen and Levinthal (1989) argue that innovation comes from a firm’s internal capabilities, but also argue that firms conduct R&D since it enables them to exploit and improve new technologies invented by other firms. Hence, this is a combination of the technology push view and the demand pull view which argues that a firm needs external stimulation to be innovative. The impact of demand pull on innovation is presented in more depth in the next paragraph.

Mowery and Rosenberg (1979) contributed with early work on the idea of market demand as the dominant force affecting the innovation process, although they at the time could not ultimately prove the connection due to insufficient empirical evidence. Other contributions that point towards demand pull as an important driver of innovation include von Hippel’s (1988) paper on lead-users. Lead user innovation is innovation driven by early adopters interested in obtaining a solution to their needs, which influence companies’ innovative work to meet and predict current and future market demand. Also Christensen (1997) argue that customer demand will affect companies’ degree of innovativeness, but that it can play in both directions. Although, demand is generally not homogeneous, something which will be discussed in greater detail in the literature study’s next part.

The heterogeneous market

Malerba (2006) has also contributed to the view of demand-driven innovation and argue that companies need to be innovative throughout an industry life cycle since changes within the industry will

continuously affect the size, growth and composition of demand. This will in turn affect differentiation and market segmentation. Malerba (2006) further argues that changes in the industry structure will result in heterogeneous demand since different customers will be in different stages of the life cycle. Also, information asymmetry, inertia, and habits play a large role in the emergence of heterogeneous needs among customers. Allenby et al (1998) argue that even though demand sometimes can be approximated as homogeneous, there is no such thing as a truly homogeneous market, and that attempts to make “sufficient” approximations might lead to overlooking customer demands beyond certain borders. Adner and Levinthal (2001) use an approach with two demand variables to describe heterogeneous demand, and this approach will be presented in the next paragraph.

Customers’ *performance threshold*, i.e. the minimum performance products must have to be of value to a customer, affects demand pull in markets with heterogeneous demand (Adner and Levinthal, 2001). Associated with performance threshold is customers’ *net utility threshold*, i.e. a customer's willingness to pay to meet their performance threshold. The performance threshold differs between customers as a result of different ability to exploit products’ performance due to variations in resources and capabilities. Also, customers’ net utility threshold differ due to e.g. buying power or the presence of substitutes. Hence, differences in both preference and utility threshold will affect market demand. Christensen (1997) use a similar approach and argues that customers’ heterogeneous performance preferences can result in radical changes in demand. Another aspect of radical changes that this literature study need to cover in order to explain demands effect on innovation is the degree of innovation radicalness and the connection between knowledge and innovation. This will be presented in the next segment.

Architectural innovation

Most of the above-mentioned literature on the topic of heterogeneous demand and its effect on innovation have been written on the topic of incremental or radical innovation. The difference between radical and incremental innovation is somewhat disputed but fundamentally lies in the degree of technological or market novelty. Alternative typologies that have been used to describe the extremes in technology and market novelty of innovation include incremental vs breakthrough (Tushman and Andersson, 1986), conservative vs radical (Abernathy and Clark, 1985), and sustaining vs disruptive (Christensen, 1997). However, recent changes in engineering tool technology would be hard to fit in one of the two mentioned categories. Henderson and Clark (1990) argue that the incremental-radical typology does not cover all types of technology innovations. They introduce the notion of *architectural innovation* which they define as innovation that involves little change to the existing core technology, but still has a large impact on customer demand. Architectural innovation destroys the value of the knowledge about the architectural composition of core technological components but preserves the value of the knowledge of the core components themselves. An example of an architectural innovation was when the GPS technology got integrated into handheld consumer devices. Henderson and Clark (1990) also introduce the concept of modular innovation, which is the opposite of architectural innovation in the sense that it reinforce the value of the knowledge about the architectural composition of core technological components, but the core technological components themselves change. An example of a modular is a change from clay bricks to concrete bricks in houses. Together with radical, incremental, and architectural innovation, these four create an innovation matrix, which is shown in figure 2.1, based on the extent to which the innovation reinforce or diminish the value of companies’ knowledge with respect to the components or architecture. Also Christensen and Rosenbloom (1995) use the notion of architectural innovation to explain how widespread core technological knowledge in the right setting can create a competitive advantage.

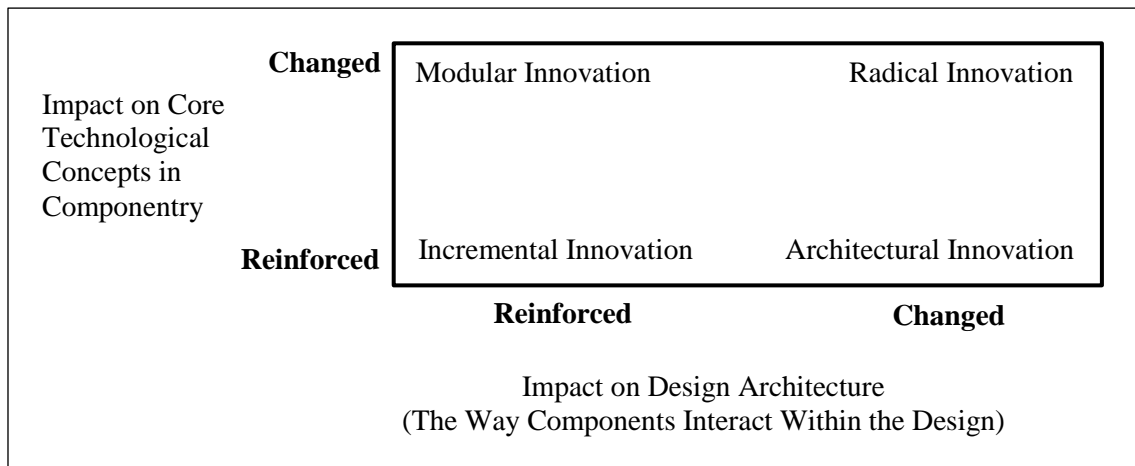


Figure 2.1. Innovation matrix. Based on Henderson and Clark (1990).

The value proposition

This segment will follow up on previously presented literature on innovation, demand pull and demand heterogeneity, and how to turn that knowledge into customer value. A successful business strategy is rooted in deep understanding of what the customers value in a given market offer, and then manage the offer over time to continuously create customer value (Porter, 1985). The offer is commonly referred to as the *value proposition*, i.e. the benefits and utility obtained from the offer by the customer in contrast to those obtained from competitors offers (Desarbo et al, 2001). A firm's competitive advantage spring from the ability create that right value for customers' that exceeds the cost to create it (Porter, 1985). Hence, much effort is put into understanding what customers value, and the best way to know that is by many argued to be customer involvement (von Hippel, 1988; Prahalad and Ramaswamy, 2000; Woodruff, 1997). Digitization has made consumers become a new source of valuable competence for companies, perhaps best seen in software development where customers provide a lot of input and do testing (Prahalad and Ramaswamy, 2000). Companies must engage customers in an ongoing dialogue and manage customer heterogeneity in order to understand what customers value and to successfully engage them in the innovation process.

It is also important to engage the customers since it allows the company to be aware of changing customer perceptions and expectations which should be taken into consideration in the firm strategy (Prahalad and Hamel, 1994). Hence, organizational values must be positive towards customer involvement and be rooted in a strong set of organizational values for the firm to be able to handle customer competence. In many cases, this requires a major change of companies' traditional organizational structures and governance systems.

Customer expectations have been shifting from concerning primarily quality and price to heavily strategy affecting criteria such as brand value, complete value offers and demands on customization, i.e. more aggressive and demanding customer requirements resulting in a more heterogeneous demand (Prahalad and Hamel, 1994). Also, Slater (1997) argue that market become more heterogeneous and fragment into many sub-segments, each with its own unique customer demands. The next segment will present strategies to meet heterogeneous needs and create customer value.

Strategies to create value in a market with heterogeneous needs

The first step in deciding how to serve a market that comprises of customers with heterogeneous needs is market segmentation, which is a marketing strategy where one divide the market into segments of customers who share similar characteristics (Mohr et al, 2010). There is no single way a market

segmentation should be done, but it has to be meaningful. There is e.g. no purpose to have a geographical segmentation if the market being served is not affected by customers' locations. A meaningful segmentation in a market with heterogeneous needs would be to e.g. bundle customers with similar needs. Kotler (2005) present a customer-driven marketing strategy to build the right relations with the right customers instead of scattering the mass market with a broad ad-hoc value proposition. The first step is to decide what customers to target. This is done by a market *segmentation* followed by a strategic decision of what segments to *target* based on an evaluation of each segment's attractiveness. The attractiveness is generally based on segment size, growth, and structure (based on e.g. porter's (1979) five forces model), but also the own company's objectives and resources.

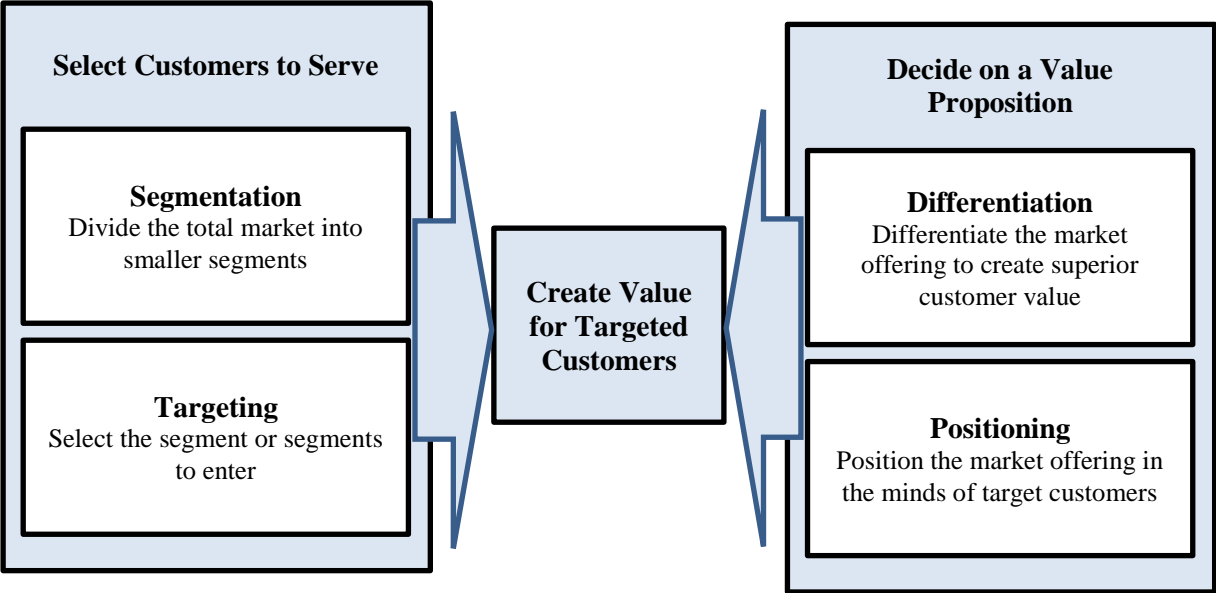


Figure 2.2. Customer-driven marketing strategy. Based on Kotler (2005)

After deciding what segments to target, the company must decide how the value proposition should differ between segments, i.e. select a *differentiation strategy* about whether to target the market broadly or narrowly (Kotler, 2005). The broadest differentiation strategy is undifferentiated (mass) marketing, where the firm focuses on commonalities rather than differences and target the whole market with one value proposition that appeals to the largest number of customers. On the other end of the scale, the narrowest strategy is micromarketing, which is individual customization. Between undifferentiated and micromarketing one find differentiated and concentrated marketing. In a differentiated marketing strategy, also called segmented marketing, the firm selects which segments to serve and create one value proposition for each segment. Concentrated marketing is a strategy where the firm targets only one segment with one value proposition. The final steps in Kotler's are excluded since it lies outside the scope of this study.

One way to meet a heterogeneous need with minimum resources is to create a product line. There is a tradeoff between the cost and profit that a differentiated value proposition infers, and a company seeks to find the profit maximizing number of offers (Fruchter et al, 2006). One way to serve a market with heterogeneous needs but the same demand origin is to create a differentiated value proposition through a product line. Rather than develop one unique product per value proposition, a product line consists of a range of customizations based on the same foundation which can be targeted towards different segments. By developing a product line companies can maximize profit by offering a variety of configurations and seek to find the best tradeoff between cost and customers net utility.

3. Methodology

This chapter describes the methodology used to fulfill the purpose and aim of the project. First, the literature study is presented which was conducted in order to gain context for the project and provide deeper knowledge in areas related to the project. After the literature study follows a section in which empirical data collection, such as interviews, are described. This is followed by an explanation of how the empirical data was analyzed and how the empirical analysis was combined with literature in the discussion.

3.1 Data Collection

The methodology for the data collection will be described in this section. Secondary data has been collected through a literature study in order to provide context to the project, and primary data has been collected from interviews to reinforce the case study.

3.1.1 Literature study

The literature study was conducted after a majority of the empirical data had been collected in order to not constrain the research. The aim of the literature study was to give the authors of the report knowledge and understanding of the research topic and provide a foundation for the discussion of empirical data.

Data in the literature study available online was gathered mainly through the databases *Scopus* and *Google Scholar*. The search strings used in order to find the articles were for example “demand heterogeneity”, “customer preferences” and “technology change”. Books and other printed literature not available online was found using the above-mentioned databases and was then gathered at Chalmers library.

The literature study’s purpose was to complement the primary sources in order to use interview data for a relevant academic purpose. Hence, it was deemed crucial that the gathered literature was of high quality and of academic interest. Therefore, used literature consist mainly of research articles and papers, and was evaluated after the number of citations and the journal's publication rating.

3.1.2 Interviews and interview technique

The data used to map engineering tool usage in the bearing market is mainly primary data from interviews made with companies that are customers to SKF. The reason behind using customers to SKF was that the study was made with support from SKF and using their network of relationships with companies made it possible to make the important first contact with the companies used in the study. Interviews were also conducted with representatives at SKF as well as with professors at Chalmers to discuss the project and to gain further knowledge in areas related to the project, which includes e.g. bearing technology and product development.

The interviews were based on a pre-decided interview sheet with open-ended questions and the questions were followed as much as possible but with room for some flexibility and follow-up questions. The methodology used during the interviews is what DiCicco-Bloom and Crabtree (2006) call a semi-structured interview. As an example, during the first customer interview, the pre-decided questions were all touched upon but resulted in different answers than anticipated. Hence, follow-up questions were necessary in order to collect data required to fulfill the overall purpose of the study. It was important that the interview sheet was standardized and that all topics on the interview sheet were covered during

the interview since the information gained from an interview would be compared to the other interviews. The interviewees were encouraged to answer the questions in as much detail as possible in order to gain as thorough data as possible.

The interview sheet was sent to the interviewees some days in advance in order for them to be more prepared for the questions which most likely increased the quality of the data. It was told to the interviewees that their and the company's name would not be presented in the report since it was argued to make them give more open and honest answers without having to keep information from the authors of the report in order to protect the company or themselves.

The interviews at Chalmers, as well as most of the interviews conducted at SKF, were made in order to gain knowledge that would facilitate the upcoming interviews with the customers to SKF and to help the authors interpret the data gained from the customer interviews. Information from the SKF intranet, as well as literature regarding the different segments, was reviewed in order to give a context to the interviews with the segment managers. Since the interviewees are experts in the area, the interviews were conducted using a semi-structured interview with a couple of predetermined questions in order to have a clear scope of the interview but was otherwise very flexible. The authors were open to all information they could acquire since it was uncertain what information that would be of good use when later on talking to the customers.

Interviews with employees at SKF

The first interview conducted with SKF was the manager for the engineering tools department and had the purpose of letting the authors acquire further understanding of the project, its context and discuss how to choose customers to interview during the study. The manager got to decide what industry segments to focus on, but not what specific customers to include in the study in order to reduce the risk of biased data from letting one stakeholder choose the data points for the study. The industries were selected based on a few key aspects. First, they had to be industries in which engineering tools are used to perform bearing calculations. Secondly, the industries had to be big enough to provide enough customers to interview. As a final aspect, there had to be customers within the industries that have contact with SKF on a regular basis. This was deemed crucial to facilitate data collection as well as improve the quality of the study since it was argued that the customers would be open to sharing all necessary information for the study.

The next step to select which customers to SKF in each industry to include in this study was to interview the segment managers in each industry. The interviews also helped the authors get an idea of what characteristic traits to expect from each customer segment. An example of such characteristic traits are single or multi-shaft applications, and more or less overall advanced engineering tool usage. The customers to include in the study were all chosen by the segment manager based on their fit to the study regarding openness to share information on engineering tool usage and geographical location to allow on-site visits to conduct the interviews.

It was considered crucial to go through both the engineering tools manager and the industry segment managers to reduce the risk for a biased selection. Since the engineering tools manager is considered a direct and biased stakeholder in the project it was suitable to let the industry segment managers select which companies to include in the study to reduce the risk of a biased selection of companies. Having several industry segment managers making a list of in total around 50 companies which were screened by the sales team also helped to reduce the risk of a biased selection. The screening will be further explained in the next paragraph.

Contact with the customers was initiated via sales teams of responsible sales representatives and/or application engineers at SKF. The study was introduced to the sales representatives and/or application engineers who decided if the customers were to be included in the project based on e.g. availability or previous commitments. If the project-customer fit seemed good, SKF's representatives forwarded the project inquiry to the customers or provided the authors with necessary contact information to contact the customer. Some companies selected by the segment managers had to be abandoned during this stage due to restrictions from SKF or customers not willing to participate in the project. After the sales representatives and application engineers had been involved the list of companies compiled by the industry segment manager was greatly reduced, and since the sales teams are not considered biased in the study the screening is considered to reduce the risk of a biased selection even further.

