Balancing product features in complex concept design

A case study at GKN Aerospace with focus on quality tools

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Abstract

Products today are getting more and more complex in design, which put higher demands on manufacturing as well as being able to make a solid business case. These requirements are conflicting by nature and therefore there often is no such thing as a final “perfect” design. This thesis aims to examine how quality tools can be used to improve the balancing act of product features in the concept design phase in order to find the best possible solution to the efficiency and complexity dilemma. The author divided the research into three different phases. First, the author performed a literature overview to identify methodologies and tools that are commonly used within new product development in order to build a literature framework. Next, the author conducted a case study at GKN examining how the organization works with balancing product features today. Finally, the author compared GKN’s use of quality tools when balancing features today with the literature framework in order to identify gaps and suggest possible improvements that can be made.

The case study included interviews, analyzing work material and observation. The author held nine semi-structured in-depth interviews with a variety of Engineers-in-charge, Manufacturing-leads and specialists within the three product areas: Commercial Aerospace, Space Propulsion and Military. After the case study the author led a workshop with a small group consisting of Engineers-in-charge, Manufacturing-leads and specialists, to validate the results and to further identify ideas on how to improve the balancing process.

The study showed that GKN uses tools for balancing product features most frequently in the concept study phase; thus, concept evaluation became the author’s main focus throughout the remainder of the study. Three alternative tools used for evaluating concepts were identified during the study. The author found handling the uncertainty within the tools to be one of the largest challenges when evaluating the concepts. In order to handle these challenges, improve how GKN works with evaluating concepts and thereby improve how the company balances product features, this study resulted in the following main recommendations.

GKN should...

...Continue to focus on platform development in order to base decisions regarding the concept evaluation on facts.

...Implement a maturity analysis. This analysis would be an easy way to gain more information when choosing the concept and would also help the company to take calculated risks within a project.

...Implement the tool used within Space Propulsion called Alternative 2 as the “standard way of working”. By using this tool, the project team will choose the concept that best suits what the customer wants in a structured manner, thereby creating a qualitative product.

...Discuss and document weighting keys for each criterion when conducting an evaluation in order to improve the valuation of the concepts and ease potential follow-up.

...Do further research on how fuzzy logic can be implemented within the evaluation tools to better handle the current crisp weighting scale 1, 3, 9.
Sammanfattning


Studien visade att verktyg för balansering av produkttegenskaper oftast används under utvärderingen av koncept i ”ta fram koncept“-fasen. Fokus på studien kom därför att ligga på utvärderingen av koncept. Studien identifierade tre olika alternativa verktyg som används för utvärdering av koncept. En av de största utmaningarna när koncept utvärderas är enligt intervjuerna att hantera den osäkerhet som finns inom verktygen. För att hantera de utmaningar som identifierats och förbättra hur GKN arbetar med att utvärdera koncept, därigenom förbättra hur de balanserar produkttegenskaper, ledde denna studie i följande rekommendationer.

GKN bör...

...Fortsätta **fokusera på plattformsutveckling** för att kunna basera beslut kring konceptutvärdering på fakta.

...**Genomföra en mognadsanalys** vid konceptutvärderingen för att på ett enkelt sätt få mer information kring konceptvalet, samt att det kan hjälpa att ta kalkylerade risker i projekten.

...Implementera det verktyg som används inom Space Propulsion, och kallas **Alternativ 2, på alla enheter**. Genom att använda detta verktyg kan projektgruppen på ett strukturerat sätt välja det koncept som är bäst anpassat till vad kunden vill ha, och därigenom skapa en kvalitativ produkt.

...Diskutera och dokumentera **viktnings nycklar för varje kriterium** när de utför en utvärdering, i syfte att förbättra värderingen av concepten samt underlätta uppföljning.

...**Undersöka vidare hur fuzzy logic kan implementeras** inom utvärderingsverktygen för att bättre hantera den nuvarande skarpa vägning 1, 3, 9.
Abbreviations

TRL – Technology Readiness Level
GDP – Global Development Process
DfR – Design for Robustness
OMS – Operational Management System
QFD – Quality Function Deployment
FMEA – Failure Mode and Effect Analysis
FMECA – Failure Mode Effect and Criticality Analysis
DoE – Design of Experiments
OEM – Original Equipment Manufacturer
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1. Introduction

This chapter introduces the reader to the thesis. A brief background and problem discussion lead to the aim and related questions to be answered in the study. The chapter also includes delimitations and further disposition of the thesis.

1.1. Background

Bergman & Klefsjö (2007, p.26) define the quality of a product to be its ability to satisfy, and hopefully exceed, the customer’s needs and expectations. These needs and expectations are often referred to as customer requirements. Another definition of quality, created by Philip Crosby, states that quality is “Conformance to requirements” (Crosby, p.2). Fung, Chen, & Tang (2007) claim that the quality of a product decides to what extent a product can satisfy customer needs and if it can be commercialized. In order to create quality by satisfying customer needs in product design, or conforming to the customer’s requirements, one needs to be able to translate the needs and requirements of the customers to specific design parameters in product development. Jared, Limage, Sherrin & Swift (1994) confirm this statement when they proclaim that decisions made in the early stages of product development have great impact on quality. These authors also claim that the product development phase not only defines the quality of a product but also greatly influences the product’s cost. It is commonly claimed that up to 70% of a product’s life-cycle cost is influenced by the chosen design (Dowlatshahi, 1992).

But how do you choose a design? Mital, Desai, Subramanian & Mital (2007, p.49) describe designing as “the application of technical and scientific principles to arrange components of a device”. Pye (1964, pp.77-79) states that no final design can be perfect since design requirements are conflicting by nature. He claims that the designer is responsible for compromising and determining the location and degree of “failures”, with consultation of the client, and thereby balancing conflicts, such as the conflicts between economy and durability, usability versus functionality and safety versus speed. Pye defines design as an art but also as a problem-solving activity, since the final design usually is the result of many compromises. The balancing of different product features usually occurs in the conceptual design phase. Fung, Chen & Tang (2007) describe the conceptual design phase as a phase where design objectives are identified, functional requirements are specified, and concepts are generated, evaluated and selected. Qui, Fok, Chen & Xu (2002) build on this description by emphasizing that within new product development, the conceptual design phase stands out as one of the most important phases. The authors’ assert this claim due to the fact that an unsuitable or wrongly balanced design concept can result in high redesign costs and delay in product realization.

In the aerospace industry, there are rigorous quality requirements in manufacturing parts, due to the fact that one manufacturing malfunction can cost many lives. The parts are usually very complex, focus on optimization of airflow, ensuring stiffness to support the engine thrust, reducing material strain, minimizing weight, and more all while still having a high focus on cost reduction. All of those design factors need to be balanced in the conceptual design phase while also including requirements from production processes.
1.2. Problem discussion
GKN Aerospace is an engineering company that consists of different departments, all which have different experiences, conditions and methods when working with product development. Initially the author focused on a problem dealing with a specific manufacturing defect on one of the current development programs within the organization. After discussions with the employees at GKN Aerospace however, the author realized that this specific problem was merely a part of a bigger issue: how GKN Aerospace balances product features in the concept design phase today.

GKN Aerospace designs very complex products, which create challenges. The divisions of the organization that work with Commercial Aerospace have little experience with design-to-make, where GKN Aerospace takes responsibility for the entire design and functionality of the product. These divisions’ previous work includes multiple projects in which they have improperly balanced the conceptual design. These imbalances have led to increased costs in the projects, delayed time plans and quality deficiencies.

1.3. Aim
The aim of this thesis is to use quality tools to improve the balancing act of product features in a complex concept design phase. These improvements will be created with the goal of assisting GKN Aerospace in meeting and exceeding customer expectations, and thus creating quality. Focus will be on understanding how GKN Aerospace currently balances product features in the concept design phase, and on how the company can improve the methods and tools it uses, with a specific focus on quality tools.

1.4. Research Questions
Three research questions have been formulated based on the aim of the research.

RQ1: How can GKN’s current work with balancing product features within the concept design phase be characterized?

RQ2: How can quality tools be used to balance product features in a technologically complex concept design phase?

RQ3: How can GKN use quality tools within the conceptual design phase in order to improve the balancing of product features?