Interviews were also held with other SKF employees with many years' experience of working with bearing calculations and simulations. The aim of these interviews was to give the authors of the report greater understanding of the topic and how to interpret the data from the interviews with customers.

Interviews with customers to SKF

Interviews with customers were mainly conducted on-site at the customer. However, some interviews had to be made via phone since the customers were not possible to meet due to geographical distance or time constraints. Twelve on-site interviews were conducted as well as two via telephone. Although, the telephone interviews were excluded from the study since the topic's complexity level was too high, and it was hard to get a thorough understanding via telephone which was argued to lead to misinterpretations and false conclusions. Conducting the interviews at the interviewees' site instead of via phone or at SKF had several benefits. One of the major benefits was that it was possible to read the body language of the interviewee which reduced the risk of misunderstandings. After a few interviews via phone, mainly with SKF representatives, it was clear that face to face meetings were superior and improved the dynamics of the group of interviewers and interviewees. It was for example much easier to know who was talking as well as when it was somebody else's turn. During the phone interviews, someone with bad reception could end up talking at the same time as another person in the call which could be problematic. Having the interviews in person also made it possible to use illustrations such as whiteboard and PowerPoints which also greatly reduced the risk of misunderstandings. Another benefit was that meeting in person at their site resulted in the interviewees feeling comfortable in the situation which most likely had a beneficial impact on the quality of the data. Further, a few on-site interviews were followed by a factory tour that further increased the understanding of the companies' businesses.

The questions to be asked during the interviews were formulated and improved in collaboration with SKF personnel with vast knowledge in product development processes that include bearing selection. Their feedback was argued to be important to ensure correct terminology and level of technical complexity in the questions.

The interviews with the customers were divided into three phases, (1) a context phase, (2) a main phase and (3) an open feedback phase. The interviews started with the context phase by asking the interviewee for background information of the company as well as about the interviewee. Such background information usually included how many years the interviewee has been at the company and for how long the interviewee has been working with bearing related engineering. In this phase, the scope of the interview was decided regarding e.g. what products were to be discussed. The scope was important to decide on since the product development process, and hence, the use of engineering tools could vary a lot within the company depending on product category. As an example, the engineering tool usage could

differ between the development of catalog products and development of custom made products. In the main phase, the focus was to get answers on the main topic regarding how engineering tools were being used at the company throughout the product development process. It was important during this stage to get a clear picture of what and why certain engineering tools were being used since this data was crucial to answer the purpose of the study. During the interviews' last phase, the open feedback phase, the questions were less structured and the interviewees were encouraged to freely talk about aspects of their engineering tool usage not being addressed in the main phase. This included discussion of needs not met by the current engineering tools as well as what needs they believed would arise in the future.

Each interview was compiled into a document containing critical information for the study was validated by employees at SKF. A copy of these documents is to be found in chapter 5 *Empirical Findings*. Each interview was also summarized into one or a few sentences which relevant key takeaways. All interview summaries were then compiled into a synthesis which then was used as a foundation for the analysis of the empirical findings. This was deemed necessary in order for the authors to grasp the vast amount of data available after the interviews.

Interviews with representatives from Chalmers University of Technology

An interview with a professor at Chalmers was conducted in order to further increase the knowledge in the field of product development processes and bearings. Generic development processes and their characteristics were discussed in detail as well as how typical companies often approach product development. Other Chalmers personnel have been involved in forming the purpose of the study as well as provide general input to the study. Examples of such input include discussions on relevant research areas and academic topics of interest e.g. if the study should be on a firm level or industry level as well as if the study should be aimed at the customer needs or the process for new development projects.

3.2 Analysis of Empirical Data

The analysis of gathered empirical data had to be done in several steps in order structure the data in a way that made it reviewable. This was argued necessary by the authors of the report due to the vast amount of data from the conducted interviews. The data from the interviews were summarized as a first step to structure the data and the key findings from the interviews presented in the synthesis. The key findings were traits that characterized the company in large as well as for engineering tools usage regarding bearings.

The key findings were then translated into three parameters, namely (1) requirements on bearing calculation, (2) bearing calculation capabilities, and (3) frequency of use. These parameters' purpose were to act as a tool for the authors of the report to categorize each company's engineering tool usage. The parameters were chosen since they were argued to impact the interviewed companies engineering tool usage to a high degree and therefore were important data points in order to fulfill the purpose of the study. Together they gave a good overview of the companies' engineering tools usage. Three different levels for each parameter (low, medium and high) were identified and formulated by the authors based on the information from the interviews. As an example, a company like Alpha that only conduct very simple bearing life calculations was classified *low* for bearing calculation capabilities. This can be compared to Juliett that conducts among the most advanced bearing calculations encountered in the study, and hence got classified as *high* for the parameter bearing calculation capabilities.

All companies were classified as either low, medium or high for each of the three parameters. Hence, each company could be found in one of 27 possible positions in a 3x3x3 matrix. The output from this

stage in the analysis was a table containing all the companies and their classification for the three dimensions.

The next step in the analysis was a cluster analysis conducted in order to find groups of companies in the market with similar characteristics with regard to the three parameters. The cluster analyses had to be done to cluster the three parameters two by two. In order to calculate the clusters, Ward's minimum variance method was chosen. Punj and Stewart (1983) argue that based on a thorough evaluation of a series of case studies, Ward's minimum variance method outperforms other clustering algorithms when no specified starting point for the number of clusters is known. This was the case for this study.

The next step was a combined analysis of the clusters and the predicted future direction regarding the parameters used for the clustering. The clusters future direction was decided from general conclusions that could be drawn from individual future predictions for each company within a cluster. An example is the first cluster, R&B1, which is a "medium/medium cluster" having medium requirements on their calculations and perform medium advanced calculations. Regarding future needs for cluster R&B1, a general conclusion shows that R&B1 will stay on the same complexity level but desire increased user friendliness.

From the analysis of the clusters and the clusters future directions, the authors could make a few generalizations from which three customer archetypes were created. The customer archetypes represented three typical engineering tool users.

The archetypes were then analyzed together with theories from the literature study in order to meet the study's purpose of answering how customer needs affect the development of new engineering tools.

4. The market for engineering tools

This chapter consists of a presentation of the bearing market followed by a presentation of engineering tools for bearing calculation and simulation officially available on the market. The tools presented in this chapter are included since they have certain characteristics and features that are valuable to know when later analyzing current and future customer needs.

4.1 The rolling bearings market

SKF, Schaeffler Group (FAG and INA), Timken, NSK, NTN and JTEKT (Koyo) are the world's top six bearing manufacturers who together comprise 60% of the global rolling bearing market (Grand View Research, 2015). SKF is together with Schaeffler Group and Timken regarded as the three premium rolling bearing manufacturers. The remaining 40% consist of Chinese bearing companies (20%) and local or niche players (20%). The market for rolling bearings is estimated to have a value of 340 billion SEK (SKF, 2016).

A general trend among the bearing manufacturers is an increasing focus on market applications where the bearing manufacturers' resources and capabilities offer a competitive advantage (Grand View Research, 2015). Also, bearing companies focus on development of fundamental bearing technology such as materials and heat treatment, but also to create offers where bearings are combined with control and sensing technology. New product development is emphasized on providing products that meet customers' demand in areas of maintenance, environment, safety, and productivity.

4.2 Engineering tool software provided by bearing manufacturers

All of the world's top six bearing manufacturers provide tools for bearing calculation and simulation to a various extent. In the following section, there will be a short presentation of the tools presented on respective company's web page.

SKF

SKF have a huge amount of engineering tools available online (approximately 15 tools directly related to bearing decisions, and another 10-15 for bearing related applications). Most tools have limited functionality and are specified for specific applications, e.g. only for lubrication decisions or mounting data. There are two tools for direct bearing selection and calculation. The first is Bearing Calculator which is used for L10mh¹ calculations on single bearings. The second tool is Bearing Select which can make L10mh calculations on single bearings or two bearings on one shaft. The predecessor to Bearing Select and Bearing calculator was called CADalog.

Among the application specific tools mentioned in the study is DialSet which is used together with SKF's automated lubrication systems to set lubrication quantities and intervals, and LubeSelect which

¹ **L10h** - basic rating life (at 90% reliability) according to ISO 281:2007. The statistical bearing life before initial signs of metal fatigue on rolling elements or the surfaces in contact with the rolling elements [operating hours at constant speed].

L10mh - modified basic rating life (at 90% reliability). The calculation method provided in ISO/TS 16281:2008 (L10mh) covers influencing parameters additional to those described in ISO 281:2007 (L10h), such as lubrication, contamination, fatigue load limit of the bearing material, misalignment, operating clearance, and internal load distribution between rolling elements [operating hours at constant speed].

is used to find application appropriate lubricants. There are also tools to calculate e.g. bearing frequencies and linear applications, as well as CAD models of SKF bearings.

Schaeffler Group

Schaeffler provides a vast range of engineering tools. INA Medias is a tool for product selection of bearings and housings. INA Medias include product data, fatigue life calculations for multiple load cases on individual bearings, CAD drawings, application examples, frequency calculator and interchange lists to help customer replace other bearing brands with Schaeffler. All features are accessible via the same interface and are compatible with both FAG and INA.

Schaeffler also provides a range of calculation software for shaft systems under the name BearinX. The full version of BearinX is the software used by Schaeffler's application engineers². The BearinX online software, which are the most stripped-down versions of BearinX, include general shaft applications on different complexity levels, but also a few specialized versions for e.g. spindles, electrical motors, rope sheaves and linear systems. The online versions can model single shaft systems with multiple bearings and load cases and use the same calculation models and algorithms as the more advanced full version but in a less advanced setting. Although the BearinX online tools are relatively simple, they are still capable of determining shaft deflections and effects from bearing elasticity. BearinX-VIP is the customer version of the full BearinX and is very advanced with the capability of e.g. MBS³ and FEM⁴. Since all versions of BearinX use the same underlying calculation models and algorithms, the calculation dossiers can be exchanged easily which help Schaeffler's application engineers to better support customers who use BearinX.

Timken

Timken provides a few simple tools via their web page. This includes mounting data, CAD drawings, frequency maps, bearing selector for a few specific applications and a bearing fatigue life calculation tool. The bearing life calculator gives L10h and L10mh. There is also a bearing selection guide available for download with similar features to the online bearing fatigue calculation tool.

NSK

NSK provide a technical calculation feature online to help select the right bearing based on L10 and L10mh calculations for a range of load cases. The tool can also give bearing frequencies, fits, and clearances when mounted, as well as friction and lubrication data. The online catalog consists of several PDF-files available for download.

NTN

NTN have an online bearing technical calculation tool which consists of five modules. There is a basic rating life calculator for multiple load cases, dual gear load calculator, a single shaft with two bearings load and life calculator, operating clearance calculator, and a bearing vibration frequency calculation

² **Application engineer (AE)** - An application engineer is a sales teams' key technical advisor. The application engineer is responsible for managing the technology aspects of a sales process and maintain the technical relationship throughout a product's life cycle.

³ **MBS** - multibody simulation. Multibody simulation is a numerical simulation method of multibody systems (i.e. systems composed of multiple parts that affect each other) composed of rigid and/or elastic bodies. In contrast to FEM, where individual bodies (parts) of mechanical systems are analyzed in detail, a MBS can study the behavior of whole systems.

⁴ **FEM** - finite element method. A numerical method to find approximate solutions to differential equations with the help of computers. FEM is used to solve complex technical problems such as for structural simulation in mechanical engineering.

module. NTN also provide CAD drawings and a bearing interchange search similar to the one available at Schaeffler.

JTEKT (Koyo)

JTEKT does not provide any bearing calculation tool features via the web page and does not seem to provide any other similar services. Although, Koyo have a partnership with the third party software SABR who have integrated Koyo's bearings into its software. Further, Koyo does have online CAD drawings and PDF catalogs.

4.3 Third party engineering tool software

There are several third party suppliers of calculations and simulation tools with a vast variety in complexity. The amount of available software is massive, hence only the most recognized software and those encountered during the interviews will be mentioned.

Romax

Romax is a provider of engineering software for gearbox and drivetrain applications. Romax offers a range of software for various stages during product development, such as software to facilitate concept generation, to help manage design updated when using multiple software, or to make detailed and advanced calculations. The concept tool for gearboxes and drivelines predicts bearing forces and suggest appropriate bearings from a database containing information on bearings from several bearing manufacturers. The tool lets the designers determine the correct size and type of bearing in the early stages of the concept phase. The RomaxDesigner software is the company's most advanced software for calculations on bearing systems. It can perform MBS as well as non-linear bearing modulation and analytical bearing fatigue life predictions. The software is fed with bearing data from the same database used by the Concept software.

SABR

SABR is developed by Ricardo, an engineering consultancy firm, and is only one in a range of engineering software for e.g. engine design or fluid dynamics. Although bearing calculations are available in other of Ricardo's software, SABR provides the most complete bearing analysis. SABR is used to design shaft, gear and bearing systems, such as power transmission systems. The bearing database consists of bearings from SKF, Timken, and Koyo, but is limited to a few bearing types. The software can make lifetime predictions using L10mh and load stress matrices.

KISSsoft

KISSsoft is a software that performs sizing calculations for e.g. shafts, gears, and bearings. The software contains a vast database of bearings from different manufacturers and helps the user select appropriate bearings since the software filter all geometrically matching bearings and calculate their fatigue life using L10mh. KISSsoft is compatible with most popular CAD programs for seamless transfer of drawings.

Mesys

Mesys is a software which can perform rolling bearing and shaft calculations for multiple shafts and bearings. The software considers e.g. the inner geometry of the bearing, load distributions, and misalignment to calculate bearing life. The inner geometry is either from user input or is approximated by the software based on bearing load capacities. The software is capable of determining centrifugal forces, load spectra on single rolling elements and the bearings stiffness matrix.

5. Empirical Findings

Empirical data collected in the study will be presented in this chapter. In total, representatives from twelve companies were interviewed and the output from the interviews has been summarized in this chapter. The companies are presented in sequence and the names have been replaced with pseudonyms such as Alpha, Bravo, Charlie etc. Empirical findings from each company are presented with a company and interviewee introduction followed by a description of the bearing selection process, then what engineering tools are used during the bearing selection process, followed by the interviewee's projection of future engineering tools usage.

5.1 Alpha

Alpha is a screw compressor developer with almost one hundred years of experience of screw compressor technology. The conducted interview concerned development of new screw compressors since it is the company's core competence. The interviewee has been working with compressor technology and conducting bearing calculations for compressors the past 26 years.

Bearing selection process

Alpha has no fixed standardized development process, but the process generally follows six stages: Idea generation, specification, design, prototype, assembly, and testing. Bearing calculations are done only a few times a year almost solemnly in the design stage, where the engineers iterate between 3D-modeling using CAD and calculations. Using CAD models, the engineers can see if the bearing dimensions are feasible, e.g. if a bearing fits in its intended position. The output from calculations done during this stage shows the bearing fatigue life in the given position. The design process is characterized by many iterations from which the final design emerge gradually. The calculations are on the same complexity level, i.e. fatigue life L10h, throughout the design stage. The overall design and bearing arrangement is the same in almost all of Alpha's products, with a combination of cylindrical roller bearings and angular contact ball bearings. Alpha's application require high precision at high rotating speeds, and hence preferably very precise calculations of clearance, rotating forces and bearing housing deformations. This is not something that is being calculated today. In almost all cases they chose the largest possible bearings that still meet the constraints in outer and inner dimensions, maximum rotation speed and the given lubricant. The rationale behind this is that "the larger the bearing, the longer the life". However, this device is about to change since the bearing arrangements become more expensive than necessary. The lubricant is determined by the gas that will flow through the compressor. Usually, only one or two dimensions of bearings are considered for each position. Another aspect that restricts the bearing choice is that they have to be divisible to be able to be mounted and that the delivery time of the bearings is not too long.

Alpha sometimes contacts SKF to get guidance during the design stage. This is mainly when a new product is developed that differs to what they have done before.

If none of the considered bearings meet the required lifetime, which can be as high as 100.000 hours, the compressor needs to be redesigned. A different bearing arrangement needs to be considered if a certain threshold for load and speed for the bearing exceeds. However, usually, it is enough with a minor dimensional redesign to accommodate a different bearing size.

Engineering tools usage

Alpha relies to a great extent on knowledge gained from previous projects in areas regarding overall compressor design and bearing arrangements. As explained, there is a limited number of suitable bearings for the products, and these are known to the interviewee who only look in the catalog or use Bearing Select to find information about these bearings. Alpha uses an in-house developed software for calculating loads on the bearings from the rotating axles and uses the load data in combination with an in-house developed excel module in order to calculate fatigue bearing life. This software uses the L10h calculation method. The rationale behind using L10h instead of the more refined L10mh is that the output is compatible with the vast database of previous L10h calculations. The inaccuracy of using the old L10h method instead of L10mh is compensated by selecting as large bearings as possible. Further, the rotating speed in compressors often exceeds the bearing speed limit set by the bearing manufacturer, which makes L10h and L10mh life calculations invalid. Alpha uses experience from previous projects in order to compensate for this and get an expected lifetime for the compressor that is more realistic.

Engineering tool usage in the future

As a first step, Alpha want to be able to access features that some of SKF's previous online tools had, such as the possibility to make L10h bearing fatigue calculations using Bearing Select and Bearing Calculator. Alpha also wants to be able to calculate the theoretical mounted clearance, as was possible in the old SKF online software CADalog. Another feature that would be of great benefit for Alpha is the ability to calculate the amount of lubrication that will be needed in order to cool and lubricate the bearing.

A second and a much bigger step for Alpha in their software usage would be to use a software capable of calculations of an entire bearing arrangement in a screw compressor. As an example, they want the software to calculate load differences between bearings in tandem arrangements, and also to take rotational forces into account. The interviewee wants the output from such a software to be a list of possible bearings and their technical specifications, as well as relative price and delivery time.

Summary

Alpha develops screw compressors which have high demands on efficiency and hence generally require advanced bearing calculations. Although, experience based estimations and L10h calculations are the main source of engineering tools used, and only a few times a year. Alpha wants to return to old SKF online software or, less likely, do a radical change to a new more advanced software that can handle the entire development process.

5.2 Bravo

Bravo is a large global pump manufacturer. The interview with Bravo concerned the development processes for pumps in general. The interviewee at Bravo has been at the company for 25 years and has worked with engineering and bearing calculations for more than 30 years.

Bearing selection process

The development process at Bravo follows a traditional stage-gate system. The process contains six stages, (1) business hypothesis, (2) feasibility study and business plan, (3) development and testing, (4) validation, (5) production and launch preparations, and (6) serial production and launch. Bearing decisions are mainly made during the third stage where the design for the pump is developed as well as the fourth stage where validations are made.

Bravo is mainly focused on the layout of the pump during the development stage. Two major decisions regarding bearings in the application are made at this stage, namely the type and size of the bearings. The type of bearing depends on the size of the pump and is mainly chosen based on knowledge gained from previously developed models at Bravo. In other words, when the size of the pump is decided, Bravo knows what type of bearings will be needed. A rough estimate of bearing dimensions from experience is made based on the size of the application. The bearings inner diameter is constrained by the diameter of the axle, and based on the inner diameter, the largest possible outer diameter will be chosen in order to have the maximum load capacity as well as to facilitate heat transfer through the bearings to the pump casing. If the application is completely different from what Bravo have done before and no similar projects exist, Bravo sometimes asks SKF for advice regarding the bearing arrangement.

Bearing calculations being made in the early stages of the development are often limited to fatigue lifetime using the method L10h and are done on a monthly basis. Demanded minimum life is 50.000 hours in order for the pump to be considered a premium product. If the calculations show that a larger bearing is needed they might change to a larger axle which makes it possible to select a larger bearing. When a design is chosen that will satisfy the need of the customers according to the rough calculations, they lock in the design choices and move to the next step in the process which is the validation stage.

During the validation stage, Bravo performs calculations that are more precise regarding the lifetime of the bearing as well as taking a broader set of parameters into consideration. The more advanced calculations include full rotor dynamic simulations to obtain more precise loads which then are used in L10mh fatigue life calculations. Several load cases are simulated which represent various running conditions the pump will encounter. Since the rotor dynamic calculations generate a lot of loads in several directions, Bravo is now forced to compile the loads in order to use them in the L10mh calculations. After these calculations are made it's clear whether or not the bearings will be able to fulfill the required needs for the lifetime. If not, they redo the process and design the pump differently in order to solve the short life issue.

Engineering tools usage

The engineering tools Bravo is using are all combined into a platform where the different software are held autonomous but at the same time integrated in a way that makes them more or less compatible with each other. They have chosen to not fully integrate the different applications in the platform in order to make system maintenance less complex. The software applications in the platform are a mix of applications made in-house as well as software made by external sources. Bravo can perform a lot of different calculations using this platform such as motor generated torque and shaft behavior. When it comes to bearings, basic L10h calculations, as well as the more advanced L10mh calculations, are made in a refined clone of the SKF developed software Bearing Select and Bearing Calculator. In the clone, it is possible to run a range of loads at the same time, something not possible in the online tools provided by SKF. The output from the clone is a graph over expected fatigue life for different load cases, i.e. different running conditions. Being able to input the range of loads instead of one case at a time saves a lot of time for Bravo. As previously mentioned, the data available during the validation phase is much more comprehensive and accurate and includes parameters such as contamination and lubrication compared to the design phase, which allows for the more complex L10mh calculations during the validation phase but not in the initial design phase.

Engineering tool usage in the future

The interviewee sees two different scenarios when it comes to Bravo's future usage of engineering tools. The first scenario is an external add-on module to the existing software platform which is compatible

with the current set of modules, especially the rotor dynamic module and lubrication module. If they would be able to fully integrate the bearing specific calculation, they would be able to remove the issue with compiling the loads, something which would result in more precise calculations. The interviewee like the idea of having an SKF developed module in their platform since they would not need to maintain and keep it updated. Also, an SKF module could contain more bearing specific data such as the number of rolling elements etc. which facilitate the rotor dynamic simulations. Another bonus that the interviewee mention is the value of being able to present an “SKF certified” bearing calculation sheet to Bravo’s customers. The second scenario would be to replace the current rotor dynamic, bearing and lubrication module with a new software, although this is regarded as a major step which would require a lot of consideration.

Summary

Bravo use L10h in the initial stages of the product development and L10mh during the validation phase. The tool used is an in-house developed clone of Bearing Select, which is used on a monthly basis. Bravo see two option for the future. Either complement the current software platform with an “SKF certified” module or, less likely, replace the current platform.

5.3 Charlie

Charlie is a technical trade company (distributor) of industry components and is currently the largest one in its home market. Charlie sells bearings along with other related components such as chains and belts. Charlie also offers its customers education in bearing engineering such a mounting and maintenance, and also perform bearing analysis in order to improve their customer's bearing performance and lifetime. The services are offered mainly to improve the value offer and increase the company’s competitiveness in a market with hard competition and advice regarding bearings are given on a monthly basis. The interviewee has been working at Charlie the last 14 years with activities regarding bearings such as training, bearing selection support, lubrication issues etc. The interviewee also worked with bearing analysis for 5 years before starting to work for Charlie.

Bearing selection support to customers.

Customers often use rough estimates when choosing bearings which most of the time results in over dimensioned bearings that are more expensive than necessary. However, the most serious problem is when the customer's rough estimates result in too weak bearings or bearings not suited for the application which results in a breakdown for the application after a short while.

In order to help the customers to choose the right bearing, Charlie calculates the expected bearing lifetime using some of the more simple tools offered online by SKF, e.g. Bearing Select, in combination with their knowledge of bearings from years of experience regarding bearing analysis. In order to help the customer with bearing selection, calculations or breakdown analysis, representatives from Charlie first receive data from the customer or travel to the customer for on-site data gathering. This data mainly concerns what type of bearings are being used as well as the load on the bearings. It's very rare that they get good data from customers since the customers seldom know how or what data to collect, something which leads to imprecise data which in turn negatively affects the results from the calculations made by Charlie. However, the data gathered by Charlie can also be quite rough and be based on assumptions and guesses combined with knowledge from previous projects. Collected data are then processed using the simple tools from SKF for L10h or L10mh in order to get a rough estimate of bearing life which then is compared to the required lifetime demanded from the customer. The interviewee argues that fairly rough calculations are enough for the majority of Charlie’s customers. After calculations have

been done, advice based on the calculations and expertise is given regarding what bearing is suitable for the application.

Engineering tool usage

The calculations made at Charlie is limited to L10h and L10mh and Charlie therefore don't need advanced calculation tools. They only use the SKF developed software Bearing Select and Bearing Calculator for fatigue life calculations.

Furthermore, a handful of other simple applications from SKF are being used in order to access certain specific knowledge such as characteristics of different lubrications, but this is not done on a regular basis.

Engineering tool usage in the future

Charlie do not need a more advanced tool but rather would appreciate if the current tools become more user-friendly. They find it inconvenient to have to use many small applications provided online by SKF to gather necessary data to be able to give Charlie's customers a feasible bearing choice. Preferably, a condensed set of the functionalities from Bering Select, Bering Calculator, and DialSet etc. would be included in one software in order to facilitate the usage. Another example of improvements for the Bearing Calculator includes the possibility to have it in other languages than only English since the engineering terminology in English sometimes can be too complicated. According to the interviewee, this opinion is common among Charlie's customers. The interviewee also mentions that the readability of the application leaves room for improvement.

Summary

Charlie assists their customers with L10h and L10mh calculations for low to medium complex applications on a monthly basis using SKF online tools. They would like to have a merged and more user-friendly version of the currently used SKF's online tools.

5.4 Delta

Delta is a technical trade company (distributor) with emphasis on providing services and high-quality products from premium manufacturers, and have roughly 200.000 items in stock, making it the third largest in its home market. Delta is positioned as a technical service provider which can provide products and services in package deals, such as product development support, smaller customization and assembly jobs, and on-site technical support. The customers compose of around 50 percent OEMs (original equipment manufacturers) and 50 percent MROs (maintenance, repair and operations). The products in stock include bearings and transmission, fluid and sealing technology. Bearings available at Delta come from all premium bearing manufacturers but mainly consist of products from SKF and Schaeffler. Services regarding customers' bearing selection cover areas such as actual selection of components, design, simulation, and calculation. The interview was conducted with two interviewees. The first interviewee has been at Delta for 15 years and is a former technical engineer who now is the manager of Delta's engineer department. The second interviewee has been at the company for 8 years and has been working with bearing calculation as the main field for the last 7 years.

Bearing selection support to customers

Delta's work with bearing selection support differs widely between customers from simply delivering physical products to extensive involvement in the product design process. Most engineering support related to bearings is breakdown analysis and how future breakdowns can be prevented. This usually

does not include any usage of engineering tools since the root causes generally are outside the scope of calculations and instead are best solved with experience from previous similar situations.

Support for product development is not common towards large companies since they usually have the competence in-house, and small companies with bearings in non-critical applications usually select bearings from experience or only ask for simple fatigue lifetime calculations, namely L10h and L10mh, or lubrication recommendations. The customers who require most engineering support during product development consist of growing companies with an expanding product offer or that requires competence in bearing selection beyond the company's own capabilities. These customers require support on a regular basis, approximately once a week, during the product development with iterations between in-house design and calculation and design support from Delta. Most of these customers manufacture specialized machines in small batches. The next section will concern the use of engineering tool usage to help this particular customer group since it is the group that receives most support.

Engineering tools usage

The majority of the decisions regarding bearings, such as overall bearing arrangement, type, and approximate dimensions are based on previous experience. For decisions requiring simulation or calculation support, SKF software Bearing Select and Bearing Calculator are used around 20 percent of the time and Schaeffler's BearinX are used the rest of the time. The choice of software depends on the need for advanced calculations (i.e. the criticality of the application), how deeply and how early in the design process Delta is involved, and the quality of the data the customers can provide.

SKF tools are perceived to be better for simple load cases on single bearings and are used for simple fatigue calculations in less advanced applications. BearinX is perceived to be more advanced and is used when there is a need for more complex calculations, involving e.g. shaft dynamics, multiple bearings and load cases, material properties, and temperature effects during load cycles. The SKF tools are deemed too simple for most applications, hence, Delta use BearinX for the vast majority of all calculations. The advantages of BearinX also include easy communication with Schaeffler's AEs and customers using BearinX Easy modules because of the common interface and seamless data transfer between different BearinX modules. BearinX is the preferred engineering tool when Delta is involved in customers' entire development processes since the complexity of bearing calculations usually increase throughout the development process from e.g. L10h calculations to heavy numerical analyses. Hence, BearinX is preferred since the different modules span the entire need range.

Delta uses the same version of BearinX as Schaeffler's AEs, but with reduced functionality which prevents them from calculations on some of Schaeffler's bearings. Other drawbacks with BearinX which was discussed are the high input data requirements and two-day training needed to be able to use the software. Hence, BearinX is preferred since the different modules span the entire need range. Further, if Delta is uncertain about the outcome of performed calculations they contact one or more bearing manufacturers to get help with the calculations.

Engineering tool usage in the future

Delta would like an engineering tool for bearing calculation which is compatible with their CAD software. There is a great dependency between the environment and the bearing, and a bearing calculation tools which could work with the CAD software would facilitate the process by minimizing iterations. Nowadays Delta need to manually update one software if changes to the design are made in the other. The difficulty with changing software frequently makes them reluctant to perform as many calculations as they would like. They argue bearing calculations today might look advantageous in the bearing calculation software where all parameters cannot be included, but not work in its real context.

Also, Delta argues that new software should be developed as modules with different complexity, from more advanced than today to the more basic ones, that work seamlessly together to facilitate the communication with the customer. Delta also say that it would be good to know the production/stockpile of special bearings such as CARB and high precision bearings since availability sometimes affect the bearing choice.

Summary

Delta assists customers with fairly complex applications using BearinX or SKF online tools. This is done on a weekly basis. Want a software where one can choose how advanced to calculate depending on the situation, and want it to be compatible with their CAD software.

5.5 Echo

Echo is a trade and service company (distributor) specialized in drive engineering. The company position itself as a partner for technical products and services. The offered products range from tools to bearings and safety equipment. Product-related services include customization jobs and bearing failure analysis. Other services include inventory management, packaging and technical consulting and construction. Approximately 50% of the customers are OEMs and 50% are MROs, and these are customers of all sizes. The interviewee has been at the company for 10 years and is head of the department conducting bearing calculations.

Bearing selection support to customers

Echo have three application engineers working with bearing calculation and related design services, among other tasks. Bearing calculations for their customers are done on a weekly basis. Most calculations are done related to customers' product development and the typical customer requiring help need competence in bearing selection beyond the customer's own capabilities. The average customer who asks for calculation support has little knowledge of bearing calculation, which affects the in-data available to perform these calculations. When customers only have a simple drawing, or even come with a blank paper, the bearing calculations possibilities are very constrained. According to Echo, the customers generally have low complexity products where bearings are not a constraining factor for product life, and L10h fatigue life calculations are usually sufficient. If more advanced calculations or FEM is required Echo sends the available data to SKF who then performs the necessary calculations. Customers with enough knowledge of bearing calculation to use the SKF software Bearing Select usually perform these calculations on their own, and in those cases Echo help when bigger questions arise regarding overall bearing arrangements. Also, many customers have simple bearing calculation features integrated with their CAD software which provided equal or better calculations than Bearing Select.

Engineering tools usage

Echo use knowledge and previous experience in most cases in order to be able to recommend bearing arrangements to customers, but also to get a rough estimation of required dimensions. Because calculations generally are limited to fatigue life L10mh the preferred tool is Bearing Select. Echo argues that Bearing Select is too advanced for most applications and that a simple L10h calculation is sufficient. They use BearinX on some occasions, but generally, the data provided by customers are not sufficient to run BearinX. Also, since the use of BearinX is limited to a few times a year, Echo rather sent the data to the bearing manufacturer since the lack of routine with BearinX might lead to faulty usage. Bearing Select is the preferred tool in most cases also since the majority of bearings sold are from SKF, and Echo prefer to have the bearing and calculations done from the same source. Echo also argue that

Bearing Select is simple to use and that the result is easy to explain to the customer, while the 16-page output from BearinX is too complicated. Although BearinX is deemed too advanced, Echo like the way it is built with many compatible versions. Some bearing types are almost always from the same bearing manufacturer, and when such a bearing is used the related calculation tool from that manufacturer is used, e.g. INA Medias selection tool for needle bearings.

Engineering tool usage in the future

Echo would like to have the SKF online tools Bering Select, Bearing Calculator and LubeSelect merged since they often are used in combination, and switching between the tools is annoying and time-consuming. Echo would like to have bearing calculation modules as add-ons which are compatible with Echo's customers' CAD-software. This would result in improved communication with the customers and accuracy of the calculations. According to Echo, customers are reluctant to change software environment and prefer to use the bearing calculation tools built into the existing CAD-software.

Summary

Echo assist customers with mostly L10h calculations since the customers usually cannot provide enough information to perform more advanced calculations. This is done on a weekly basis. Want a merged version of SKF's online tools that is compatible with their customers' CAD software.

5.6 Foxtrot

Foxtrot is a leading manufacturer of hydropower equipment and the company is usually a subcontractor in large hydropower projects such as dams. The size of Foxtrots turbines vary a lot depending on the application but range from among the largest in the world to the smallest used in hydropower plants. Most turbines built by Foxtrot are too big to use rolling bearings due to high loads. Instead, hydrodynamic bearings are used to support the loads and minimize friction losses, clearance, and vibrations, and maximize the bearings dampening effect. For these large applications, each turbine unit is unique to fit the hydropower plant and the hydrodynamic bearings are custom made. Rolling bearings are being used in the smallest turbines. Therefore, the scope of the interview will be the development of these smaller turbines. The smaller turbines consist of pre-designed modular components where the overall turbine design is standardized. The interviewee has worked at Foxtrot for 12 years and is now working as a construction engineer.

Bearing selection process

The large design process to set the standardized design was done several years ago, and the bearing arrangement is now fixed. Consequently, only minor calculations jobs need to be done on a monthly basis to determine what bearing size to use. Usually, the inner diameter is constrained by the shaft diameter and hence fixed, and the engineers adjust the bearings' outer diameter and width to find the proper bearing. The bearing choice is also constrained by the type of oil used in the application since the oil not only lubricate the bearings but all components within the turbine unit. Foxtrot also need to take into consideration that the rotating bearings affect the oil flow inside the turbine unit which in turn affects the lubricating and cooling effect.

The minimum required fatigue life for a bearing in a turbine unit is 150.000 hours (around 17 years of continuous drive) during maximum loads. However, Foxtrot always tries to achieve the longest possible life. The company internal target is to achieve more than 25 years fatigue life. Springs are used to preload the bearings to pass the lower load limit in order to be able to select larger bearings and hence achieve longer life during running conditions. Foxtrot use the L10h formula to calculate the fatigue life, and since they do not know the lubrication contamination levels they cannot use the modified life formula

L10mh. Also, since the turbines run at optimal conditions (i.e. under relative continuous rotating speed and loads) for extensive time periods, Foxtrot do not feel the need to do calculations for start and stop conditions.