The first research question concerns the situation at GKN today, the second concerns the literature on the studied area and lastly the third research question concern how GKN can work in the future. The relation between the research questions is illustrated in Figure 1.
1.5. Delimitations
In order to narrow down the research certain delimitations have been made:

- The main focus of this thesis has been on the departments that are developing new hardware and therefore have to account for producibility when balancing product features. This makes it a more complex situation and the use of balancing tools is more common.
- Focus of the study was on the concept design phase of major new projects, since the company most commonly uses the tools in this phase.
- The thesis relates to only GKN Aerospace in Trollhättan since all interviews were conducted at that location.

1.6. Disposition
Further disposition of the thesis:

2. Method describes how the thesis was conducted in terms of research purpose, strategy, approach, data collection, sample selection, data analysis, reliability and validity.

3. Theoretical frame of reference presents the theory within the scope of the thesis used to answer RQ 2 and to compare towards the findings from the case study.

4. GKN Aerospace presents the findings from the case study performed at GKN Aerospace in Trollhättan.

5. Analyze summarizes the data from the thesis. This section focuses on comparing the findings from the case study to the findings from the theoretical frame of reference. This comparison will illustrate the current situation and what important factors should be considered when improving the company’s ability to balance product features in concept development.

6. Results and recommendations summarize the results of the study and gives recommendations on how the company can improve their work with balancing product features in concept development.
7. **Conclusion and discussion** will evaluate the methodology used to conduct this research. It will then reflect on the result, whether the research has answered the research questions and purpose of the thesis. This is followed by a discussion regarding validity and reliability of the thesis and general conclusions on a Meta level. Finally, this section provides recommendations for further studies.
2. Method

This chapter describes the research methodology used for this study. It begins with summarizing the choices made regarding methodology and methods for this study and continues by describing and motivating the choices made.

When conducting research it is important to work in a systematic manner in order to create reliable answers to your research questions, as well to assist others in understanding the logic and result of your work (Ghauri & Gronhaug, 2005, p.3; Holme & Solvang, 1991, p.11). Conscious choices of methodology and methods create this systematic manner (Ejvegård, 2003, p.31). Saunders, Lewis & Thornhill (2009, p.3) define research methodology as a description of how research should be undertaken; further, they define research methods as the techniques and procedures used to collect and analyze data. Table 1 (shown below) documents the methodology and methods chosen for this study.

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Methodology</th>
<th>Thesis Methodology/Method</th>
</tr>
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<td>2.2</td>
<td>Research approach</td>
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<td>2.6</td>
<td>Sample selection</td>
<td>Non probability sampling, Judgmental sampling</td>
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<td>2.7</td>
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<tr>
<td>2.8</td>
<td>Reliability and validity</td>
<td>Workshop, reviews, documentation</td>
</tr>
</tbody>
</table>

2.1. Research purpose

According to Saunders et al. (2009, p.139) research consists of either an exploratory, descriptive or explanatory purpose of the study, or a combination of these. Research questions and how they will be answered determine the decision of research purpose.

A researcher uses an exploratory purpose when the research questions aim to gain further information and understanding of the selected topic. The researcher usually formulates these questions in an open manner, which leads to the exploratory purpose being very flexible and adaptable to change. This flexibility is an advantage as it gives the researcher the opportunity to start with a wide focus, which he/she can narrow down later in the process. (Saunders et al. 2009, pp.139-140)

Saunders et al. (2009, p.140) continues to explain the descriptive purpose, which the researcher uses when he/she needs to obtain a correct view of a situation, event or person. Saunders states that the descriptive research purpose can be used as a pre study or an extension to exploratory research; however it is more often used as a part of explanatory research. Ghauri & Gronhaug (2005, p.58) explain that when using descriptive research, a researcher needs to have a clear picture of the stated
problem area and a clear idea of how best to structure the research, in order to obtain the right information.

Saunders et al. (2009, p.140) describe the third and final research purpose, explanatory purpose, as a research study designed to establish causal relationships between variables. Ghauri & Gronhaug (2005, p.59) define it simply as “casual research” and research confronted with cause-and-effect problems: the main task of which being to isolate the causes and then attempt to conclude the extent these causes an effect.

This thesis utilizes both an exploratory and a descriptive purpose with the intention of gaining more insight into how a technologically advanced company balances product features in conceptual design of complex products.

### 2.2. Research approach

According to Saunders et al. (2009, pp.125-127) a research study can be based on two different approaches, or a combination of the two. One common first step of a project is to design a theory-based research strategy. A researcher then tests this theory within the study, and the results of this test either confirm the existing theory or give input on relevant deviations. This approach is called a deductive approach. Saunders describes another approach in which the study begins with collecting data in order to explore a topic. From that data, new theory is generated. This approach is called an inductive approach.

The authors further state that there is no rigid division between the two approaches; on the contrary they state that researchers have the possibility to combine the two approaches within the same study. Moreover, according to their experience, researchers often find a combination of the approaches to be advantageous. Olsson & Sörensen (2007, pp.32-33) define this combination as an abductive approach, where the researcher conducts continuous loops between using a deductive approach and an inductive approach.

The approach of this study can best be described as being abductive. It begins with research designed to gain an understanding of the company, which leads to the formulation of an initial hypothesis. This hypothesis then leads to an initial literature overview, which guides the author to begin the case study. During the case study, the author continuously analyzes the gathered material and includes new literature in their findings. This analysis then leads to the author uncovering more in-depth questions about the company, which are further inspected and send back to the analysis phase. Hence, the author relies heavily on a clear cycle of continuous looping from an inductive to a deductive research approach throughout the study.

### 2.3. Research strategy

Saunders et al. (2009, p.141) define a research strategy as a plan for how the study will answer the stated research questions. The authors further define the most important aspect of choosing a research strategy as the ability to enable a reasonable level of consistency in the research, onto which the research questions can be answered and the objectives can be met. The objectives of the study and the research questions therefore influence the development of the strategy; however, pre-
existing knowledge and the amount of time and other resources needed to conduct the study take a part in shaping the strategy as well.

Yin (2009, p.8) mentions five different strategies that can be chosen when conducting research; these are displayed in Table 2. In the same table there are three conditions that according to Yin can help guide the researcher when choosing the strategy of the study.

Table 2 Relevant situations for different research strategies. Source: (Yin, 2009, p.8)

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Form of Research Question</th>
<th>Requires Control of Behavioral Events?</th>
<th>Focuses on Contemporary Events?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment</td>
<td>How, why?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Survey</td>
<td>Who, what, where, how many, how much?</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Archival Analysis</td>
<td>Who, what, where, how many, how much?</td>
<td>No</td>
<td>Yes/No</td>
</tr>
<tr>
<td>History</td>
<td>How, why?</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Case Study</td>
<td>How, why?</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The first condition examines how the research questions are formulated; the second condition focuses on whether or not the research is considered to require control of behavioral events; lastly, the third column takes into account whether or not the research will focus on contemporary events. Yin (2009, pp.7-8) further states that each strategy can be used for exploratory, descriptive and explanatory research purposes, however some might be a better match than others. Saunders et al. (2009, p.141) build on this statement by noting that none of the strategies should be thought of as being mutually exclusive, and gives the example that a survey study could be well suited as a part of a case study.

When formulating the research questions for this thesis, the author focused primarily on the “How” and on contemporary events, without total control of behavioral events. Further, in constructing the thesis, the author tried to understand a contemporary phenomenon in debt within its real-life context, making the author’s research an example of the definition of a case study provided by Yin (2009, p.18).

A case study explores a research topic within its context or a number of real-life contexts, and normally involves data collection methods such as interviews, observations, questionnaires and document analysis. When choosing data sources, a researcher in a case study must consider triangulation, meaning that he/she must establish validity of the data by using different data collection techniques. (Saunders et al., 2009, p.146)

According to Saunders et al. (2009, pp.146-147) a case study can be described in four different strategies based upon two discrete dimensions, single versus multiple cases and holistic versus embedded cases. Researchers often use a single case study when the research focuses on a unique or extreme situation/case. When using a multiple case study, the researcher usually aims to discover whether the findings of the first case can be connected to any other case. In a holistic case study the researcher only focuses on one unit, e.g. analyzing an entire organization. The opposite, an embedded case, occurs when the researcher studies several units, e.g. several departments within the organization.
This research focuses on the entire organization and can therefore be described as a holistic case study. In order to reach generalizability the author would have preferred to have conducted a multiple case study, however this type of study would have proven challenging to complete within the given timeframe.