Foxtrot contact the bearing suppliers when more advanced calculations are needed as well as when their customers require specific reports for the bearings. Furthermore, during the development of brand new product lines, there is an extensive collaboration with bearing suppliers who perform much of the calculations.

Engineering tools usage

Since the calculations are limited to L10h, the company has developed a simple excel file. Foxtrot have also looked at some online tools like Bearing Select and Bearing Calculator, but they require in-data Foxtrot do not have. Foxtrot contact the bearing manufacturers to get more accurate calculations for basically all calculations more advanced than L10h.

Engineering tool usage in the future

The major need Foxtrot have when it comes to tools for calculations on bearings are not related to bearing life, but the earlier mentioned effect from the rotating bearings on the lubrication flow. Foxtrot wish to have an engineering tool which can simulate the pumping effect from a rotating bearing where in-data such as oil pressure, cage, and bearing type and diameter can be combined with bearing specific data such as the number of rolling elements and surface areas. Foxtrot also raises the need of a tool which calculates how the housing behaves in different temperature and how it affects the bearings.

Summary

Foxtrot use products that contain rolling bearings are few and standardized and only use the L10h formula added to an excel file. Calculations are done on a monthly basis. Want to be able to simulate the bearings lubricant pumping effect and bearing house deflections.

5.7 Golf

Golf is one of the world's leading elevator manufacturers. The interviewees have been working with elevators for 40 years and have managing positions at the R&D department for drives (the mechanical system of wheels and pulleys which move the cabin). The interview focused on the development and use of bearings in high-rise elevators. This put a lot higher demands on the drive unit compared to low-rise elevators and decisions regarding bearings are made on a weekly basis.

Bearing selection process

The bearing selection process is long and has an important part in the development of new elevators. When a new elevator program is launched the drives department get specifications and system requirements which define the new elevator model's running conditions. The product development process is highly iterative. Generally, they rely on knowledge from previous projects of what have worked combined with the new features. Since drives is a part of a larger context, there are high demands on the interface between the drive unit and the rest of the elevator. The most important in-data for the bearing selection that comes from other engineering teams involved in the process are loads and torque requirements.

The interviewees use input data from other involved engineering teams combined with experience from old projects as a basis for the overall layout of the drive system. The interviewees use this in-data combined with a rough estimate of the bearing lifetime using L10mh to make the initial bearing

selection. Often the target lifetime is as much as 20 years. Since the operating conditions for bearings in elevators differs a lot from other applications, the calculation requirements on bearings in elevator differ a lot from those needed for normal bearing usage. Bearings usually rotate in one direction and at a fairly continuous speed. In elevators, on the other hand, the rotating direction depends on if the elevator goes up or down. Also, there is a lot of start/stop and also oscillating movements in the bearings when people step in and out of the cabin. Hence, normal fatigue life calculations cannot provide the required information on fatigue life. This means that the final bearing selection to a great extent is based on experience. Experience is usually combined with advanced simulations and recommendations from a few bearing manufacturers.

Engineering tools usage

The interviewees previously used bearing catalogs as decision support, and later switched to online tools and now they combine multiple software and support from bearing manufacturers to get a reliable lifetime figure. Less advanced calculation tools such as INA Medias are used in the early stages of the product development process to get a hunch of the fatigue life. Overall static calculations are done in CAD, shaft deflection is simulated in KISSsoft and Golf have just started to use an in-house developed software (which will be called Z in this section) for more advanced bearing calculations. Although Z can be used to simulate shaft deflection, the software is generally not accepted by other stakeholders in the project for various reasons.

The transition from L10h fatigue life calculations to Z which uses L10mh has not been easy since Z cannot simulate the actual running conditions of an elevator. The effect is that a calculated life figure of one million hours in Z or equal software can be as low as two to three thousand hours during actual conditions.

Engineering tool usage in the future

Golf do not get reliable results for bearing life using the tools they have today and therefore need more advanced software that can simulate actual running conditions for an elevator. Golf want to perform calculations more frequently but the lack of accuracy for the calculations limits them today. Needs that have to be fulfilled by a future software include short running cycles (many start/stop, 0-200 rpm), frequent change in rotating direction, temperature fluctuations and oscillating movements. This also includes the possibility to calculate life outside the boundary values within which the bearing is meant to operate.

Summary

Golf develop products that require advanced bearing simulations but are due to lack of appropriate tools constrained to L10mh calculations which are done on a weekly basis. Golf want to have an advanced software that simulates actual elevator conditions.

5.8 Hotel

Hotel is a large global crane manufacturer. The interviewee is a manager at the gearbox technology department and has been at the company for 5 years. The scope of the interview is on the engineering tools used for bearing selection for the gearboxes at Hotel. The interview covered both serial produced and customized gearboxes.

Bearing selection process

The selection of the right bearings for the new gearboxes is of big importance for Hotel because bearings are a critical component in the gearbox since the lifetime of the gearbox can be limited by the lifetime

of the bearings. Selecting the right bearings means selecting the smallest and cheapest bearings that will have the required expected lifetime when used in the specified application.

The bearing selection process starts during the concept phase where a list specifications are presented for the gearbox team. These specifications concern e.g. load capacity and sometimes what bearing manufacturer to use. Some specifications are often standard in the market such as what load capacity an elevator of a particular size should be able to handle, but also minimum bearing fatigue life. From these specifications, a gearbox from their product line is chosen if possible (this is often the case for smaller cranes), otherwise a custom made gearbox needs to be developed.

When the specification from the customer match one of the serial produced (catalogue) crane gearboxes, the lifetime of the bearings in the catalogue unit is being calculated for the specific application of the unit. If calculated lifetime of the bearings satisfies the customers' expectations, no further considerations concerning the bearings will be needed. However, more calculation work is needed when a custom made gearbox is developed.

During the concept phase for the custom made gearboxes, a rough estimate of the bearings is made which will be refined throughout the development process. The initial choice of bearings is to a large extent based on previously developed gearboxes of similar performance which are complemented with bearing life calculations based on the required specifications.

Since bearings are a critical component in a gearbox, the selection process and the calculations for the bearings go through an iterative process that continues throughout the product development process, from the concept phase to the final product, in order to optimize the bearing arrangement. The iterative process also makes it possible to react to possible changes in design affecting the bearing choice. In order to verify and get more accurate calculations, Hotel uses SKF as an external expert. SKF is consulted a few times a year depending on the number of projects.

Engineering tools usage

Hotel used only paper catalogs a decade ago and are today using more advanced calculation methods. An in-house developed software used for smaller crane gearboxes is fed with customer specifications in order to see if there is a product line at Hotel that matches the needs of the customer. Hotel performs more advanced calculations if the initial search in the product line units does not meet the required minimum lifetime, or when a custom made gearbox is required.

The more advanced calculations take a lot more time than the simple ones made by their own software which is why Hotel prefer to use their own software whenever possible. In order to conduct the more advanced calculations, Hotel uses the software KISSsoft on a weekly basis. KISSsoft is by Hotel considered to fit their present needs quite well but has some major limitations that hinder Hotel in their calculations. One of the major benefits of KISSsoft, according to Hotel, is that it follows market standards for calculations, something often required by Hotel's customers. Another benefit using KISSsoft is that Hotel can transfer sketches between KISSsoft and their CAD program which facilitates the usage a lot. The major downside is that the calculations, even though they are lot more precise than the calculations done using their own software, are still pretty rough estimates. The lifetime calculation method used in KISSsoft is L10mh which according to Hotel does not provide an accurate enough lifetime figure for crane gearbox running conditions, which are similar to elevator conditions. Also, a crane might be used as little as once a year, or lift items in a vast weigh span. Another downside with KISSsoft according to Hotel is that it can't handle any special situations that could occur during normal

use like cold weather starts with too little grease or very slow movement with extremely high loads. The lack of accuracy in KISSsoft leads Hotel to contact SKF to get more accurate bearing life estimations.

Engineering tool usage in the future

Hotel want to do more advanced bearing calculations in-house then they do today, and hence seek more advanced tools. The main reason for this is to increase the company's internal knowledge of their applications and bearings, as well as get calculation results faster than when contracting SKF.

Lubrication and contamination issues are the biggest cause of malfunctioning bearings, as well as issues rooted in the crane specific running conditions. Since these situations are not possible to simulate using KISSsoft according to Hotel, a new software needs to be able to simulate and calculate bearing life during these specific conditions. Other features mentioned by Hotel that they would like to be implemented is to be able to calculate and simulate clearance, shaft deflection, and deformation of the housing. It's also important for Hotel that the software is relatively easy to use. They have tried the software BearinX and soon stopped using it since the user interface was too complicated. The interviewee at Hotel also mentioned that they would prefer to have it installed on their computers instead of having a web based interface, something they have tried before but abandoned.

Implementing a software that would fulfill the needs mentioned above would require new and more advanced calculation skills and knowledge to be developed at Hotel and they are well aware of this. These new skills would not only concern how to use the software but also how to interpret the results, something that SKF today help them with. Hotel believes that they have the required know how to start that process and are willing to put in the required effort in order to develop the necessary skills. Even though Hotel wants to be able to perform more advanced calculations, they would not want to do everything themselves. They still want to have SKF as an external provider of expertise and use their reports as quality assurance for their customers.

Summary

Hotel develops gearboxes used in harsh conditions that put high demands on the bearings. Although, at this moment Hotel lack the advanced enough engineering tools and are constrained to L10mh calculations used on a weekly basis. Want to do more advanced real situation simulations in-house.

5.9 India

The company India is a global elevator manufacturer. The interview was conducted with two interviewees from the drives department. The first interviewee is a senior chief design engineer and has worked at India for 16 years with decisions concerning the drive unit. The second interviewee is a chief design engineer for drive units and has worked at India for 10 years with, among other tasks, bearing calculations. The scope of the interview will cover India's development process for new drives units. Development of new drive units happens only a few times a year. These are manufactured in house and have a special design relative to other elevator drive units, and the special design requires more from the bearings than competitive designs.

Bearing selection process

The development of a new drive unit is a subproject of the development of a new elevator at India. The drive unit department at India receives specifications from other development departments whose parts are affected by the drive unit. These specifications can cover areas such as the size, torque, speed and

shaft loads affecting the drive unit. If no drive unit in India's current product range can satisfy the parameters in the project specification, a new drive unit needs to be developed.

In large, the development of new drive units at India covers four steps namely design, calculation, prototype and final product. However, the process is very iterative and many design drafts and prototypes are made and reworked for a single project. During the design phase, a new basic design of a drive unit is created using the given project specifications. The bearings to use is one of the first decision made during this phase. A bearing that fits inside the given dimensions and that, based on knowledge gained from previous projects, can handle the given parameters will be selected. India tries to limit the selection to ball bearings that can be ordered from bearing manufacturing plants all around the world to reduce lead times and get a low price. After selecting the bearings to use, the designs are sent to different bearing manufacturers who perform lifetime calculations for the selected bearings in the specified application. The calculated lifetime is the lifetime for the bearing during maximum load and speed in the application. This is done to be safe even though India knows that the bearings won't need to perform at maximum at all times. After their calculations have been done, India arranges workshops with a few selected manufacturers where the lifetime figures are discussed and possible design changes are discussed. This is done once or twice in order to gain as much knowledge as possible concerning how the bearings will behave. After this is done, SKF will be contacted and asked to validate the calculations. SKF validate the calculations since SKF and India have a good relationship, but also because SKF is one of India's main suppliers of bearings. One or a couple of prototypes of the drive unit will be created after SKF has given approval for the bearings. If a problem is revealed when analyzing the prototype a new design will be created and the process starts over. An average project has somewhere between 5 and 10 prototypes according to India.

Engineering tools usage

India's engineers at the design department for drive units don't perform much calculations or simulations on bearings. They sometimes use some L10h fatigue life calculations when selecting the bearings but this is very rare. Instead, they rely on the bearing suppliers to make the needed calculations. The main reason for this is that the bearing manufacturers can make much more advanced calculations and have the required knowledge from assisting India for many years.

India uses an in-house developed software to generate data required to select bearings, such as loads and rotating speed cycles. This data is sent to bearing manufacturers together with CAD models from which the bearing manufacturers' recommend appropriate bearings. The consultation with bearing manufacturers usually happen one or two times per project, and India usually consults SKF in the end to get a final verdict.

Engineering tool usage in the future

India would like to conduct some of the calculations in-house. However, it's very important that the calculations made will be simple since they aren't bearing experts and don't try to become one. Preferably, they would do some of the simpler modelling that SKF do today to reduce the workload from SKF and shorter the lead time. In that case, the software would need to be compatible with the software that SKF use in order to realize the potential time savings this solution would provide. One example would be to model internal bearing surface pressure which would improve the accuracy of the initial bearing size decision. However, since the bearing life depends on so many parameters such as the sealing and grease, the interviewee think it is better to let SKF perform the more advanced calculations.

One feature that India would appreciate in a software would be some kind of compatibility with their CAD software since this would reduce the need to remodel the design when moving between the software. It would also be of great use for India to be able to see if the selected bearing is a standard bearing or a more expensive special bearing, as well as where in the world the selected bearing is in stock in order to save money and lower delivery times.

Summary

India develops advanced drive units used in applications which are tough on bearing life. Although, all advance calculations are outsourced and L10h calculations are done in-house a few times a year. They want to do more advanced calculations in-house in a software compatible with their CAD software.

5.10 Juliett

Juliett is a manufacturer of mainly custom made, small batch, gearboxes and have over 100 years' experience from gearbox development. The interviewees are working in the product development department where one interviewee has been a team manager for 3 years and is responsible for the department's projects. The second interviewee has worked for Juliett for 3 years and is a chief structural analyst. Both the interviewees work with decisions regarding bearings daily. The scope of the interview will cover bearing calculations and simulations for new product development of Juliett's custom made gearboxes.

Bearing selection process

The development of a new gearbox starts with a specification from the customer concerning parameters such as load, output torque and the dimensions of components attached to the gearbox.

From these specifications, a rough model will be created. This model usually takes two weeks to make, and will then be discussed with the customer. It's during this early stage that bearings are considered, and they are according to the interviewees one of the most important components in the gearbox. They select bearing types and size based on knowledge from previous projects and then do bearing lifetime calculations in order to see if the selected bearing can manage the specific application. Juliett describes the gearbox market as sometimes very conservative and one example is that some customer wants Juliett to calculate the lifetime using basic L10h. Juliett calculates the bearing lifetime for the gearbox peak operating condition.

Juliett's in-house calculations are sufficient 9 projects out of 10, but for projects that is radically different than what they have done before (around 5 projects per year), they will contact bearing suppliers for more advanced calculations as well as advice concerning the bearing arrangement. The more advanced calculations take into account how the bearings behave when there are a lot of starts and stops as well as high shock loads. Juliett mainly use SKF since they have a close relationship with SKF, but sometimes use Schaeffler as additional advisors.

The calculated expected lifetime of the bearings is compared to the required lifetime from the customer which is usually between 40.000 hours to 100.000 hours. If the expected life matches the required life, no further work is needed concerning the bearing but if it greatly exceeds or is insufficient, new bearings are needed and the calculations reworked.

Engineering tools usage

The main tool for performing bearing calculations is Juliatt's in-house developed software which is used on a daily basis. This software has been used for over 20 years and has during this time been improved in order to better simulate how bearings behave in a gearbox. A model of a previously made gearbox is selected in the software which then is modified according to the specification of the customer. Bearings are added to the model from an integrated database containing bearings from several manufacturers and the software calculates the expected bearing life using either L10h or L10mh fatigue life calculation. The software is quite powerful and fits their need well. Some functions that were mentioned by the interviewees are the ability to include shaft deflections and load distribution as well as lubrication.

Some cases, such as non-standard or damaged gear teeth, cannot be simulated using Juliatt's software. In order to calculate this, Juliatt instead uses either KISSsoft or a software called T in this report. These kinds of calculations are only conducted a few times a year.

Juliatt recently started to use BearinX after completing a two-day course. The idea is to use BearinX as a complement to Juliatt's in-house developed software described above. The main benefit with BearinX according to Juliatt is that it is more powerful than the software that they usually use. Using BearinX Juliatt will be able to design the whole gearbox unit in a 3D model and perform more advanced calculations and simulations than was possible before. This will allow them to simulate for example thermal expansion of the bearings as well as to gain a better understanding of individual situations that can occur during usage of the gearbox which might stress individual bearings. Using BearinX, Juliatt can also reduce the gap between what their own software can manage and what they need external help for, and hence believes that they will use BearinX very frequently in the future.

Engineering tool usage in the future

The interviewees believe that Juliatt will perform a lot more calculations in-house in the future instead of relying so much on external help. The fact that they have started to use BearinX and want to use it frequently in the future is according to the interviewees a clear indicator that they move towards that direction.

Summary

Juliatt develops gearboxes that put high demands on the bearings and hence use the advanced bearing calculation and simulation software BearinX as well as in-house developed software on a daily basis. Will in the future increase the usage of BearinX.

5.11 Kilo

Kilo is a global gearbox manufacturer. The interviewee has been at the company for 16 years and is now working as a senior engineer. The position requires work with bearing calculations which are conducted by the interviewee on a daily basis. The scope of the interview will be limited to product development of Kilo's serial produced and custom made gearboxes. The number of ongoing projects at the department is as many as 30 projects at a time.

Bearing selection process

Customers to Kilo require larger gearboxes than ever before, and hence Kilo need bigger bearings and more precise calculations since large gearboxes are more demanding to get right. An example of this is that larger gearboxes generate more heat, and the larger the bearings, the more it will be affected by increasing temperatures. The bearing is a critical component in Kilos gearboxes since they sometimes

limit the gearbox lifetime. This makes the choice of bearings for new gearboxes a very important decision.