### 2.4. Data collection

When conducting research, researchers use two types of data, primary and secondary data. Primary data is new data collected for the purpose of the particular study. Secondary data is data that already has been collected for some other previous purpose but can still be used in the new study. In order to answer the research questions and to meet the set objectives, a combination of primary and secondary data is often required. (Saunders et al., 2009, p.256)

#### 2.4.1. Primary data

The author used interviews and observations to collect primary data for this study.

**Interviews**

Saunders et al. (2009, p.318) define a research interview as a purposeful conversation between an interviewer and a respondent, or multiple respondents. Saunders et al. further describe an interview as a way to collect valid and reliable data that relates to the purpose of the study. The authors also define three types of interviews: structured, semi-structured and unstructured.

A structured interview, based on a predetermined and identical set of questions, is also called a questionnaire. In this type of interview, the interviewer reads the interview questions in the same order, with the exact, predetermined words, and in the same tone of voice for each and every person interviewed. During the interview, the interviewer notes the answers on a standardized schedule, often with pre-coded answers, in order to avoid bias. A structured interview produces what is known as quantitative data. (Saunders et al., 2009, p.320)

In a semi-structured interview, the interviewer prepares a list of themes and key questions that are used during the interview. The specific questions and their order can vary from interview to interview, depending on the flow of the conversation and the situation. Interviewers use audio recording as a preferable means to save the data, as well as some note taking. The result from a semi-structured interview can be defined as qualitative data. (Saunders et al., 2009, pp.320-321)

An unstructured interview is informal. An interviewer uses this type of interview to explore an area of interest in more depth. In this particular kind of interview, the interviewer uses no predetermined questions, as all questions are based on exploration of the area by the interviewer. Like the results of semi-structured interviews, the results from an unstructured interview can also be defined as qualitative data. (Saunders et al., 2009, p.321)

**Observations**

Saunders et al. (2009, p.288) describe observation as the systematic observation, description, recording, interpretation and analysis of people’s behavior. They further define two different types of observation as participant and structured observation. The authors describe participant observation as a qualitative method of observation designed to describe what meaning people
attach to their actions; they further describe structured observation as a quantitative method concerned with studying the frequency of people’s actions.

2.4.2. Secondary data
Researchers most frequently use secondary data within business and management research as a part of a case study or survey research strategy. By definition, secondary data is data that has been collected for another purpose but can be employed as an efficient source of information when answering research questions. Many different types of secondary data sources exist and the number of secondary data sources continues to increase. Examples of secondary data can be notices, reports to shareholders, texts from the web and administrative and public records as well as non-text material such as pictures, videos, drawings, web pages and DVDs. Furthermore, secondary data can be used in triangulation, a process that involves finding two or more separate, yet conforming, sources which enhance the credibility of the collected data. (Saunders et al. 2009, pp.256-258)

2.4.3. Chosen data collection methods
For the explorative research in the study, the author used semi-structured interviews in order to get answers to specific questions yet leave room for other questions that would increase the understanding of the topic. The author also collected primary data through participant observation, where the author attended specific meetings and watched every day work in the company. In order to create credibility, the author used secondary data in the form of documents, which helped triangulate the data.

2.5. Qualitative and quantitative method
When conducting research, data collection and data analysis are key aspects. Saunders et al. (2009, p.182) and Ghauri & Gronhaug (2005, pp.109-110) describe two different methods for handling these aspects effectively; they define these methods as qualitative and quantitative. According to the authors, the difference in these methods lies not in the quality of the results, but rather in how a researcher conducts the research. The authors further state that a quantitative method uses statistical methods, or other procedures of quantification, in order to gain data. A qualitative method on the other hand, uses interviews and observation to collect data. According to the authors the qualitative method gives a more holistic perspective and is more process oriented, whilst the quantitative method is more particularistic, analytical and result oriented. Moreover, these two methods need not be separated: Holme & Solvang (1991, p.85) state that qualitative and quantitative elements can be advantageously combined in a research study.

In this study a qualitative method has been used when gathering information. In order to obtain a holistic view of the process, the author ensured that the majority of the data collected consisted of semi-structured interviews combined with participant observations. The author used no quantitative data due to the fact that the abductive process changed the scope of the study during the interview process.

2.6. Sample selection
A researcher uses the collection of data from a sample in cases where collecting data from the entire population is impossible and/or resources such as money and time are limited (Saunders et al., 2009,
Method


According to Saunders et al. (2009, pp.212-213) probability sampling is often associated with experiment and survey research strategies where everyone within the population has an equal chance to be selected for the sample, e.g. answering a survey. On the other hand, a researcher is unable to draw any statistical inferences when using non-probability sampling due to the fact each sample unit has an unknown non-zero chance of being included in the sample (Ghauri & Gronhaug, 2005, p.146). According to Saunders et al. (2009, pp.212-233) researchers have the ability to generalize from non-probability samples in order to reach conclusions, but not on statistical grounds. Ghauri & Gronhaug (2005, p.146) describe two different examples of non-probability samples: convenience sample and judgment samples. The authors describe convenience sampling as a method in which the researcher simply selects units that are convenient for some reason. Judgment sampling, the authors continue, is a technique in which the researcher must use his/her own judgment in order to obtain a representative sample of the population.

Due to the need of specific knowledge and information, as well as the need to save resources and time, the author used a non-probability sampling selection throughout this entire study. The author also used a judgment sampling method when selecting people to take part in the study in an effort to create a sample of people from different business areas working with concept development. This method assisted in validating the study due to the fact the selected individuals worked independently of one another prior to this study.

2.7. Data analysis

The author summarized the data collected during the case study in the form of semi-structured interviews, participant observations and documents into a description of the current situation. The author then compared this situation to recent theoretical research within the field in order to analyze similarities and deviations. The author utilized this method with the hope that the findings would be able to provide guidance to the company on how to improve its process.

2.8. Reliability and validity

To assess the quality of a study, a researcher must reflect over the reliability and validity of the study’s methods and findings. Saunders et al. (2009, p.326) mention that both characteristics are needed to ensure the desired quality of the research.

2.8.1. Reliability

Saunders et al. (2009, p.156) state that a reliable study is one that will produce similar findings if it was to be repeated by someone else or at another time. They further argue that in order to achieve high reliability, a researcher must minimize bias and errors of participants and researchers when conducting research, i.e. conducting an interview study. The authors also mention the importance of using detailed documentation, which can help future researchers repeat the given procedure with ease, and produce findings consistent with those of the original researcher.

To increase the reliability of this study and to better show exactly how the work was completed, the author carefully documented its process and presented it in detail in chapter 2.9. Since much of the
needed information is classified, the author had to omit certain items from the thesis. If a reader desires to see the omitted information, he/she can issue a special request to GKN, which has access to the extra information. Where possible, the author re-coded the information in the study with different names and numbers in order to preserve the general facts on a meta level. Things that the author documented for example are the different versions of the interview guide, the thesis process, evaluation templates etc.

2.8.2. Validity

McNeill & Chapman (2005, p.131) describe validity as an inspection as to whether or not the collected data relate to what is being studied. As they further show when describing differences between data collected in the real world and data collected in a laboratory, the authors evince the importance of collecting valid data that can be used in the study. Saunders et al. (2009, p.158, pp.372-373) divide validity into several categories, all of which are outlined below:

- **Construct validity** consists of ensuring that the research measurements are measuring what is intended to be measured.
- **Internal validity** is concerned with the demonstration of a causal relationship between two variables within the study.
- **External validity** describes the generalizability of the study and how applicable the findings are to other related settings or groups.

Merriam & Simpson (1995) give a wider perspective on internal validity when they describe that it evaluates how well the results coincide with reality. They further describe different approaches on how to handle internal validity in a qualitative study, where focus is on understanding the accuracy of the measurement. The five approaches they describe are:

- Triangulation – Using multiple sources when collecting data.
- Participant control – the collected data is confirmed by the participants of the study.
- Collecting data under a longer time period – creates a deeper understanding of the problem area within the study.
- Validation of an equal – have the material continuously validated during the study by an equal.
- Impact of researcher - define what assumptions made by the researcher.

To increase this study’s construct validity, supervisors and other stakeholders within the company has reviewed the study within reasonable intervals so as to catch and erase potential errors. The author strengthened the internal validity of the study by using all five of the approaches described by Merriam & Simpson. First the author used multiple sources of information from interviews, documents and observations in the study. Secondly the data have been presented by the author to the interviewees and put under scrutiny during a validation workshop and via email. He further collected the data during a long period of time which has helped to obtain a deeper understanding of the company's problems. The authors work has also been evaluated by an equal, in this case a fellow student also writing his master thesis, and finally he has defined his assumptions in the delimitations and within the discussion at the end of the thesis. The author enforced the external validity by comparing the research findings to the theory displayed in the theoretical frame of reference, which he used to draw conclusions on a meta level.
2.9. Thesis process
The methodological process of this thesis is presented in Figure 2. The author first conducted an initial problem identification, which lead to an initial literature study. He then defined the methodology of the study in order to maximize the output of the research. Further the author conducted several abductive loops where focus switched between empiric research and literature studies, while continuously conducting analysis. The author then conducted a final analysis by comparing the current situation to theory found during the literature study. The final analysis was then validated through a workshop held by the author. Lastly he presented the results and recommendations followed by documenting the conclusion and discussion, which summarize the thesis and leave suggestions for further studies.

Figure 2 Process chart illustrating the thesis process
3. Theoretical frame of reference

This chapter presents an overview of the theory that was gathered during the process and used to analyze and compare to the findings of the case study in order to answer the research questions.

In order to conduct a gap analysis based on the data gathered and answer the research questions, the author started with describing specific theoretical areas important to the analysis. Figure 3 presents an overview of these theoretical areas, and shows how the author used these to answer the research questions within this study. As mentioned in chapter 2.2, this thesis was conducted with an abductive approach, meaning the author alternated between gathering information from empirical studies and theoretical research. This chapter is a summary of all theory gathered by the author that was used in analyzing the findings within the case study. This chapter begins with presenting the importance of design for quality and then describes the traditional product development process before moving on to the more modern way of thinking, called Concurrent Engineering. This chapter then describes certain areas in more detail and discusses the use of Platforms, Robust design, and different quality tools used within the area. Finally, this chapter briefly presents a theory called Fuzzy Logic, which is a theoretical field applied frequently on recent research of the quality tools discussed in this chapter.

The author chose the theoretical frame of reference within design for quality since it was repeatedly mentioned in the initial interviews as an interesting subject within GKN in terms of understanding how to balance product features in the concept design phase. The author chose the quality tools described in the theoretical frame of reference after a literature overview where he identified the most commonly used quality tools and also through analysis of the evaluation tools used at GKN.

For this literature overview the author has used a search engine called PRIMO as the primary source of information, which is the academic search engine on the Luleå University Library website that browses through an extensive amount of databases throughout the world. The following literary terms have been used by the author, separately and in different combinations, for searches within PRIMO: Product development, Concept evaluation, Concept design, Concurrent engineering, Product platforms, QFD, Quality Function Deployment, Pugh matrix, Matrix diagram, FMEA, Robust design, Evaluation matrix, and Complex products.

Many of the combinations resulted in extensive amounts of hits especially within product development, QFD, Robust Design, etc. Areas where the author struggled to find articles were how the different quality tools are used specifically on complex products and in concept evaluation. Hopefully this study can help to further build that knowledgebase.
3.1. Design for quality

Quality was in the beginning of the 1970’s perceived as conformance to requirements, according to Pullan, Bhasi, & Madhu (2010). They continue to describe how that first changed into quality being perceived as to meet customer requirements, and now has evolved even further into how a product/process can meet and exceed the customer’s expectations and create superior value. Fung, Chen, and Tang (2007) define quality of a product to be the deciding factor to what extent a product can satisfy customer needs and if it can be commercialized. In this study, the author chose to use the definition made by Bergman and Klefsjö (2007, p.26) who define the quality of a product to be its ability to satisfy, and hopefully exceed, the customer’s needs and expectations.

Bergman & Klefsjö (2007, p.113) state that in order for an organization to reach long term success, they need to focus not only on satisfying their current customers but also to create opportunities to satisfy future customers. They further claim that the focus on product development has increased, especially in a quality perspective, emphasizing the importance of design for quality. Pullan et al. (2010) describe the overall objectives of design for quality to be:
Theoretical frame of reference

a) Design a product that meets the spoken and unspoken customer requirements.
b) Design a robust product that focuses on managing or minimizing the effect of variation in both production and usage of the product.
c) Design a product by continuously improving its performance, reliability and technology in order to exceed the customer expectations and offer superior value.

Bergman & Klefsjö (2007, pp.114-116) claim that by working systematically, creatively, and with great precision in the product development process, you can create an environment that thrives for high quality at a low cost. They further describe how both Concurrent Engineering and working with Platforms are methods that can be applied to reach that goal, and as Pullan et al. (2010), together with Bergman & Klefsjö (2007, p.226), describe it is also important to focus on designing a robust product. These three methods will be described further below, but first there will be a small introduction on traditional product development and how that has evolved into Concurrent Engineering.

3.2. Traditional product development

According to Pullan et al. (2010), decisions in product design have traditionally been taken in a serial pattern, as visualized in Figure 4. They describe that the design process usually started with the selection of a product design from a number of feasible designs, generated primarily with focus on marketing objectives and engineering constraints. The next step was according to the authors to develop an appropriate manufacturing plan for the chosen design, which was done by the production planning function and was guided primarily by operational objectives (e.g. cost minimization, load balancing, capacity utilization, etc.). The decisions made regarding product design and production plan then finally became constraints for the logistics function that determined the supply sources.

![Figure 4 An example of a sequential design process (Pullan, Bhasi, & Madhu, 2010)](image)

The traditional sequential design pattern is however, according to Gunasekaran, Goyal, Virtanen, & Yli-Oli (1994), described to suffer from two major deficiencies. They describe the serial pattern approach to be slow due to the fact that parallel processing opportunities often are missed. The other problem being that each stage in the process tries to make sequential local optimal choices which leads to sub-optimal solutions. Concurrent engineering is by Pullan et al. (2010) described as a paradigm that aims to eliminate those problems.

3.3. Concurrent Engineering

When working with Concurrent Engineering, it is, according to Pullan et al. (2010), important to have cross-functional input early in the product design phase (see Figure 5), especially regarding
production considerations. They further stress the importance of product and process decisions being made simultaneously when possible.

Figure 5 An example of a concurrent design process (Pullan et al., 2010)

A downside of Concurrent Engineering, described by Wu & O’Grady (1999), is however that it complicates the design process and makes it more complex, as more constraints needs to be balanced. However with the customers placing more emphasis on quality and reliability while simultaneously looking for good value and short time to market, it is essential according to Pullan et al. (2010) to work with Concurrent Engineering. They describe Concurrent Engineering as a management philosophy with the purpose of improving customer satisfaction through faster product development, improved quality, reduced costs and time to market. There are many studies that support this. Pullan et al. (2010) claims that Rolls-Royce reduced their lead time by 30% when developing a new aircraft engine. Another example they describe is from Boeing’s Ballistic System Division. They managed the following improvements (Pullan et al., 2010):

a) 16%-46% in cost reduction in manufacturing.
b) Engineering changes reduced from 15-20 to 1-2 drafts per drawing.
c) Materials shortage reduced from 12% to 1%.
d) Inspection costs cut by a factor of 3.

Pullan et al. (2010) further state that Concurrent Engineering will have the greatest benefits and impact within the design stage of product development. They refer to a study made of 2000 components at Rolls Royce, where it was revealed that design determined 80% of the final production cost for these products. The problem they claim is that once this cost is locked in, usually when the design is set, it is very difficult for manufacturing to remove it, as can be seen in Figure 6.
Theoretical frame of reference

![Diagram of product cost lifecycle](image)

**Figure 6** Product cost displayed on a products lifecycle (Pullan et al., 2010)

### 3.4. Platforms

Bergman & Klefsjö (2007, p.115) claim that in order to save money within product development, the use of a platform strategy can be applied, meaning that the organization is able to use a common base for many different product types. Robertsson & Ulrich (1998) define a platform as the collection of assets that are shared by a set of products. They further describe that these assets can be divided into four different sub-categories, which are components, processes, knowledge and people and relationships.