The product development process at Kilo starts with a list of specifications from the customer for the gearbox that is given to the development department at Kilo. These specifications often concern technical data on the motor that will be connected to the gearbox as well as the required gearbox output in speed and torque.

From the specifications, it's decided if a custom gearbox will be needed or if Kilo has a catalogue gearbox that fits the requirements. If no gearbox in the catalogue matches the needs they start to develop a new one by making a rough sketch for the gear, shaft and bearing sizes based on the specifications from the customer via the sales department. The bearings will be chosen based on knowledge gained from previous projects and no calculations are done at this stage. They try to not put too much effort into this stage since it's still uncertain if Kilo will get the project since their customers often request the same kind of gearbox from several gearbox manufacturers. If Kilo gets the contract for the gearbox, the development process continues with a more detailed design of the gearbox together with calculations.

It's mainly lifetime calculations that are made for the bearings and are done using 'either L10h or L10mh depending on what calculation method the customer demand. The required bearing life is usually around 200.000 hours. Kilo makes the designs and calculations non-bearing manufacturer specific as possible in order to in the end be able to order a bearing that matches the specifications from an as wide range of bearing manufacturers as possible. This is done since price and delivery time for the bearings are very important factors for Kilo. Kilo has previously locked the bearing choice to just one manufacturer and has ended up in a situation where the manufacturer ran out of bearings in stock and they had to order bearings from a distributor which became very expensive. Many calculations are done in order to find a large range of bearings that can satisfy the lifetime needs of the customer as possible.

Kilo also uses the bearing suppliers as advisors and let them provide Kilo with bearing calculations that are more advanced. More advanced calculations and simulations could be for example what happens with the bearing during shaft expansion. This is done around once a month and is mainly done with SKF and Schaeffler. One thing that they have noticed is that the calculated lifetime is almost always longer when external parties conduct the calculations which could indicate on their software having too much of a safety margin.

The recommended bearings are inserted into an in-house developed software that the sales department looks at to select the bearings that have the best combination of price and delivery time.

Engineering tools usage

Kilo uses mainly three software for all in-house calculations: KISSsoft as well as two software that are developed in-house which will be called X and Y. KISSsoft, as well as X, is used daily and Y is used less frequently.

KISSsoft is the main tool the engineers use at the gearbox development department at Kilo. They use this software during the first rough sketches of the gearbox and then throughout the whole development process. One of the main benefits of using KISSsoft is that it's a well-known brand among Kilo's customers and the calculations that they get from the software is easy to interpret for the customers. Being an external software, it has all major bearing manufacturers' standard bearings already in it, and hence there is no need for Kilo to update or maintain it themselves. KISSsoft can also communicate

with the CAD program they use to design the gearbox via an in-house developed interface. However, KISSsoft is due to the many functionalities very slow to use compared to the software they have developed in house. Another negative aspect is that the sales department can't use it to get access to information needed for bearing orders.

The software X is an internally developed software which has gained a lot of resources lately in order to be further improved. The software uses customer specifications as input and search through the catalogue gearbox range for a suitable gearbox and then automatically make small adjustments to it if necessary. The main benefit, and the reason why it is used a lot at Kilo, is that it's directly connected to the sales departments system which facilitates component orders. The main drawback of X is that it is not possible to use it for new designs for gearboxes since it is based on Kilo's current product portfolio.

The in-house developed software Y is less and less used in favor for KISSsoft, and might in the near future be integrated into X. Y is used basically for the same things as KISSsoft and is frequently used by the more senior engineers during the development of new gearboxes. One of the major benefits with Y is the smooth communication with their CAD program in contrast to the interface they have created for KISSsoft. Another benefit of Y compared to KISSsoft is that it's used by the sales department to see what components will be needed to order in order to manufacture the gearbox. Y can perform calculations for both serial produced and custom made gearboxes compared to X which only can perform calculations for the serial units. The drawbacks with Y is that it's made and managed in-house which means that it is not always up to date with available bearings. Hence, Kilo needs to frequently ask the main suppliers of bearings for product information in order to update the information in the software. Another negative aspect of Y is that the calculations are very hard to interpret for the customers and doesn't look very professional.

Engineering tool usage in the future

Kilo wants to be able to perform more advanced and frequent calculations in-house that the bearing suppliers make for them today. What they miss today is detailed analyses for some application specific scenarios such as the startup phase which put the bearings under harsh conditions. They also need a program that can recommend lubrication based on temperature and how that affects the lifetime of the lubrication.

User friendliness is an important parameter for Kilo. They would like to be able to have software for the basic calculations where they can input the parameters and using one button get the results.

Kilo doesn't believe that a program that would satisfy the needs mentioned above would replace the software they use today. It would rather be something like an add-on or a separate program that is used when a special analysis is needed.

Summary

Kilo develops gearboxes which require advanced bearing calculations. Although, Kilo's in-house and externally developed software is limited to L10mh calculations. The software are used on a daily basis. Want to complement their current range of tools with a more advanced bearing simulation software.

5.12 Lima

Lima is a manufacturer of large industrial fans. To put it in perspective, the length of a single fan blade reach around 2, 5 meters. The interviewee has worked with engineering calculations the past 35 years and at Lima during the last seven years.

Bearing selection process

Lima is a manufacturer of custom made products and each fan is unique. The development process starts with a more or less complete technical specification from the customer. The specification contains information about the fans running conditions such as fluid pressure, flow rate, and temperature. The specified running conditions vary a lot between applications. Although, fans have a relatively simple overall mechanical design with a single shaft held by two large bearings. This means that the overall mechanical design does not alter much between different installations, and blueprints from previously manufactured fans used in similar conditions generally decide what type of bearings are used. The initial choice of bearings is made from required minimum shaft diameter and loads. In almost all cases one of two different bearing arrangements are used.

After an initial bearing selection, the designer has information on all basic bearing properties, including bearing stiffness which is a crucial factor for the extensive rotor dynamic simulations that follows the initial bearing selection. During the rotor dynamic simulations Lima receives information about shaft movements and shaft frequencies which need to be kept to a minimum during optimal running conditions. The two bearings' positions relative the shaft's axial direction are altered between simulations to find the optimal positions where harmful frequencies are avoided. If no acceptable result is found during these simulations the interviewee increases the shaft diameter where possible along the shaft. If this is not enough, which rarely happens, either the design needs to be altered with a new overall shaft diameter and a new set of bearings with new inner diameters.

Rolling bearings are also used between the rotor wheel and the blades since the blades need to be able to turn in order to adjust the fan capacity. These bearings are always axial ball bearings and are always in the same position. Hence, this is a standardized design which is never altered.

All bearings in the fan must meet the required fatigue life of 100.000 hours. The two large bearings on the shaft usually exceed this life by a vast margin. There is a different situation for the smaller axial ball bearings since they do not rotate, but rather adjust slightly in an oscillating movement in order to regulate the fan capacity. In this case, Lima must rely on experience from previous cases.

Engineering tools usage

Lima's engineering tools usage related to a bearing selection of the two large roller bearings is limited to support from SKF. Lima sends specifications on required fatigue life, bearing type, shaft diameter, static loads, rotating speeds and temperature from which SKF recommend two bearings. SKF recommend a new set of bearings if the first ones do not pass the previous mentioned rotor dynamic simulations. SKF also provide Lima with fatigue life calculations and other bearing data such as lubrication oil viscosity and quantity. Further, the interviewee admits that during actual running conditions the oil quantity used might be as low as one-third of what was recommended by SKF, but that lubrication quantity related breakdowns have not yet occurred. The number of fan developments at Lima per year is in the range five to eight, and SKF is in general consulted equally many times. The lead time for a calculation requests to SKF is usually one week.

The axial ball bearings between the rotor wheel and the blades are selected from an in-house excel file using L10h. The excel file contain bearing data from SKF's standard catalogue range, as well as few bearings modified by Lima.

Engineering tools usage in the future

The interviewee does not see a reason to change the current bearing calculation routines and is satisfied with the calculation support from SKF. The argument behind this is the low number of calculations needed each year, but also since the personal contact is highly valued and needed in order to keep SKF's application engineers up to date with Lima's products. This is argued to decrease the response time if any trouble emerges with the bearings. On the other hand, since the interviewee has the technical knowledge to perform all required bearing calculations he says he would be able to do the calculations himself if he had access to the right tools. But as long as the support from SKF is good enough things will probably not change.

Summary

To conclude Lima, the products overall bearing arrangement is simple but the application requires fairly advanced bearing calculations. Although, almost all bearing calculations are done externally. Simple L10 load calculations using are done in-house a few times a year. Prefer to keep the current solution.

5.13 Synthesis of empirical findings

The empirical findings from 12 companies are synthesized into key takeaways in table 5.1. Three aspects have emerged as critical for the companies' engineering tool needs and the decision of what tools are currently used. These three aspects are also related to wishes on future tool usage. The three aspects are (1) the products overall complexity, i.e. the products' inherent complexity level, (2) the companies' bearing selection capabilities, i.e. present use capabilities and use of various engineering tools, and (3) the frequency of which engineering tools are used. The three aspects will be further elaborated upon in chapter 6.

Company	Key Findings
Alpha	Alpha develops screw compressors which have high demands on efficiency and hence generally require advanced bearing calculations. Although, experience based estimations and L10h calculations are the main source of engineering tools used, and only a few times a year. Alpha wants to return to old SKF online software or, less likely, do a radical change to a new more advanced software that can handle the entire development process.
Bravo	Bravo uses L10h in the initial stages of the product development and L10mh during the validation phase. The tool used is an in-house developed clone of Bearing Select, which is used on a monthly basis. Bravo see two option for the future. Either complement the current software platform with an “SKF certified” module or, less likely, replace the current platform.
Charlie	Charlie assists their customers with L10h and L10mh calculations for low to medium complex applications on a monthly basis using SKF online tools. They would like to have a merged and more user-friendly version of the currently used SKF’s online tools.
Delta	Delta assists customers with fairly complex applications using BearinX or SKF online tools. This is done on a weekly basis. Want a software where one can choose how advanced to calculate depending on the situation, and want it to be compatible with their CAD software.
Echo	Echo assists customers with mostly L10h calculations since the customers usually cannot provide enough information to perform more advanced calculations. This is done on a weekly basis. Want a merged version of SKF’s online tools that is compatible with their customers’ CAD software.
Foxtrot	Foxtrot uses products that contain rolling bearings are few and standardized and only use the L10h formula added to an excel file. Calculations are done on a monthly basis. Want to be able to simulate the bearings lubricant pumping effect and bearing house deflections.
Golf	Golf develops products that require advanced bearing simulations but are due to lack of appropriate tools constrained to L10mh calculations which are done on a weekly basis. Golf wants to an advanced software that simulates actual elevator conditions.
Hotel	Hotel develops gearboxes used in harsh conditions that put high demands on the bearings. Although, at this moment Hotel lack the advanced enough engineering tools and are constrained to L10mh calculations used on a weekly basis. Want to do more advanced real situation simulations in-house.
India	India develops advanced drive units used in applications which are tough on bearing life. Although, all advance calculations are outsourced and L10h calculations are done in-house a few times a year. They want to do more advanced calculations in-house in a software compatible with their CAD software.
Juliatt	Juliatt develops gearboxes that put high demands on the bearings and hence use the advanced bearing calculation and simulation software BearinX as well as in-house developed software on a daily basis. Will in the future increase the usage of BearinX.
Kilo	Kilo develops gearboxes which require advanced bearing calculations. Although, Kilo’s in-house and externally developed software are limited to L10mh calculations. The software is used on a daily basis. Want to complement their current range of tools with a more advanced bearing simulation software.
Lima	To conclude Lima, the products overall bearing arrangement is simple but the application requires fairly advanced bearing calculations. Although, almost all bearing calculations are done externally. Simple load calculations are done in-house a few times a year. Prefer to keep the current solution.

Table 5.1. Synthesis of key findings from the companies in the study.

6. Analysis of interview data

The collected empirical data will be analyzed in this chapter. First, the three parameters used for classifying the companies (1) Requirements on Bearing Calculation (RBC), (2) Bearing Calculation Capabilities (BCC) and (3) Frequency of Use (FoU) are described. Next, the twelve companies in the study are analyzed based on these three parameters and are given a value for each parameter. Clusters are then identified and using the data about the future needs of these clusters, three archetypes of companies are identified.

6.1 Parameters for cluster classification

In this section, three parameters will be described and defined which will then be used in a cluster analysis. The three parameters will be divided into three levels (low, medium and high) which represent certain company characteristics.

As described in chapter 5, key takeaways from the initial analysis of empirical data revealed three major drivers for the use of certain engineering tools. The three major drivers are (1) the products overall complexity, i.e. the products' inherent complexity level, (2) the companies' bearing selection capabilities, i.e. present use capabilities and use of various engineering tools, and (3) the frequency of which engineering tools are used.

The three drivers have been categorized into three parameters used to classify the companies. The three parameters are (1) Requirements on Bearing Calculation (RBC), (2) Bearing Calculation Capabilities (BCC), and (3) Frequency of Use (FoU). The three have been selected because they represent the empirically found major drivers of what engineering tools are used and since the three parameters influence the bearing selection. Three classification levels (low, medium and high) will in the coming three sections be presented for each parameter. The classification levels depend on company and product characteristics, which will be further elaborated upon in the three consecutive sections that follow.

6.1.1 Requirements on Bearing Calculations

In this section, the parameter Requirements on Bearing Calculations will be presented as well as the characteristics of companies for the different levels low, medium and high.

Requirements on Bearing Calculations (RBC) is a measure of how important precise calculations are for a company. These requirements can come from the customers to the company or from bearings being a constraining life factor of the product.

Companies given *low* in RBC are companies that do not need any advanced calculations. This means that the application or customer do not require them to use precise calculation methods, but rather rough estimates. This could be due to the bearings not being a constraining factor for the applications expected lifetime or performance. Low RBC is acceptable in e.g. simple applications where the lubricant contamination is completely unknown and more advanced than L10h are hence hard or impossible to do.

Medium categorized companies regarding RBC are companies where the bearings expected life can sometimes be a constraining factor but not necessarily. Medium RBC is acceptable in e.g. applications where the bearings can reach significantly longer life than other components, but are then dependent on known load figures and correct lubrication. Typical bearing mountings are on single shafts with one continuous rotating direction.

Typical companies that are considered *high* in RBC are companies having the bearings as a constraining factor for their applications performance or lifetime or where customers require them to deliver detailed

reports of the bearings expected life and hence have high requirements on the bearing calculations. An example of applications with high RBC is e.g. elevators or similar applications where the bearings face slow oscillating movements under high load.

6.1.2 Bearing Calculation Capabilities

In this section, the parameter Bearing Calculation Capabilities will be presented as well as the characteristics of companies for the different levels low, medium and high.

Bearing Calculation Capabilities (BCC) is a measure of how advanced and thorough bearing calculations and simulations a company are performing. In other words, based on the calculation methods as well as the software at hand for the company, what capabilities regarding bearing calculations the company have at the moment. A company can have either low, medium or high BCC.

A company considered *low* regarding BCC typically do not perform any advanced bearing calculations. Either, the company performs no calculations for bearings at all and instead outsource all the needed calculations to for example the bearing suppliers or they perform very basic calculations. Calculations considered basic calculations are the fatigue life of the bearings using the L10h method. Often, these kinds of calculations are performed using a paper catalog or a simple excel file.

Typical companies that are *medium* in their BCC are companies calculating bearing lifetime using the L10mh method which is more advanced than L10h. Companies that use L10mh tend to also use in-house developed software made specifically for their needs and their specific application. They might also complement current software with, or only use, Bearing Select, Bearing Calculator, INA Medias or similar. More advanced users in this range use KISSsoft or similar.

Companies in the *high* segment on BCC are the ones performing the most thorough and advanced calculations, and also simulations, among the companies in the study. They usually model bearings as flexible elements and account for bearing deformations and internal bearing geometries. Software that is common here are for example BearinX or advanced FEM software used on the bearings.

6.1.3 Frequency of Use

In this section, the parameter Frequency of Use will be presented as well as the characteristics of companies for the different levels low, medium and high.

The Frequency of Use (FoU), is a measure of how often companies use engineering tools to conduct calculations for their bearings.

Companies that are considered *low* when it comes to FoU are those performing calculations for bearings only a few times a year or less.

Companies performing bearing calculations on a monthly or weekly basis are considered *medium* in FoU.

In order to be categorized *high* in FoU, a company needs to perform bearing calculations more or less on a daily basis.

6.1.4 Summary of the parameters

The above-described parameters RBC, BCC and FoU are summarized below in table 6.1.

	LOW	MEDIUM	HIGH
RBC	<p>Bearings are not constraining factor for the lifetime or performance of the product.</p> <p>Input data are rough estimates or simple load cases.</p>	<p>Bearings can be limiting factor for the application life and performance.</p>	<p>Bearings are a constraining factor in the application.</p> <p>High requirements on the bearings from stakeholders.</p>
BCC	<p>Often outsource the calculations.</p> <p>The ones made in-house uses L10h.</p> <p>Uses catalogue or excel.</p>	<p>Using in-house developed software, Bearing Select or Bearing Calculator. More advanced use KISSsoft.</p> <p>Using L10mh as calculation formula.</p>	<p>Includes internal geometry of the bearings.</p> <p>Use BearinX, FEM or similar.</p>
FoU	<p>Using engineering tools for bearing calculation or simulation a few times a year or less.</p>	<p>Using engineering tools for bearing calculation or simulation weekly or monthly.</p>	<p>Use engineering tools for bearing calculation or simulation more or less every day.</p>

Table 6.1. Summary of the three parameters RBC, BCC, and FoU.

6.2 Categorization of Firms

Each company in the study's grading in the range low, medium, high, regarding the above-described dimensions will be presented in this section as well as the analysis that led to the grading. The analysis is based on the information given from the interviews presented in chapter 5, Empirical Findings.