- **Components**: the different parts that make up the product
- **Processes**: how the components are produced and the associated production processes.
- **Knowledge**: know-how within design, technology limitations and applications.
- **People and relationships**: team relations within the group, with internal stakeholders, and external suppliers.

These together make up the product platform. They continue to describe the potential benefits that can come from using successful platform planning:

- Greater ability to create product solutions to different market segments and customers.
- Development time and costs can be reduced.
- Manufacturing costs can be reduced.
- Production investments can be reduced.
- Support functions costs can be reduced.
- Risk can be lowered.
- Services can be improved.

Most of the research conducted within platforms concerns the use of components as building blocks, where the blocks have a fixed design and different products can be assembled using different blocks. More modern research within platforms is now focusing more on reusable knowledge; see for example Levandowski et al. (2012) and Högman (2011).
3.5. Robust Design

According to Bergman & Klefsjö (2007, p.208), all products are exposed to different types of variation during their lifecycle and therefore it is of great importance for designers and product developers to try and use their own, and the experience of others to determine tradeoffs, considering such variations. Bergman, de Maré, Lorén, & Svensson (2009, p. 39) describe their view on robust design methodology by discussing four different areas:

1. **Awareness of variation** – Products are affected not only by factors that can be controlled, but also by factors that are uncontrollable or hard to control, commonly referred to as noise factors. These factors often cause the desired and/or specified level of a certain characteristic to deviate, causing problems with robustness. Prior to 2009, research in variation reduction has mainly been focused on method development, rather than increasing and emphasizing the awareness of variation.

2. **Create insensitivity to noise factors** – Noise factors are often by nature impossible or expensive to eliminate or control, which makes it an unappealing approach when trying to achieve robustness. The goal with robust design methodology is instead to make the product insensitive to noise factors.

3. **A methodology** – Robust design does not in itself prescribe the use of certain methods in predetermined steps. Not to be interpreted as though one can create a robust product in any way, but rather that one needs to focus on the awareness and the insensitivity of noise factors. Within robust design methodology a number of different tools can be used such as FMEA and Design of Experiments.

4. **Entire development process** – It is necessary to apply robust design methodology throughout the entire development process, from concept generation to the production of the product, in order to identify all categories of noise factors and thereby all possibilities for robustness improvements.

The authors then summarize these four areas within robust design methodology in the following definition:

“Robust Design Methodology means systematic efforts to achieve insensitivity to noise factors. These efforts are founded on an awareness of variation and can be applied in all stages of product design”

3.6. Definition of quality tools within design

There are many different tools defined within quality. In this theoretical framework, the most relevant ones in terms of designing for quality will be presented. In the book “Quality from customer needs to customer satisfaction”, Bergman & Klefsjö (2007) describe many tools that can be applied to this definition: the Pugh matrix, Matrix diagram, FMEA, QFD, and Design of Experiments are a few of the tools mentioned. Thia, Chai, Bauly, & Xin confirm that these tools are used within product development in their exploratory study of the use of quality tools and techniques in product development, done in 2005. These tools will now be described more in detail with focus on functionality and perceived benefits from using them in product development.
3.7. Matrix diagram

Matrix diagrams are one of the seven management tools mentioned by Tari & Sabater (2004) in their summary of quality tools used for quality improvement. Another reference describing this tool are Klefsjö, Eliasson, Kennerfalk, Lundbäck, & Sandström (1999, p.68), who further claim that matrixes are commonly used when working with verbal information in order to identify and evaluate correlation and dependence between factors, and thereby prioritize and chose the most relevant alternative. They continue describing different types of matrixes, with the most simple and commonly used being the L-matrix. The L-matrix consists of one horizontal and one vertical axis, together forming a grid (see Figure 7). Other matrixes the authors mention include the T, Y and X-matrixes, where the letter represents the layout of the grid.

![Figure 7 an example Matrix diagram, used to describe correlation between the different alternatives in Factor 1 & 2.](image)

The correlations between the different alternatives for the different factors are then evaluated within the project team. This can be done with using the following grading scheme (Klefsjö et al., 1999, p.73):

- 0 – No connection
- 1 – Weak connection
- 3 – Moderate connection
- 9 – Strong connection

If there is a negative correlation there is also a possibility to put a minus in front of the number. It is also common to use symbols when showing correlation, however Klefsjö et al. (1999, p.74) suggest the use of numbers since you don’t have to translate the symbols to numeric values if you want to summarize a column or a row. They do however point out that using numbers has been criticized since it can be perceived as “truths” when they are merely estimated values. They also bring forth that there are other grading schemes used such as 3, 2, 1, 0.

3.8. Quality Function Deployment

Further development of the matrix diagram is the so-called “house of quality” which is used in Quality Function Deployment (QFD) (Klefsjö et al., 1999, p.68). Bergman & Klefsjö (2007, p.133) define QFD as a way to structure and systematize the product development process. They further describe that QFD originates from Japan in the late 1960’s and was developed in order to find a structured method for achieving quality by design.

QFD has by many companies shown to be an efficient method when trying to translate the voice of the customer into product development and thereby, in a structured way, making sure to meet and exceed the customer requirements (Andersson, 1991, pp.1-3). QFD was, according to Chan & Wu
Theoretical frame of reference

(2002), originally used to develop products with better quality in order to meet or exceed the customer’s needs. They describe that the primary function of QFD thus has been within product development, quality management, and customer needs analysis. However, through their literature overview based on a reference bank of around 650 QFD publications, they have found that the functions of QFD have expanded to wider fields such as design, decision-making, planning, management, engineering, teamwork, timing, and pricing. They claim that there is essentially no definite boundary for the QFDs potential field of application.

3.8.1. The QFD process
According to Bouchereau & Rowlands (2000) QFD is a visual and well-structured process that helps the teams to focus on what the customer wants during the entire development life cycle of a product or a process. They further describe the basics of the complete QFD process to include four phases:

1. Product planning (House of Quality)
2. Product design (Parts deployment)
3. Process planning
4. Process control (Quality control charts)

Each phase is represented by an individual matrix (Figure 8), which according to Bouchereau & Rowlands (2000) give input to each other in a sequential order. It starts with the customer requirements, which generates the most important characteristics. These characteristics will then be used as input in phase two and so on.

![Figure 8 The four phases of QFD (Bouchereau & Rowlands, 2000)](image)

The different matrixes or “houses” can be designed in many different ways, but Bouchereau & Rowlands (2000) describe the first “House of Quality” according to Figure 9. They claim that the matrix helps the team to set targets on issues that are important to the customer and how the team will be able to achieve those targets technically. In Figure 10, there is an example of a House of Quality, based on a paper-roll manufacturing process. For more details on how the QFD is set up and alternations of the method, see for example Bergman & Klefsjö (2007, pp. 133-144).
Theoretical frame of reference

**Figure 9** House of quality (Bouchereau & Rowlands, 2000)

**Figure 10** House of Quality from a paper-roll manufacturing process, (Bouchereau & Rowlands, 2000)
3.8.2. Drawbacks with QFD
Although there are four phases in the complete process of QFD, Cauchick Miguel (2005) state that the method is seldom applied to its full capability and that in most cases, only the first matrix is used. He further claims that companies with a robust development process tend to use QFD more simplistically. He argues that this limits the potential benefits from a full scale QFD, but on the other hand, simplifies the use of the tool, this because companies often see the method as too complex and heavy (Bruce Han, Chen, Ebrahimpour, & Sodhi, 2001; Schmidt, 1997; Bouchereau & Rowlands, 2000; Cauchick Miguel, 2005).

Bouchereau & Rowlands (2000) describe another drawback being “Strength of relationship is ill-defined”. Schmidt (1997) further builds on that since he claims that there is often a problem with determining the weights, and thereby level of importance, of the design characteristics. This due to the different scales and weighting schemes that measure the relationship between the design characteristics and the customer needs.

3.9. Pugh matrix
The Pugh’s concept selection method is, according to Wang (2002), a systematic approach to determine the “best” concepts and can also help a group to quickly form a consensus on major issues. Wang (2002) describe the five steps included in the method:

1. **Set up the concept selection matrix** (see Figure 11): Place the concepts on the top of the matrix and the chosen selection criteria on the left-hand side of the matrix. Then, choose one concept to use as a reference concept (usually the reference concept is an obvious solution to the problem or some sort of industry standard.)
2. **Concept rating:** The original rating scale being “better than (+)”, “same as (0)” or “worse than (-)” the reference concept on the specified criteria.
3. **Concept ranking:** Summarize the total ratings.
4. **Select concept/concepts:** Select concepts for further development.
5. **Further concept improvement:** Develop new concepts by combining and improving the concepts with good design features.
3.10. FMEA
Fail Mode and Effect Analysis (FMEA) is a commonly used tool when conducting reliability analysis, according to (Bergman & Klefsjö, 2007, p.170). They claim that FMEA often is used to do a qualitative analysis of the relationships between the components failure modes and corresponding consequences, in order to take preventive actions to stop or reduce the effect of the problem/problems. Further, they describe how FMEA advantageously can be used in different areas when developing a product or service. Often, it is used to study the failure modes on a system level, but it also is commonly used in the planning and definition phase of a project. A more thorough analysis can be very beneficial during the design phase, called a construction-FMEA, and also when conducting a production preparation, a process-FMEA can be very useful in order to identify potential risks.

Bergman & Klefsjö (2007, p.170) also describe a further development of the model called FMECA (Failure Mode, Effect and Criticality Analysis) with the purpose of using a quantitative and numerical analysis in order to be able to rank the different Failure Modes. They claim that there are multiple methods to conduct this numeric evaluation; however, they give one example where you conduct an evaluation by grading the failure probability, severity/criticality, and the detection probability. The sum product of these numbers is then calculated to gain a "risk priority number". For more information about FMEA see for example Bergman & Klefsjö (2007, p.170).

3.11. Design of Experiments
Design of Experiments is a method used to understand how different parameters affect products and processes and what values they should have, in order to make the best possible product or process at a minimum cost (Bergman & Klefsjö, 2007, p.181). Montgomery (1997, p.1) claims that experiments play an important role in new product design, manufacturing process development, and process improvement. He further describes how experimental design methods can play a major role in engineering design activities, and lists a number of applications (Montgomery, 1997, p.8):
1. Evaluation and comparison of basic design configurations.
2. Evaluation of material alternatives.
3. Selection of design parameters so that the product will work well under a wide variety of field conditions, that is, so that the product is robust.
4. Determination of key product design parameters that impact product performance.

The results, according to Montgomery, from applying Design of Experiments within these applications can lower product cost, enhance product field performance and reliability, shorten product design and development time, and help design products that are easier to manufacture.

**3.11.1. Factorial designs**

Factorial design is a method associated with Design of Experiments. Montgomery (1997, p.228) states that a factorial design is the most efficient method when it is vital to study the joint effects of several factors. The most commonly used factorial design according to the author, is the $2^k$ factorial design with the $k$ representing the number of factors and “2” the number of levels; High (+) and Low (−). In Figure 12, you can see a geometric view of a $2^3$ factorial design, where the factors A, B and C are used. Figure 13 is the design matrix for the experiment where you can see how each run is being done within the experiment, i.e. the first run would be to see what result the experiment would get when all three factors (A, B and C) were set to “Low”.

![Figure 12 2^3 factorial design geometric view (Montgomery, 1997) p.302](image)
Theoretical frame of reference

<table>
<thead>
<tr>
<th>Run</th>
<th>A</th>
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<th>C</th>
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<td>(1)</td>
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Figure 13 $2^3$ factorial design matrix (Montgomery, 1997) p.302

The different runs will all have a result on the chosen output variable for the experiment, resulting in a ranking of the different combinations. Through the analysis, it will also be able to calculate which factors that have the biggest effects, which means that they have the greatest effect on the output variable (Montgomery, 1997, p.306). This is an extremely basic view of Design of Experiments, but since this is not the main focus of this thesis, interested readers can find more detailed information in Douglas C. Montgomery’s book “Design and analysis of experiments”.

### 3.12. Fuzzy logic

One thing that Matrix diagrams, QFD, Pugh matrix and FMECA have in common is that they all use some form of valuation in their model. This valuation is often based on subjective judgment or limited/uncertain information. When searching for recently published articles regarding the tools mentioned earlier, the author found many titles regarding Fuzzy logic, which is a model for imprecise concepts such as height, age, and weight (Berthold, 2005). As an example, there is usually not a fixed line between who is tall and who is short, young or old or fat or thin. If someone turns 30, does that mean he automatically becomes old? Or does he just become a little less young?

Bouchereau & Rowlands (2000) suggest, in unity with Schmidt (1997), that the use of fuzzy logic can be very beneficial when trying to reduce the uncertainty of data collected. They claim that fuzzy logic in a formal way can model vagueness in relationships and/or data, by manipulating fuzzy qualitative data in terms of linguistic variables. Bouchereau & Rowlands (2000) further list useful features of using fuzzy logic:

- It uses human linguistic understanding to express knowledge of the system.
- It allows decision making with estimated values under incomplete or uncertain information.
- It is suitable for uncertain or approximate reasoning.
- Interpretation of its rules is simple and easy to understand.
- It deals with multi-input, multi-output systems.

#### 3.12.1. Fuzzy logic basics

Berthold (2005) gives a lecture on fuzzy logic where he starts off with explaining crisp sets. In a crisp set, the element $x$ is either in the set or it is not. It can be described in mathematical terms by the following characteristic, according to Berthold:
Theoretical frame of reference

\[ m_A(x) := \begin{cases} 
1 & x \in A \\
0 & x \notin A 
\end{cases} \quad m_A(x) \in \{0,1\} \]

He further describes this by giving an example. In Figure 14, it can be seen that the value of \( x \) can belong to \( A \), if \( x \) is between or equal to \( a \) or \( b \). As you can see, it is either within the set or it is not.

\[ A = \{x|a \leq x \leq b\} \]

A fuzzy set on the other hand lacks these predefined boundaries between which objects that are, or are not, members of the set (Jia & Bai, 2011) and (Berthold, 2005). Jia & Bai (2011) describe the key concept of fuzzy logic to be the definition of “membership”, and understanding to what degree or value an element is a member of a set. They continue to describe that the degree or value always stays within the range of 0 to 1. Those numbers represents the maximum and the minimum degree of membership and all values in-between indicate the degree of “partial” membership. Berthold (2005) gives an example of this in his lecture as seen in Figure 15.

![Figure 14 Example of a crisp set (Berthold, 2005)](image)

- **Age**: young, old
  
  ![Figure 15 Examples of fuzzy sets (Berthold, 2005)](image)

- **Size**: small, medium, tall
3.12.2. Fuzzy logic in quality tools

When the author searched for recent research concerning the quality tools mentioned in the theoretical frame of reference, there were many articles concerning the use of Fuzzy logic within the tools; FMECA (Lee, Kim, Cha, & Kim, 2010), Pugh matrix (Lu, 2008), Matrix diagram and QFD (Bouchereau & Rowlands, 2000) (Schmidt, 1997). They all described similar benefits in all the articles, and one example regarding fuzzy logic in quality tools will be presented focusing on QFD.

Bouchereau & Rowlands (2000) describe many benefits from integrating fuzzy logic within QFD. They claim that the Voice of the customer (Room 1 in Figure 9) usually comes in a qualitative form, but that their performance measures and other associated data should if possible be described quantitatively in order to ease further analysis in the next phases of the QFD. They highlight the difficulty of setting up the relationship matrix (Room 4 in Figure 9) because of all the decisions that have to be made on subjective judgment. The weighting scheme in the QFD’s relationship matrix traditionally uses crisp values according to Schmidt (1997), and often neglects the high amount of uncertainty that the group has to face. He describes one possible solution to improve this situation would be by implementing fuzzy logic within QFD.
This chapter presents the findings from the case study. It starts by giving a brief description of the company regarding organization, internal processes within product development and the internal view on platforms and robust design. Emphasis is placed on the concept study phase, and in particular on the different tools used when evaluating concepts and the challenges with balancing product features.