6.2.1 Alpha

Alpha is high in RBC, low in BCC and low in FoU based on the analysis conducted below.

Having an application that requires high precision for their bearings due to high rotating speed and minimal shaft movements indicates a need for advanced calculations. This results in *high* for RBC.

The software Alpha use for calculating the loads on the bearings from the rotating axles is developed in-house for their specific needs and is considered somewhat advanced. However, using only L10h calculations for bearing fatigue life in combination with mostly estimations based on previous knowledge results in Alpha being categorized as *low* in BCC.

For FoU, Alpha is *low*. They iterate frequently between calculations and design during the development of new compressors. However, most of the calculations done are mainly for other things than for bearings which are done only a few times per year.

6.2.2 Bravo

Bravo is medium in RBC, medium in BCC and medium in FoU based on the analysis conducted below.

A pump is a fairly simple application, but due to the need of rotor dynamic simulations and bearings with long life, Bravo needs to use at least L10mh calculations. Hence, Bravos RBC is *medium*.

Bravos' in-house developed platform with combined external software as well as the clones of Bearing Select and Bearing Calculator are considered *medium* in BCC. Bravo's clones use L10mh which is combined with load data from rotor dynamics simulation. The software are capable of taking parameters such as contamination as well as lubrication into consideration in order to calculate the lifetime using L10mh.

Since most of the parameters for the bearings are decided using knowledge from previous projects, calculations are done mostly to validate the choice of bearings. This is done on a monthly basis according to Bravo which results in *medium* for FoU.

6.2.3 Charlie

Charlie is medium in RBC, medium in BCC and medium in FoU based on the analysis conducted below.

Charlie often performs their calculations with very limited in-data, often rough estimates. However, no calculations that are very advanced and accurate are generally asked for according to them. Instead, their customers are often seeking estimates for bearing fatigue life using L10h or L10mh. Though the in-data often is imperfect, having requirements for performing L10mh calculations results in *medium* for RBC.

Since Charlie is using L10mh they are considered *medium* in BCC. However, the input data they use are often based on pure assumptions and estimations instead of simulations which put them close to being considered low in BCC.

Charlie provides their customers advice regarding bearing selection a few times a month which gives them a *medium* in FoU.

6.2.4 Delta

Delta is high in RBC, high in BCC and medium in FoU based on the analysis conducted below.

Delta has customers with various complexity level in the customer's applications and some of them require Delta to calculate fairly complex calculations. Hence, Delta is given *high* in RBC.

Delta is using BearinX online for the customers that require more advanced calculations such as shaft dynamics, multiple bearings and load cases, material properties, and temperature effects during load cycles. This results in them being *high* in BCC.

Not all of Deltas' customers request their services regarding bearing calculations but only the middle sized ones. This results in usage on a weekly basis and positions them as *medium* in FoU.

6.2.5 Echo

Echo is medium in RBC, medium in BCC and medium in FoU based on the analysis conducted below.

When it comes to RBC, the calculations that need to be performed are often similar to the ones Delta calculates but are less complex. Echo's customers seem to be able to perform more calculations in-house and some rely on Echo to be their advisor when it comes to bearing arrangements. Having SKF as a close expert advisor to Echo is also an important factor when evaluating RBC for them. Consulting SKF is often done when customers require very precise calculation reports which would indicate on a high RBC. Combining the low average RBC together with the peaks in high RBC results in giving Echo *medium* in RBC.

The calculations that are requested by Echo's customers are often basic calculations where L10h is sufficient. However, they are able to perform L10mh calculations using Bearing Select when needed. The need for advanced calculations are limited and if requested, they mainly outsource it to SKF. Echo said that they sometimes tried to use BearinX in order to perform calculations. However, the quality of the calculations for bearing lifetime are depending on the quality of the in-data, and having the customers with little technical knowledge gathering the needed data will result in calculations of varying quality. Having the capability to perform calculations using BearinX is usually considered high in BCC but when using in-data that lack trustworthiness in combination with a very low frequency of use for this specific software results in Echo being considered a *medium* in BCC.

Echo performs bearing calculations as well as giving advice concerning bearings on a weekly basis which results in *medium* for FoU.

6.2.6 Foxtrot

Foxtrot is medium in RBC, low in BCC and medium in FoU based on the analysis conducted below.

The customers require more calculations than the basic L10h calculations Foxtrot can perform which results in Foxtrot outsourcing those calculations to SKF. This indicates that some customers have applications that are dependent on precise bearing calculations. Therefore Foxtrot has RBC higher than low, hence, *medium* is chosen.

Foxtrot are a given *low* when it comes to BCC. Since they already have conducted most of the calculations a long time ago for their models they only do very basic calculations in combination with the knowledge they have gained from previous projects regarding the selection of bearing calculations. The only calculations they perform is the L10h to calculate the fatigue life of the bearing and they use only a simple excel file in order to perform these calculations.

Foxtrot conducts bearing calculations on a monthly basis and are therefore considered *medium* for FoU.

6.2.7 Golf

Golf is high in RBC, medium in BCC and medium in FoU based on the analysis conducted below.

Golf is considered a *high* in RBC. This is foremost due to the fact that elevators are an application that needs advanced software in order to calculate bearing life. The reason is that normal L10mh calculations are designed for continuously running bearings in one direction, which is not the case for elevators and therefore need more powerful calculation tools. It should also be noted that bearings are an important part for Golf which also results in high in RBC.

Golf uses a wide range of software in order to perform calculations for their bearings during different stages in the development process. A combination of online tools as well as more advanced software is used. Having the capability to use KISSsoft positions them as *medium* in BCC.

The calculations done at Golf are made on a weekly basis which positions them as *medium* in FoU.

6.2.8 Hotel

Hotel is high in RBC, medium in BCC and medium in FoU based on the analysis conducted below.

Bearings are considered a critical component in gearboxes since the lifetime of the gearboxes is limited to the bearings. The gearboxes at Hotel are used in a way that is not well suited for basic or semi-advanced bearing calculations due to a lot of starts and stops as well as running conditions similar to elevators mentioned above. Having bearings as a critical component in combination with using the bearings in a very demanding way results in them being considered *high* in RBC.

Hotel is considered a *medium* in BCC because they use KISSsoft combined with their CAD program in order to conduct L10mh calculations.

Calculations for bearings are conducted on a weekly basis for Hotel which results in them being considered *medium* in FoU.

6.2.9 India

India is high in RBC, low in BCC and low in FoU based on the analysis conducted below.

India is manufacturing drives for elevators which are a very demanding application for the bearings and advanced software are required to simulate how the bearings behave in the application as well to calculate the expected lifetime. L10mh is designed for calculating the expected lifetime for a bearing under continuous running in one direction but the elevator requires the bearing to perform a lot of starts and stops as well as to run in both directions. India's drive units are also unique compared to other drive units and due to the unique design require are more dependent on the bearings lifetime. These characteristics of Lima results in them being considered a *high* in RBC.

India is given *low* when it comes to BCC. They perform barely any calculations themselves except the basic L10h fatigue life which happens very seldom. Instead, they outsource all the calculations to the bearing suppliers due to lack of capability in-house.

India is considered a *low* in FoU since they only require calculations a few times a year.

6.2.10 Juliett

Juliett is high in RBC, high in BCC and high in FoU based on the analysis conducted below.

Juliett is a manufacturer of drives units which is an application using bearings in a very different way than what normal fatigue life calculations are designed for. This puts high requirements on the tools that are used for the bearing calculations. This in combination with regarding bearings as one of the most important components in the application results in them being considered *high* in RBC.

The BCC for Juliett is considered *high*. This is due to a combination of powerful in-house developed software capable of performing shaft deflection, load distributions and lubrication for the bearings used in combination with the newly acquired advanced software BearinX.

Juliett performs bearing calculations on a daily basis and hence are given a *high* on FoU.

6.2.11 Kilo

Kilo is high in RBC, medium in BCC and high in FoU based on the analysis conducted below.

Kilo is regarded *high* in RBC. This is due to the fact that they manufacture gearboxes which require advanced bearing calculations as mentioned above. They also consider bearings as a very important component in their gearboxes since the gearboxes are becoming larger and larger which requires more from the bearings which also speaks for being high in RBC.

Kilo is given a *medium* in BCC. This is due to Kilo's usage of in-house developed software in combination with KISSsoft in order to calculate L10mh. Their software is closely intertwined which can both raise their capabilities due to less loss of data when moving between the software, but can also hinder them since it's harder to implement new software and make changes to the current fleet.

Kilo conducts bearing calculations on a daily basis which results in being considered *high* in FoU.

6.2.12 Lima

Lima is medium in RBC, low in BCC and low in FoU based on the analysis conducted below.

Fans are generally a somewhat simple application. However, the need for correct data to perform accurate rotor dynamic simulation put requirements on the calculations. Hence, RBC for Lima is considered *medium*.

Lima is considered *low* in BCC since most of the calculations for the bearings are outsourced to SKF and only simple L10h calculations are done in-house a few times a year.

Lima is *low* in FoU since they only conduct calculations a few time a year.

6.2.13 Summary of firm categorization

The 12 companies’ values for the three parameters are presented below in table 6.2.

Company	Requirements on Bearing Calculation	Bearing Calculation Complexity	Frequency of Calculations
Alpha	High	Low	Low
Bravo	Medium	Medium	Medium
Charlie	Medium	Medium	Medium
Delta	High	High	Medium
Echo	Medium	Medium	Medium
Foxtrot	Medium	Low	Medium
Golf	High	Medium	Medium
Hotel	High	Medium	Medium
India	High	Low	Low
Juliett	High	High	High
Kilo	High	Medium	High
Lima	Medium	Low	Low

Table 6.2. Presentation of the parameters for the 12 companies in the study.

6.3 Cluster identification

In this section, the above-analyzed companies in the three dimensions RBC, BCC and FoU will be plotted in three graphs in order to find and analyze possible clusters in the market. The three graphs will show the companies for the dimensions RBC and BCC, one for RBC and FoU and one for the final BCC and FoU.

6.3.1 Clusters regarding RBC and BCC

In this section, the clusters for the dimensions RBC and BCC will be identified and analyzed. Four clusters were identified, each with its own characteristics.

In figure 6.1, the 12 companies in the study have been plotted for the dimensions RBC and BCC in order to visualize their relative values. This plot shows the relationship between the complexity level of the tools used by the companies and how advanced calculation tools the companies need.

The companies have been divided into four clusters using Ward's method and are visualized with different colors in figure 6.1. The clusters will be named R&B after the first letter from the two dimensions RBC and BCC together with a number representing the order of which they are described in the report e.g. the first described cluster will be named R&B1 and the second R&B2 and so forth.

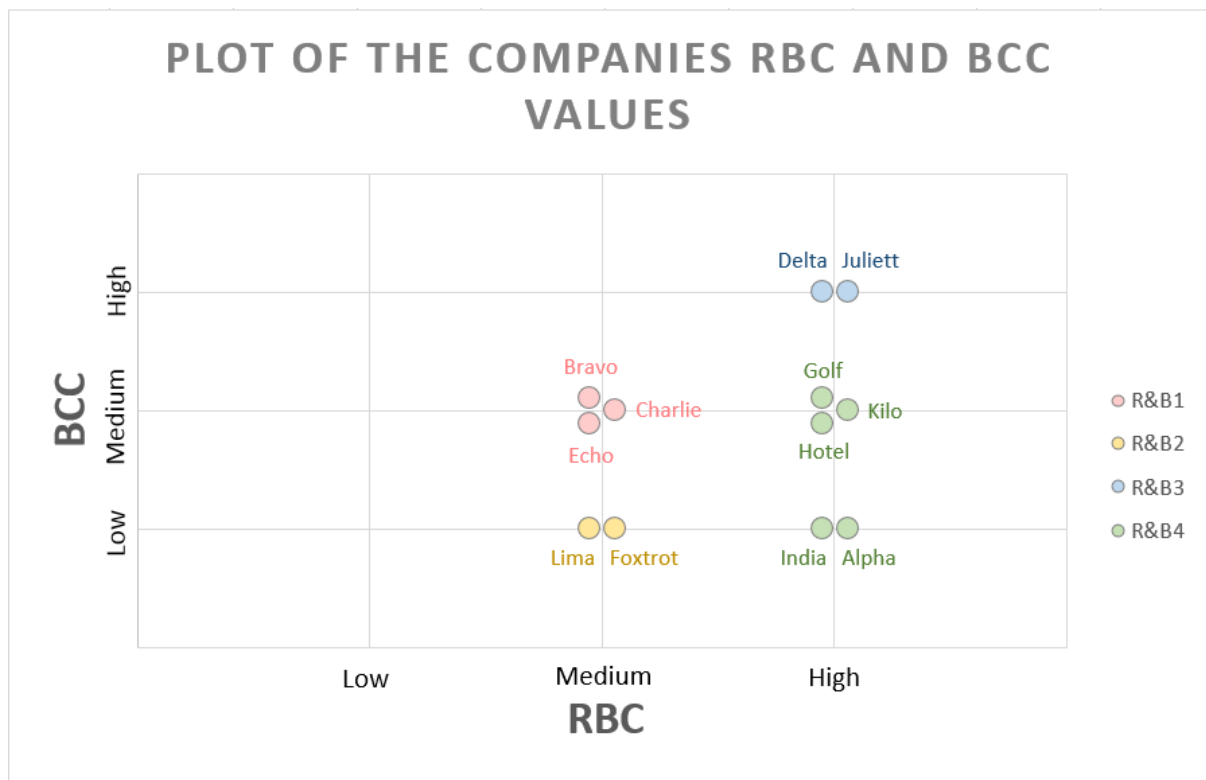


Figure 6.1. The relationship between RBC and BCC for the 12 companies. Companies with the same value have been slightly separated to give a better overview.

The first cluster R&B1 contains Bravo, Charlie, and Echo. This cluster is a medium, medium cluster having medium requirements on their calculations and performing semi-advanced calculations. In other words, they match their requirements with their capabilities well.

The second cluster R&B2 contains Foxtrot and Lima which is characterized by low requirements on their calculations but limited to basic calculations. This puts them in a situation where the application needs semi-advanced calculations but can only perform very rough calculations.

The third cluster R&B3 contains Delta and Juliett. This cluster has the most advanced software seen in the study and is also in need of complex software since the requirements on their applications are high and need to be accurate.

The fourth and final cluster for the RBC and BCC dimensions are R&B4 and contains Alpha, India, Golf, Hotel, and Kilo. This cluster is characterized by having high requirements on their product but are only able to perform very rough or medium advanced calculations. This puts them in a situation where they might perform too rough calculations or rely on external companies to perform their calculations.

6.3.2 Clusters regarding RBC and FoU

In this section, the clusters for the dimensions RBC and BCC will be identified and analyzed. Four clusters were identified, each with its own characteristics.

In figure 6.2. the 12 companies in the study have been plotted for the dimensions RBC and FoU in order to visualize their relative values. This plot shows the relationship between the requirement level the companies have on their bearing calculation tools and the frequency of use of them.

The companies have been divided into four clusters using Ward's method and are visualized with different colors in figure 6.2. The clusters will be named R&F after the first letter from the two dimensions RBC and FoU together with a number representing the order of which they are described in the report e.g. the first described cluster will be named R&F1 and the second R&F2 and so forth.

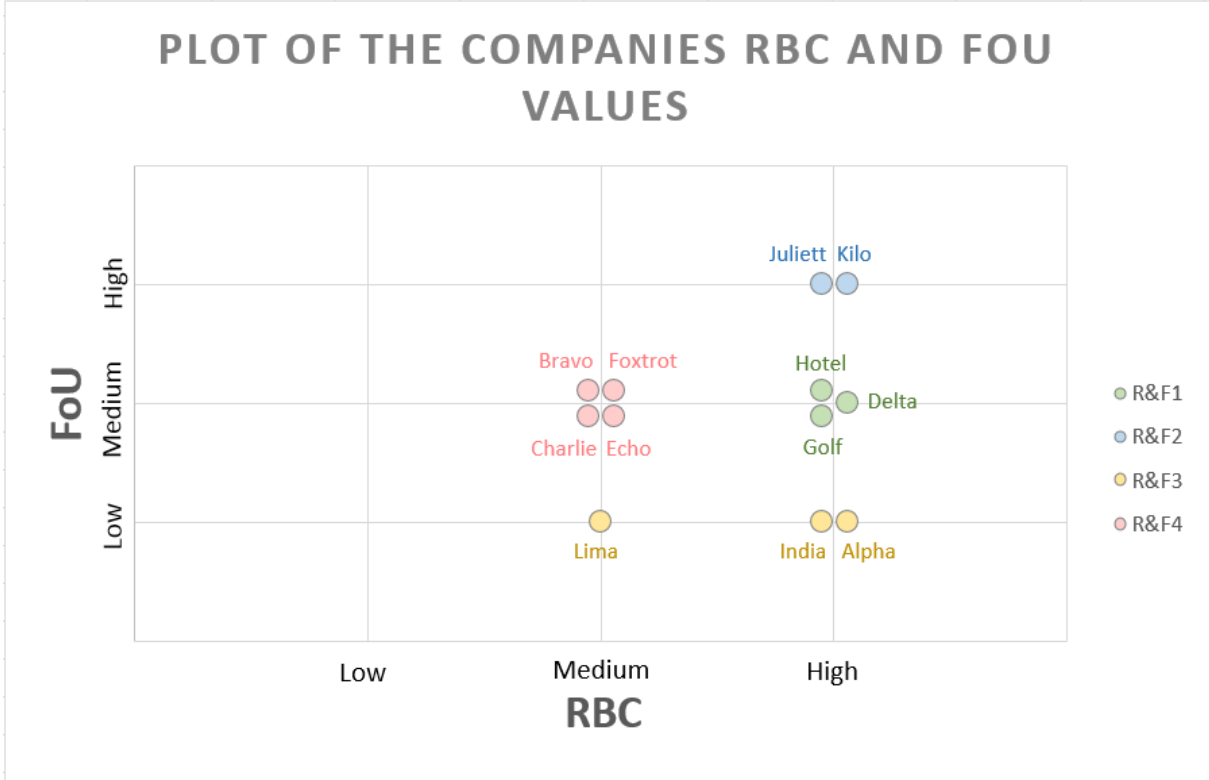


Figure 6.2. The relationship between RBC and FoU for the 12 companies. Companies with the same value have been separated in order to see them.