The data collected for this case study originated from interviews, analyzed documents and observations. The author conducted nine semi-structured interviews within Commercial Aerospace, Space Propulsion and Military. All interviews lasted for about an hour and were based on a questionnaire found in appendix A. The author used this questionnaire as support and many follow-up questions and sidetrack questions were asked in order to get information on the current situation. The documents analyzed by the author were mainly Concept Books, a document describing all evaluated concepts, and Concept evaluation matrixes in Excel. To achieve triangulation of the data the author obtained information by observing current work meetings at GKN Aerospace mapping the “Concept study” process in OMS (Operational Management System), as well as informal conversations with employees.

4.1. GKN

GKN is a global engineering group with four different divisions, Driveline, Powder Metallurgy, Aerospace and Land Systems, illustrated in Figure 16. During the fall of 2012 GKN bought Volvo Aero, from the Volvo Group, to further expand their aerospace division. GKN Aerospace has major sites in Trollhättan (Sweden), Kongsberg (Norway) and Newington (USA), and it employs approximately 12000 people in total in more than 35 facilities across 4 continents (www.gkn.com, 2013).

![GKN Dividends](gkn_dividends.png)

Figure 16 The four divisions at GKN plc. (courtesy of GKN Aerospace)

GKN Aerospace Engine Systems employs around 3000 people and has a turnover of 5.75 billion SEK. They develop and manufacture components for commercial and military aircraft engines, aero derivative gas turbines (lighter weight variations of gas turbines) and rocket engine turbines and exhaust nozzles. With experience since 1966 they also offer commercial engine overhaul services within tailored maintenance solutions, on-site services, around-the-clock technical support, leasing/exchanging engines and repairing services for engine parts. These four departments are illustrated in Figure 17. (Internal GKN aerospace presentation, 2013)
Throughout the remainder of this thesis, unless stated otherwise, when referring to GKN, the author refers to GKN Aerospace in Trollhättan.

### 4.1.1. Organization

Out of the aforementioned four departments, three produce physical products: Commercial Aerospace, Space Propulsion and Military. All new product development within Military is however within software development, which differs from Commercial Aerospace and Space Propulsion. After GKN acquired Volvo Aero, a new organization was launched and a major revision regarding the project organization was conducted. The exact layout of the new project organization has been hard for the author to identify, since GKN has not published the corresponding directions yet. The roles in Table 3 have been identified during the interviews, so they might be a mix from the old and the new project organization.

**Table 3 Roles within the project organization**

<table>
<thead>
<tr>
<th>Role</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chief engineer</td>
<td>Responsible for a development program or product in production. Acts as project manager</td>
</tr>
<tr>
<td>Engineer-in-charge</td>
<td>Responsible for the construction/design aspects in a project.</td>
</tr>
<tr>
<td>Manufacturing-lead</td>
<td>Responsible for the producibility aspects in a project.</td>
</tr>
<tr>
<td>Validation-lead</td>
<td>Responsible for the validation aspects in a project.</td>
</tr>
<tr>
<td>Configuration-lead</td>
<td>Responsible for the configuration aspects in a project.</td>
</tr>
<tr>
<td>Business-lead</td>
<td>Responsible for the internal business case</td>
</tr>
</tbody>
</table>

When working with development projects and existing products, GKN has applied a new matrix organization. Each development program and current program has one Chief Engineer that is the head of the program, as well as multiple resources from Engineering Operations, such as Engineer-in-charge, Manufacturing-lead etc. Each of the employees involved reports to both his/her respective line manager and program manager. Figure 18 illustrates an outline of the management structure.
Each development program, or program within production also has a Program Control Board, sometimes referred to as the Steering Group. Representatives from purchasing, quality, production, technology and marketing all sit on the board, as can be seen in Figure 19.

The purpose of the Program Control Board is to monitor and optimize GKN’s financial interests and if needed prepare material for renegotiations with the customer. The group controls the activities that ensure that all new or changed requirements or demands from the customer are being addressed.

### 4.1.2. Product development

Each department at GKN has different levels of history and experience within product development. Space propulsion has been responsible for the entire process from designing the product to making the product since the eighties, and Military even longer than that. This process is called “design to make responsibility”. Commercial Aerospace, on the other hand, has until quite recently mainly worked as a “make to print” department, meaning it received a blueprint of a product and manufactured that product without design responsibility. In 2006 Commercial Aerospace made its
GKN Aerospace

first product with a design to make responsibility when delivering parts to General Electric’s engine called GEnx.

GKN works with a product development process called Global Development Process, originally developed by the Volvo Group. It is a stage gate process, which GKN has further developed to suit its needs. The process is divided into six phases, each of which is intended to indicate a certain focus area in the project work. The phases start and end at various gates. The phases are Pre-study, Concept Study, Detailed Development, Final Verification, Industrialization & Commercialization and Follow-up, all which are illustrated in Figure 20.

Figure 20 Global Development Process (Volvo Group 2012)

The general consensus among the interviewees was that GKN has had a history of focusing primarily on the design of the product and putting manufacturing and other functions aside. One Engineer in charge states that products have often been “design driven”, meaning that the design has been set and that the other factors, i.e. producibility, are then adjusted to fit the design, often resulting in high production cost and long lead-times. This is an area where GKN has greatly improved in recent years; yet according to a few interviewees, the company still battles with a design-first culture. However, the general consensus is that the lessons learned from prior projects have put more effort on Concurrent Engineering. Team members from different functions now sit close together during the projects, the company involves more functions from earlier in the process, and new tools with more focus on producibility and the business case, are used when evaluating concepts.

4.1.3. Platforms
GKN started working with platforms in 2009 and currently work with Chalmers University of Technology to conduct research regarding platform development (Levandowski et al., 2012) and (Högman, 2011). They divide the term platform into three different areas; Product platform, Production platform and Technology platform, as illustrated in Figure 21. According to a former Engineer-in-charge they are still working on fully implementing the idea of working with platforms within product development in all three areas.
According to another Engineer-in-charge from Commercial Aerospace, certain products have been successfully created via the platform approach, one of which has even reached the seventh version. By re-using the product platform from prior versions and knowing what their production platforms are capable of, they have been able to reduce risk, manufacturing cost and investment cost (in new production equipment) as well as shorten the lead time of product development.

According to a former Engineer in charge, now working within the Research Center, GKN’s plan is to be able to use platform development within their Research Center. When the product, production process or technology has reached a certain level of maturity or “Technological Readiness Level” (TRL), a scale used to describe how mature a technology is which is described on the next page, then it can be transferred into a new product development project. This is illustrated in Figure 22.
Technological Readiness Level

The Technological Readiness Level scale, also known as the TRL scale, is a method used by NASA in order to determine how mature a technology project is. The 9 different steps are illustrated in Figure 23.

At GKN, the goal is to be able to develop the platforms to TRL 6 before using them in new product development, thereby ensuring that the production process, product or technology has been tested in a relevant environment before it is used as an alternative within the concept design. In Figure 24 you can see how the TRL roughly compares to the Global Development Process.

Working with platforms

The interviewees all agreed that working with platforms is a positive thing. One Manufacturing-lead mentioned that they were sometimes too “free”, leading to similar projects having different solutions to quite similar problems. One Engineer-in-charge stated that the platforms help the design
team to not do “too much new”. It rather helps the team to conduct the 30-40% of “new” that is necessary to have a competitive product with an as little risk as possible. According to employees, GKN has lost money on projects due to the platforms not being developed at the pace that the initial estimate predicted. Many of the interviewees highlighted the necessity of technology and manufacturing processes to be at TRL 6 before being included in a project, in order to avoid taking major risks. One Engineer-in-charge stated, “We need to identify our biggest knowledge gaps and spend the money there”. He further explained that the resources should be spent on developing the platforms until they have reached TRL 6 and then bring them in to product development. One Design-lead however, argued that there is a need for clearer goals of the research center and a more visual plan of how their work is to be implemented within the business.