The first cluster R&F1 consisting of Delta, Hotel, and Golf. This cluster has high requirements on their calculations and performs them on a monthly to weekly basis.

The second cluster R&F2 is characterized by the companies performing calculations most frequently among the studies companies, which is on a daily basis. These companies, Juliett, and Kilo, share requirement level with R&F1 and hence have high requirement on their bearing calculations.

R&F3 contains the three companies which perform calculations least frequent among the companies in the study, namely Lima, Alpha and India. These companies conduct bearing calculations very seldom, only a few times a year or even less. Lima does not have as high requirements on their calculations as India and Alpha which have high requirements.

The final cluster R&F4 for the dimensions RBC and FoU is Foxtrot, Echo, Bravo and Charlie which all have medium requirements. The companies in the cluster are all conducting bearing calculations on medium level frequency wise meaning on a monthly to weekly basis.

6.3.3 Clusters regarding BCC and FoU

In this section, the clusters for the dimensions RBC and BCC will be identified and analyzed. Three clusters were identified, each with its own characteristics.

In figure 6.3. the 12 companies in the study have been plotted for the dimensions BCC and FoU in order to visualize their relative values. This plot shows the relationship between the complexity level of the tools used by the companies and the frequency of use of their bearing calculation tools.

The companies have been divided into three clusters using Ward's method and are visualized with different colors in figure 6.3. The clusters will be named B&F after the first letter from the two dimensions BCC and FoU together with a number representing the order of which they are described in the report e.g. the first described cluster will be named B&F1 and the second B&F2 and so forth.

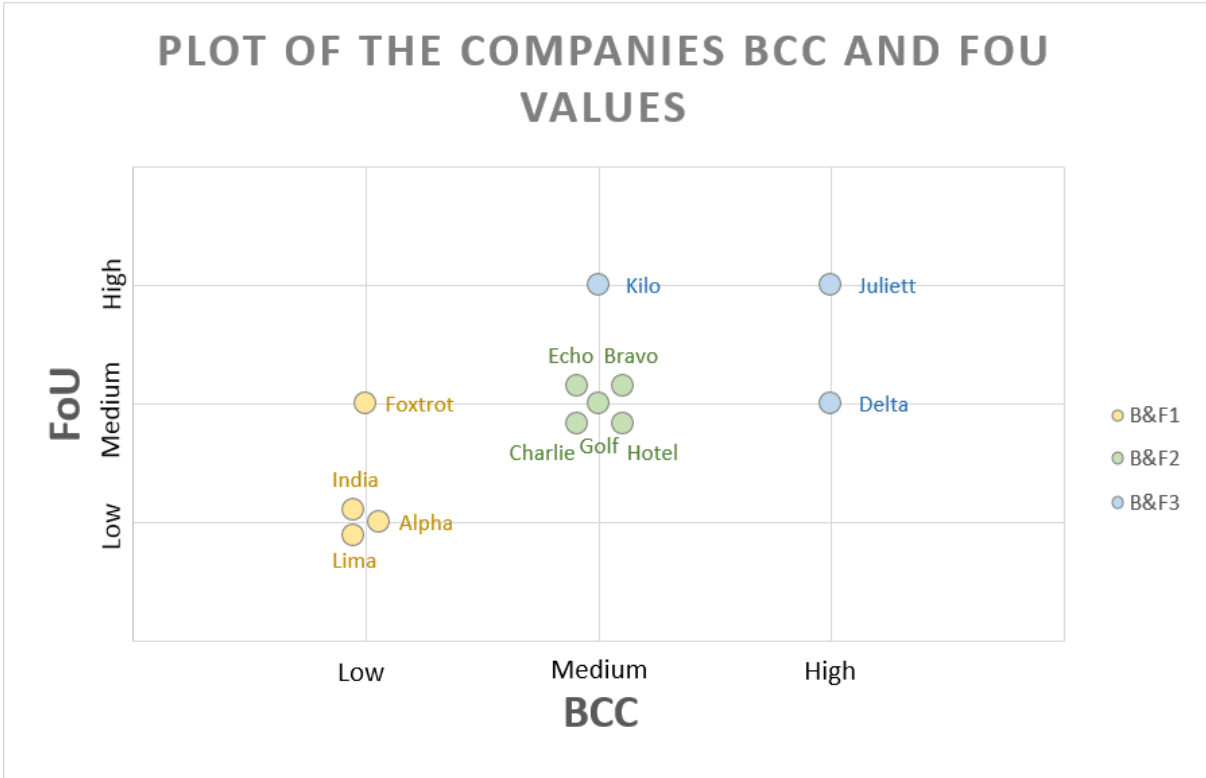


Figure 6.3. The relationship between BCC and FoU for the 12 companies. Companies with the same value have been separated in order to see them.

The first cluster B&F1 is made up by the companies that have the lowest bearing calculation capabilities namely Foxtrot, Alpha, India and Lima. All the companies in the cluster also perform calculations very seldom with Alpha, India and Lima only a few times a year or less and Foxtrot monthly or weekly.

The second cluster B&F2 which are the companies Charlie, Hotel, Bravo, Golf and Echo are all medium-medium companies in these dimensions. This means that they have medium capabilities when it comes to bearing calculation and that they are conducting calculations concerning bearings on a monthly or weekly basis.

B&F3 contains the companies Kilo, Juliatt and Delta. These companies are the extreme companies regarding bearing calculation capabilities and/or frequency of calculation. Kilo performs calculations on a daily basis and the ones conducted are seen as medium advanced. Delta, on the other hand, performs

its calculations on a medium level regarding frequency but the calculations conducted are seen as the most advanced in the study. Delta shares the title of being the company with the largest capability when it comes to bearing calculations with Juliett but with the difference that Juliett performs these advanced calculations on a daily basis.

6.4 Archetype classification

In this section, cluster data is combined with the individual companies' predictions about future engineering tool needs and usage. A number of archetypes emerge from the combined data, i.e. clusters in which the companies have the same or diverse opinion of where they are heading.

Intra-cluster predictions about the future are fairly homogenous, i.e. the companies with similar traits from the cluster analysis have similar predictions about future engineering tool usage. Although, some clusters show internal differences but are still small enough to be able to make generalizations. A short presentation of the clusters and the predictions follows.

6.4.1 Future direction of R&B clusters

The clusters described in chapter 6.3 for the RBC and BCC dimensions are shown in figure 6.4 together with the direction of their future needs based on the analysis in this section.

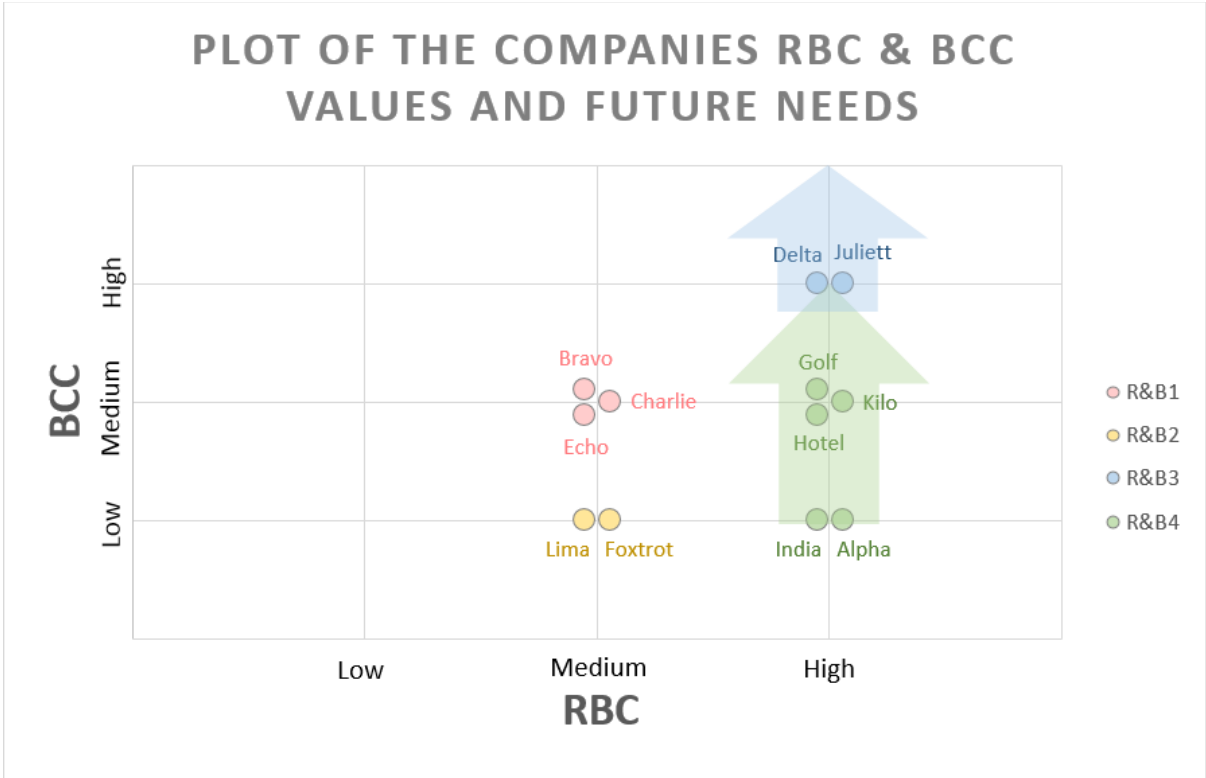


Figure 6.4. The future needs for the clusters in the RBC and BCC values figure. The direction of the future needs is visualized as an arrow with the same color as the clusters. Companies with the same value have been separated in order to see them.

The cluster R&B1 contains customers having medium requirements on their calculations and meet those requirements with having medium capabilities. The companies in this cluster want to increase the engineering tools user friendliness, but don't need to perform more advanced calculations. They also express a wish to merge current calculation software that today are incompatible in order to reduce the

inconvenience of doing work in several applications. A merged software could be either a separate version or an add-on compatible with common CAD software that would facilitate companies' usage or facilitate the communication with the companies' customers.

R&B2 is a cluster that has higher requirements for their bearing calculations than their capabilities, namely medium requirements and low capabilities. However, they don't believe they need perform any more advanced calculations for the bearings. The needs in this cluster are rather to either continue outsourcing the calculations or focus more on features that target their specific application in areas other than bearings.

The cluster R&B3 has high requirements on their calculations and is the cluster with the highest calculations capabilities for bearings in the study. For the future, they want to be able to perform more advanced calculations with the software they currently use, i.e. better use the software's potential. This is since there are needs in this cluster for the calculations to be done in-house instead of relying on external parties as well as to calculate the expected lifetime for the bearings more accurately in the context they will be used. The distributor in the cluster has specific needs such as a software covering the range from basic calculations to more advance as well as features that facilitate the communication with customers.

The cluster R&B4 is considered high in requirements but with low to medium capabilities for bearing calculations. This cluster wants to conduct more advanced calculations in-house and consider user friendliness very important. The capabilities in this cluster are lower than what is required of the companies regarding bearing calculations. The trend for more or less all the companies in this cluster is to move some of the outsourced calculations in-house. Almost all the companies in the cluster mention need regarding user friendliness such as compatibility with other software, ease of use in large and easy to understand user interface. All the companies have application specific needs that are not being satisfied with the software they use today. The calculations also need to become more advanced in order to fulfill their needs, and provide for simulation of real operating conditions.

6.4.2 Future direction of R&F clusters

The clusters described in chapter 6.3 for the RBC and FoU dimensions are shown in figure 6.5 together with the direction of their future needs based on the analysis in this section.

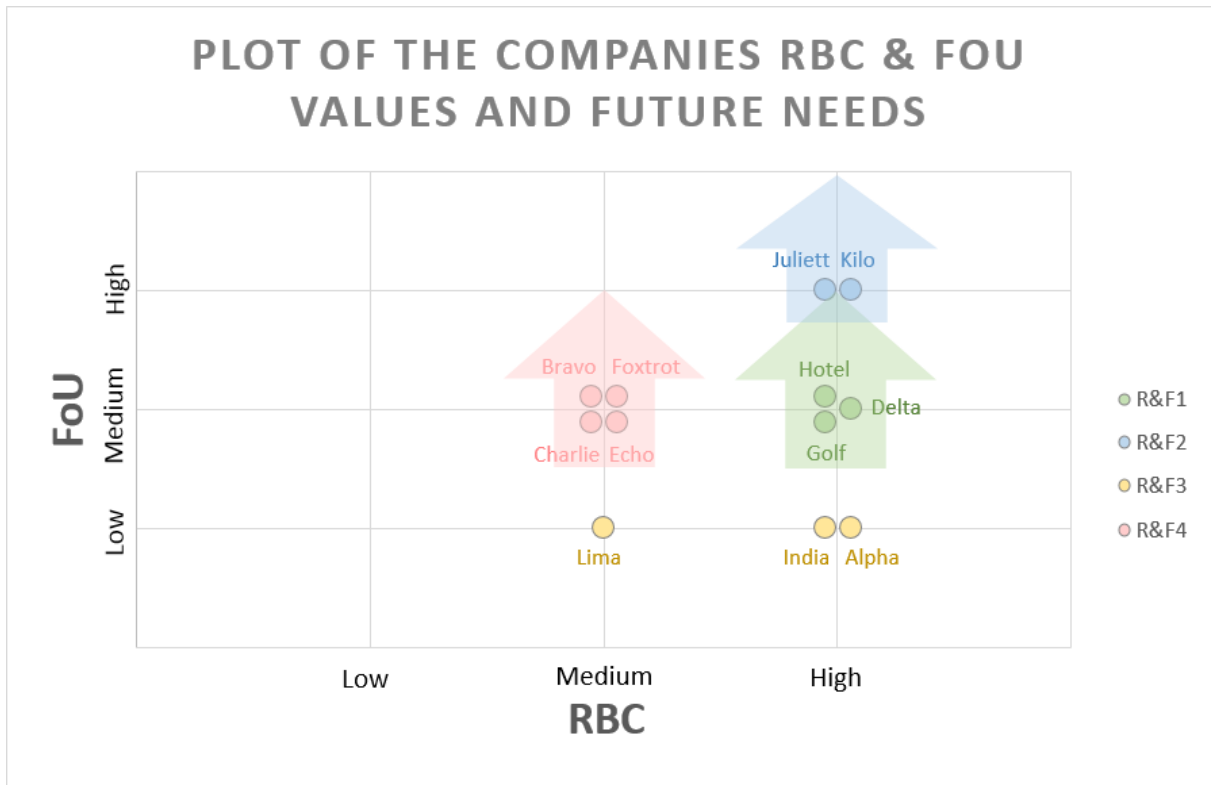


Figure 6.5. The future needs for the clusters in the RBC and FoU values figure. The direction of the future needs is visualized as an arrow with the same color as the clusters. Companies with the same value have been separated in order to see them.

The cluster R&F1 is made of companies with medium requirements on their calculations and are conducting calculations with medium frequency. These companies are believed to move towards more frequent use of their engineering tools concerning bearing calculations. They all state that they want to perform more calculations in-house in the future but that they are today limited by the capabilities of the software they use in terms of lack of fit for their application or having software that is not easy to use since they are not compatible with their other software.

R&F2 contains the companies that have the highest requirements on the calculations and also perform calculations most frequently. In the future, this cluster wants to perform calculations even more frequently than they do today. This will come from for example moving calculations in-house that was previously outsourced to the suppliers.

The characteristics of cluster R&F3 is that it consists of companies that have a low frequency of use when it comes to bearing calculations. Regarding the RBC dimension, these companies have both medium and high requirements on the calculations. The future needs of this cluster is a tendency to continue having the same low frequency they have today. The companies rely on SKF when it comes to calculations, guidance as well as expert advice and like to more or less stay that way. A slight increase of frequency for the calculations can be seen at some of the companies but these are only minor steps coming from taking over the more basic calculations from SKF and will most likely not affect the workload much.

The cluster R&F4 is considered medium when it comes to frequency of use for bearing calculations and they have medium requirements for their calculations. They are considered to increase their frequency of use in the future but on the premises that the tools become easier to use. A clear majority of the

companies in the cluster expresses needs regarding user friendliness and convenience regarding the tools. The cluster is very similar to R&F1 with the difference of having medium requirements instead of high for their calculations. It could be that R&F1 would increase the usage of the tools if they became more convenient to use and the same is considered for this cluster.

6.4.3 Future direction of B&F clusters

The clusters described in chapter 6.3 for the BCC and FoU dimensions are shown in figure 6.6 together with the direction of their future needs based on the analysis in this section.

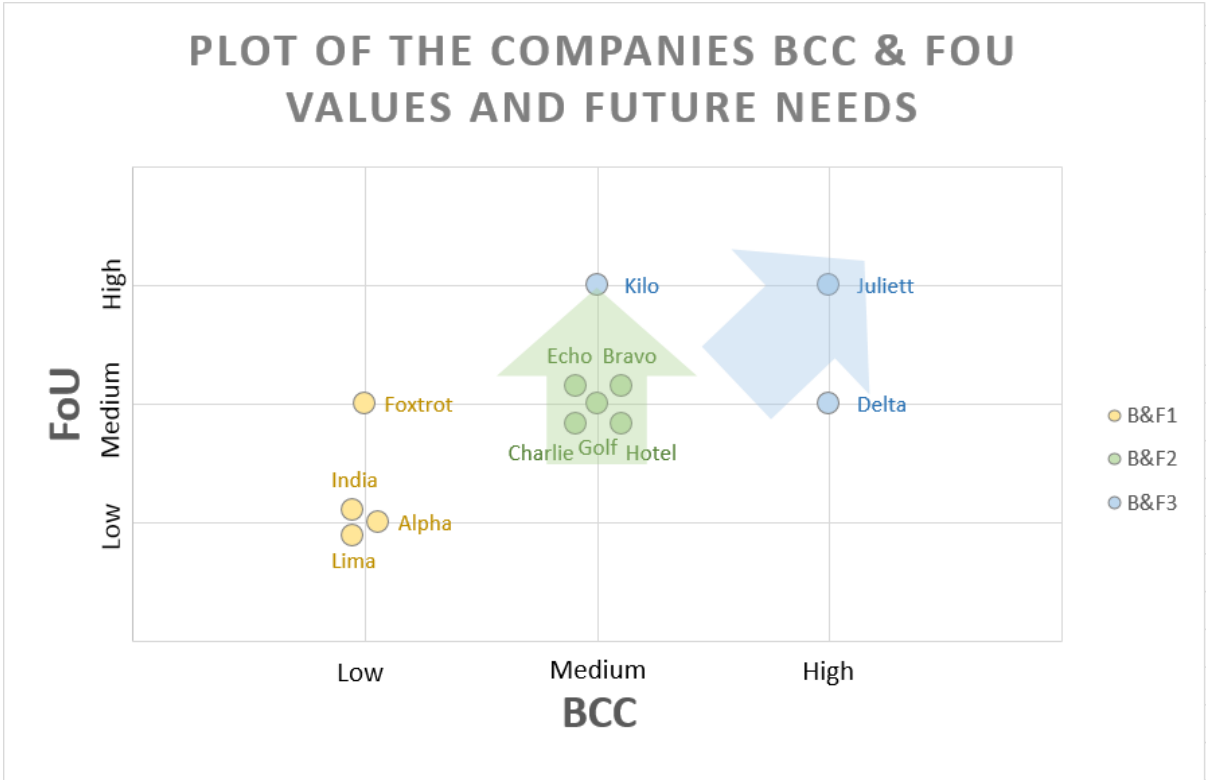


Figure 6.6. The future needs for the clusters in the BCC and FoU values figure. The direction of the future needs is visualized as an arrow with the same color as the clusters. Companies with the same value have been separated in order to see them.

The cluster B&F1 are characterized by having the lowest capabilities regarding bearing calculations in the study. The frequency of use of the engineering tools for these companies is low to medium. Regarding future needs, these companies seem to be pleased with where they are regarding BCC and FoU and do not want to increase the level of complexity for the calculations or increase the frequency of conducting calculations. The companies in the cluster outsource the advanced bearing calculations to the bearing suppliers and generally prefer to have it that way.

B&F2 is made of five companies with medium capabilities for bearing calculations and are considered medium in usage frequency. The cluster is considered to conduct calculations more frequently if the tools become more user-friendly and some of the companies in the cluster want more advanced tools but it's not a general trend. Almost all the companies in this cluster express needs regarding improved user friendliness. Features such as merged tools to one software as well as increased compatibility with other software are important for them. With these improvements in place, the companies will more likely use the tools which will lead to higher frequency of use. More advanced calculation tools are not needed

by as many as increased user friendliness in this cluster and hence can't be considered a common trait or that the cluster most likely will be moving towards that direction.

The companies in the cluster B&F3 are characterized by having most bearing calculation capabilities and/or highest frequency of use of these tools. Regarding needs for the future, the companies will perform more calculations than they do today and the general trend among these companies are to perform more advanced calculations. The majority of the companies in the cluster want to reduce the risk of having the calculations done externally and move the calculations in-house which will lead to more calculations to perform. The need for more advanced calculations seems to come from needing to perform calculations that take into consideration the application specific scenarios and the use of bearings in complex applications.

6.4.4 Cluster generalization and archetype formulation

From the eleven clusters it is possible to draw three general conclusions:

1. Companies with lower calculation capabilities and/or less frequent users are thought to stay that way.
2. Medium frequent engineering tool users at medium complexity levels are believed to increase the usage frequency if the user-friendliness is improved.
3. Companies with a high need for accurate calculations want to be able to meet those needs with increased in-house calculation and simulation capabilities and more frequent engineering tool usage.

The three generalizations give a representative overall view of the current situation among users of engineering tools for bearing calculation and simulation. Hence, three engineering tool user archetypes are condensed from the generalizations.

The first archetype is the *indifferent user*. The indifferent user has relatively low internal calculation capabilities and uses simple excel files or similar to perform fairly basic computations on sporadic occasions. Although, there is usually a need to perform more advanced calculations to improve the bearing selection, but this is compensated by high safety margins or outsourcing of the more advanced calculation work. The indifferent user is reluctant to make any major changes to the current engineering tool usage.

The second archetype is the *satisfied user*. The satisfied user is a relative frequent engineering tool user at a similar or higher complexity level as the indifferent user but aims for more accurate calculations. The satisfied user is more ambitious than the indifferent user and uses more advanced tools and methods. The satisfied user premieres high user friendliness over more complexity and seeks to get more user-friendly tools in the future with e.g. increased compatibility with other used software.

The third archetype is the *advanced user*. The advanced user develop products of high complexity that require precise bearing selections, and often requires the most advanced customer available bearing calculations and simulations software. The companies' know-how and engineering tool usage are already on an advanced level, or efforts are made to move the company in a direction towards more advanced and/or frequent use level. Although, the advanced user might have very application specific needs that could be hard to meet with a standardized software.

7. Discussion

In this chapter, empirical findings are analyzed together with literature from the literature study. The first part discuss the changing bearing industry and the market for engineering tools for bearing calculation and simulation, both from the perspective of the supply side and the demand side. Further, key takeaways from the empirical findings are discussed, as well as the cluster analysis and the generation of archetypes. Finally, strategies are discussed for market segmentation and value creation, and how this might affect the future direction of engineering tool development.

As first described in the background, the market for engineering tools for bearing calculation and simulation is changing in the light of increasing digitalization. The combined trends of increasing computational capabilities, digitalization and the need of more advanced calculation and simulation tools have affected the way bearings are selected. To understand how this have affected the bearing industry, this study has investigated a bearing manufacturer. The bearing industry is a mature industry where incremental improvements of bearing technology are the main focus for many bearing manufacturers (Grand View Research, 2015). The situation with a focus on incremental innovation is in line with previous contributions of how industries evolve over time (Utterback and Abernathy, 1978; Klepper, 1996). At the same time as bearings evolve with incremental innovation, the engineering tools used to make calculation and simulations in order to select the right bearings have gone through a rapid change. Only 20 years ago, paper catalogs were the dominant source of knowledge available for engineers designing applications with bearings. Since then, the computational capabilities have increased drastically and is available at a lower price (Moore, 1975). This has made knowledge of bearing technology previously only available to bearing manufacturers available to more people, at the same time as software needed to use this knowledge have become good and cheap enough to be used by individual industrial companies. Although, companies react to change at a different pace (Malerba, 2006), which is seen in differences in both supply and demand of engineering tools for bearing calculation.

On the supply side, there are several actors that offer bearing calculation and simulation software, both bearing manufacturers and various engineering and software companies. The bearing market is fairly consolidated and the world's top six bearing manufacturers together comprise 60% of the global market. All six bearing manufacturers offer engineering tools in various forms, with Schaeffler group being the leading force offering a substantial range of software covering basically all complexity needs. Some of the bearing manufacturers have partnerships with external engineering and software companies in order to offer engineering tools that cover a larger part of the product development process than just bearing calculation. As Cohen and Levinthal (1989) argue, companies need to combine internal and external innovation, which seem to be the case for bearing calculation tools since bearing manufacturers' efforts to improve bearing life and associated calculations needs to be combined with adequate software engineering.

Although, competition from engineering and software companies not specialized in bearing technology can challenge the bearing manufacturers. As the core knowledge of bearing technology become accessible to more actors the likelihood increase of a bigger change on the engineering tools market. When underlying knowledge becomes available to more actors it can be packaged in ways not thought of before and disrupt a market. This phenomenon is described as architectural innovation (Henderson and Clark, 1990; Christensen and Rosenbloom, 1995). Architectural innovation can be used to describe the rapid change in the engineering tools market since core knowledge in bearing technology and

software engineering have led to third party actors challenging established bearing manufacturers as the main source of knowledge used for bearing selection.

Several academics argue the demand side is the dominant force to affect innovation (Mowery and Rosenberg, 1979; Malerba, 2006). Hence, it is important to be perceptive to customer needs (von Hippel, 1988) and to have organizational values that allow for customer interaction (Prahalad and Hamel, 1994). As industries evolve the industry structure change and demand become more heterogeneous (Malerba, 2006), and some even say there is no homogeneous demand at all (Allenby et al, 1998). Apart from overall changes in an industry, demand heterogeneity also comes from information asymmetry, inertia, and habits (Malerba, 2006). As the empirical data analysis revealed, demand and need heterogeneity exist among users of engineering tools for bearing calculation and simulation, but also differences in the users' predicted future needs. Empirical findings were synthesized into key takeaways from which three parameters emerged as critical for engineering tools users' decision of what engineering tools to use. The three parameters (RBC, BCC, and FoU) give an overview of what needs exist for bearing calculation and simulation, but also to which extent advanced enough tools are currently being used. Applications in which bearings are used have characteristics that can help to determine how detailed calculations or simulations are needed. Although, empirical findings reveal vast differences between companies' fit between application complexity and engineering tool usage. A good fit would mean that as the requirements on precise bearing calculations increase, so should the engineering tools ability to perform precise bearing calculations. As the empirical data reveals, companies either have a good fit or use too simple tools. In no case were engineering tools used that could provide too advanced calculations. An explanation to this could be found in Adner and Levinthal's (2001) discussion of performance thresholds and net utility thresholds. The performance threshold is the minimum performance, e.g. calculation capability, which a product must have. If the price was the same for all tools independent of performance level, a rational user would choose a tool capable of advanced calculations. However, the performance threshold is linked with the net utility threshold, i.e. the willingness to pay to meet the performance threshold. Since increasing performance comes at a higher price, both monetary and knowledge wise, users do not choose a tool more advanced, i.e. costly, than necessary. As the empirical data show, the performance threshold sometimes differs as a result of different ability to exploit the tools performance due to variations in resources and capabilities. Some of the investigated companies have tried to use tools that better fit the applications general complexity but reversed to use simpler tool due to constraints in e.g. knowledge and time. Also, the presence of substitutes, e.g. a call to SKF, affects the decision of how complex tool to use.

The empirical data was also analyzed using the hierarchical cluster analysis method *Ward's method*, where the three parameters RBC, BCC, and FoU were analyzed two by two in order to identify clusters among the interviewed companies. Three or four clusters of companies with similar traits were identified in each of the three cluster analyses. Hence, in total eleven clusters were identified and analyzed. The next step in order to understand the future needs of the investigated companies is to see in which direction the clusters are predicted to move. Data from the cluster analysis combined with the individual companies' predictions of their future engineering tool needs and usage showed that differences in intra-cluster predictions about the future are low, but that inter-cluster differences exist. The analysis shows that the identified clusters have certain characteristics, and a few generalizations were drawn from the analysis of the clusters and the companies' predictions about the future. Three archetype engineering tool users emerged from these generalizations. The archetypes, the *indifferent user*, the *satisfied user*, and the *advanced user*, are good representations of three typical engineering tool users, and all three archetypes have different current and projected diverging future needs. This is in compliance with work done by several researchers (Malerba, 2006; Prahalad and Hamel, 1994; Slater, 1997) who argue that

markets become more fragmented and heterogeneous over time and that customers become increasingly demanding. This chapter will continue with a discussion of how to meet the archetypes' diverging needs.

The archetypes' characteristics and inter-heterogeneity show a need for a diverse range of engineering tools with different levels of complexity, i.e. several value offers. A market offer must bring value to the customers (Desarbo et al, 2001) and meet the customers' performance and net value threshold (Adner and Levinthal, 2001), but at the same time not cost the supplier more than the value it creates (Porter, 1985). Hence, it is most probable that the demands and needs of individual companies and cannot be met. Hence, the archetypes provide a good basis for further evaluation of the future direction of engineering tools and provide a likely foundation for a market segmentation. A segment's attractiveness is decided on an evaluation of e.g. size and structure, that decide what segments to target and hence if to develop a value proposition (Kotler, 2005). A short evaluation of the archetypes' adequateness as segments will follow.

The three archetypes have very different needs. The *indifferent user's* needs can be satisfied easily and to a low cost since the tools currently being used are very basic and advanced calculations are outsourced. Hence, a new bearing calculation tool for this archetype should allow for basic bearing calculations via a simple interface, and be compatible with external calculation providers' software, e.g. CAD software, for simplified communication. Due to the tools low complexity and cost, it is likely that such tools will be developed.

The *satisfied user* can also be satisfied to a low cost compared to the potential benefit. This archetype is believed to increase the usage of bearing calculation tools if the tools become more user-friendly, but will at the same time remain on the current complexity level. Hence, several of the today available tools that meet the required complexity level can be redesigned and merged with complementary tools in order to provide a more user-friendly experience. An engineering tool that meets these needs is likely to get a large market share since the users of these tools, in general, don't have strong preferences between software or bearing providers and, in combination with a low cost to develop, it is likely such tools will be developed and provided to the market.

The *advanced user* might be more difficult to please. The more advanced the user, the more specialized the engineering tools will probably have to be. An engineering tool designed to satisfy all needs this archetype have could risk being too complicated to use. Also, since the advanced user is keen to improve the company's internal bearing calculation and simulation competence the advanced users will always differ in needs. Hence, the advanced user archetype might not be a sufficient basis as a single segment, and a wider range of value offers should be considered for this archetype. A possible way to solve the diverging needs, the use of segmentation and a product line, will be presented in the following paragraph.

Kotler (2005) argue that market segmentation is necessary in a customer-driven marketing strategy in order to divide the market into feasible groups. The size of these segments might vary depending on firms' prerequisites, and span from an undifferentiated approach to micromarketing. Although, the archetypes in the engineering tool market point towards a *differentiated* marketing strategy, where one value proposition can be presented to each segment/archetype. This seems suitable for at least *the indifferent* and *the satisfied* archetypes, although it might not be suitable for *the advanced* user. Hence, the perhaps most convenient way to meet the heterogeneous needs and demands on inter-tool compatibility is to develop a product line. A product line consists of a range of customized value offers based on the same foundation which can be targeted towards different segments (Fruchter et al, 2006).

The engineering tools that today have the characteristics of a product line is Schaeffler's BearinX. A well-designed product line of engineering tools could result in a good tradeoff between the cost to provide multiple tools and the user's net utility. Although, the best way to supply the market with engineering tools is outside the scope of this study.

8. Conclusions

The following chapter contains conclusions drawn from the discussion and serve to answer the thesis' purpose. The chapter continues with practical implications and recommendations for further research.

During this study, the market for engineering tools for bearing calculation and simulation has been investigated and analyzed in order to fulfill the study's purpose. The purpose was to understand how changing user needs affect the requirements of new engineering tools. Two research questions were stated in the beginning of this thesis, both of which had to be answered to fulfill the purpose. The research questions were: (1) How are engineering tools for bearing calculations and simulations used today? (2) How do present and future needs affect the requirements of new engineering tools?

The research questions were answered through a case study in which representatives from twelve companies were interviewed to get an insight into the use of engineering tools for bearing calculation and simulation at respective company. The empirical findings reveal differences between companies' required bearing calculation level, bearing calculation capabilities, as well as the frequency of bearing calculation tool usage. A cluster analysis based on the empirical findings, together with the companies' predictions of engineering tool usage in the future, resulted in three engineering tool user archetypes: the *indifferent user*, the *satisfied user*, and the *advanced user*. The archetypes are representations of three typical engineering tool users, and all three archetypes have different current and projected future needs. The archetypes showed sign of diverging further from each other due to mainly demands differences regarding the degree of complexity in bearing calculations. In the light of findings from the cluster analysis and archetype generation, the second research question can be answered, and hence also the purpose of the study. The findings are in compliance with work done by several researchers who argue the markets become more fragmented and heterogeneous with time (Malerba, 2006; Prahalad and Hamel, 1994; Slater, 1997).

The practical implications from this study suggest a consumer-oriented approach when developing new value propositions. Companies, especially incumbent ones, need to be aware of changing customer demand and be responsive when demand differences lead to intra-segment conflicts. Hence, companies need to adopt strategies to avoid being overrun by more agile actors that are faster to react to changing customer preferences. One suggestion is to adopt Kotler's (2005) customer-driven marketing strategy in combination with von Hippel's (1988) lead-user strategy which can help companies be more successful in acquiring knowledge of customer needs and how to meet those needs in an efficient way.

A few areas of interest outside the scope of this study have been identified where further research can be suggested. First of all, as concluded in this study, customer needs diverge. Although, in this study, the signs of increasing heterogeneity is most common among the advanced engineering tool users. The advanced users' needs diverge because they become more specialized, while the least advanced customers' needs are more or less unchanged. Hence, it would be interesting if future research investigates the underlying reasons behind this phenomena. Also, further research could be conducted on the same topic but also look much deeper into past engineering tool usage. This might provide deeper insights of how differences in demand between companies have evolved and why companies have ended up with the tools the currently use.

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