4.2. Robust design

GKN has a competence center called Design for Robustness (DfR), which specializes in assisting the company as method specialists within areas of robust design, such as risk management, geometric assurance, and probabilistic analysis. There was recently a study made within the company that evinced differences in views of what design for robustness means between the method specialists at DfR and the actual users within the company. The users in the study were so-called leaders with responsibility of: the overall project, manufacturing, design, quality, procurement and cost. They perceived design for robustness as a methodology used for easy manufacturing of products where focus of its application was in manufacturing. The method specialists from DfR on the other hand described design for robustness more in the terms of understanding and handling variation.

DfR is however quite new within the company, being established in 2009, and is constantly working on getting more exposure. In geometric assurance they are now assisting a project where it seems as if their work has led to the project being able to choose a much more economical solution in terms of production, due to computer based analysis of the variation. Other areas DfR acts as method support are within the tools FMECA and Design of Experiments. An FMECA is usually performed during the evaluation of concepts; however it is often only performed on the top two or three concepts identified from the concept evaluation matrix. Design of Experiments is sometimes used when conducting research on the different concepts prior to the concept evaluation. It has also been used when problems have been identified within specific production technologies, in order to investigate which parameters were affecting the end result.

4.3. Concept study

In order to assist in delivering quality within all aspects of GKN, and to help with describing the company’s operation to customers and authorities, GKN has documented its “standard way of working,” called Operational Management System (OMS). All processes within GKN are documented in OMS; see Figure 25, which is accessible for all employees on the internal web.
Under the Product Development & Technical Product Support process the Concept study phase is described. According to OMS the overall purpose of a concept study is to show how requirements are translated into realizable concept suggestions. OMS further describes the concept study in more detail:

- A concept is defined as a technical solution described to the extent that it can be analyzed and evaluated in relation to the product requirement specification.
- All tasks concerning concepts are led by an Engineer-in-charge and shall be conducted in cross functional groups that cover areas such as system, design (strength/aerodynamics/thermodynamics), materials, and manufacturing- and inspection methods.
- Conceptual work shall always take prior development into consideration, regarding existing patents, former solutions and lessons learned.
- All concept studies shall be documented in a concept book.

The concept study phase within OMS is currently under revision by GKN. The part of the concept study that pertains to this thesis is, according to the team conducting the revision, not to be revised at all. This part is called “Prepare the concept”.

Figure 25 Operational Management System, GKN Aerospace Sweden Main Processes
4.3.1. Prepare the concept
The interviewees were asked to describe where the balancing of product features takes place.

In both Commercial Aerospace and Space Propulsion, the balancing of product features occurred in the “Evaluate the concept” phase in the process for “Prepare the concept” in OMS (Figure 26). There was a small indication that balancing also occurred during the studies performed on the concepts prior to the evaluation. In the Military department, the main focus in new product development was within system development. This lacks most of the tradeoffs that come from optimizing the hardware production process. According to one Engineer-in-charge, there is often an easier balance within Military product development projects, between system functions and the financial constraints of the project.

![Figure 26 “Prepare the concept”, a sub process in the Concept study phase in Operational Management System](image)

4.3.2. Balancing product features
The concept evaluation or concept selection process varies from department to department. For some, there were smaller concept selections happening more frequently within the projects, but the consensus among the interviewees was that major concept evaluations and selections rarely happen. This thesis will focus on the major concept evaluation and selection process at GKN since that is where the tools and processes are most applicable.

4.3.3. Business methodology
According to several interviewees, and informal communication had at GKN, different business areas maintain different business methodologies. This leads to different input regarding the conditions for the concept study phase and the use of different evaluation tools.

Commercial Aerospace
Commercial Aerospace has the most differentiated business methodology. According to a specialist within GKN this is because they maintain several different ways of starting projects. GKN and the motor Original Equipment Manufacturer (OEM) enters into an agreement within a field, technology, product or process etc., where they formulate a common goal. During this phase, the motor OEM usually have not fully developed the requirement specifications. Many interviewees describe that this can cause problems because concepts are generated and selected during this phase. There is a common view within the engineers at GKN that Commercial Aerospace has less time for the concept study and product development phases. As a result, this causes uncertainty when signing final contracts because the concept has not been finalized.
**Space Propulsion**
In comparison to other divisions, the engineers in Space Propulsion receive very distinct criteria from their customer at the beginning of the project. According to one Engineer-in-charge from Space Propulsion the concept is often decided on during the quote phase, which provides a well-defined concept during negotiations for the final contract.

**Military**
Military is the OEM of the system that they supply, meaning that they produce and sell the entire system and do not produce parts that are combined in to a final product by another organization. The material division of the Swedish military (Marteriorverket) orders each phase of the project separately, and evaluates the product before the next order is placed.

**4.4. GKN concept evaluation tools**
The majority of the interviewees claimed that the balancing of product features mainly take place when the concepts are evaluated. The departments work differently when evaluating and choosing their concepts because they have different input from their respective external customer. The interviews revealed that there were three different prominent tools used when evaluating concepts.

**4.4.1. Alternative 1: OMS model**
There is one model in OMS that is recommended to use as a template by the project teams when evaluating concepts. The template can be seen in Figure 27. This is a basic evaluation matrix where the concepts are placed on the top of the matrix and the criteria for the evaluation are placed in the left column of the matrix.
First, the Group Weight (column 2) for each of the Top Requirements are decided on and approved by the Steering Group. Both the Steering Group and the project leader are involved in suggesting the weights, which are often based upon the values from similar projects. The Steering Group then finalizes the values. The total weight of the Top Requirement Weights is 100, and they are broken down into Sub Requirements that are more specific. Generally, the breakdown shown on the template is used for most of the projects, but they are not mandatory and Sub Requirements can be added or removed. The tool displayed in OMS has very few Sub Requirements within Manufacturing and Producibility. A new updated tool is being developed with more detailed examples of Sub Requirements for these areas. The Sub Requirements are then weighted by the project team on how important they are with a scale from 1-10 in column 4 (Figure 27). Column 5 (Figure 27) is then used to display how that weighting relates to the Top Requirements total weight of 100. The Absolute Requirements are inserted in the top of the matrix (from row 2) in column 3. These are requirements that need to be fulfilled in order for the concept to be evaluated. Lastly, the target values are inserted in column 7 (Figure 27).
The concepts are first evaluated on each of the Absolute Requirements. If the concept fulfill an Absolute Requirement it earns a one, and if they do not, a zero. The concepts that fulfill all Absolute Requirements are then evaluated on how well they fit towards the target value of each Sub Requirement. The concepts are evaluated on how well they fulfill each Sub Requirement by being assigned a value from one to five. A ranking of the final concepts is developed through summarizing the result of multiplying that value with the relative weight of the Sub Requirement (column 5).

**4.4.2. Alternative 2: Space Propulsion model**

Alternative 2 is commonly used in Space Propulsion and is divided into three different steps. The first step is similar to the Absolute Requirement evaluation in the OMS model, but as can be seen in Figure 28, the Absolute Requirements in this model are called GO/NO GO requirements. If a concept fails to fulfill one GO/NO GO requirement they are excluded from further evaluation.

![Figure 28](image)

Figure 28 Alternative 2, sheet 1/3, compares the concepts towards the Go/No Go requirements

Alternative 2 uses Evaluation Criteria or Tradeoff Criteria (from now on referred to as Tradeoff Criteria) to calculate the weighting of the Objectives (Sub Requirements in the OMS model). These Trade-off Criteria are defined by the external customer and presented in the technical specifications. The following are examples of various requirements.

- Reliability (50%)
- Technological potential (14%)
- Performance (20%)
- Recurring cost (10%)
- Development logic (6%)

These requirements give input on how to weigh the different objectives. The Objectives are a combination of technical requirements from the external customer and internal know-how from the engineers working on the project.
The different Trade-off Criteria are broken down into Sub Tradeoff Criteria by the project team based upon their engineering knowledge. The Objectives are then evaluated by the extent to which they affect the Sub Trade-off Criteria. The correlation is described on a scale of 1, 3, 9, and each row has to have at least one 1 and one 9. By multiplying each Sub Trade-off Criteria’s weight with the correlation factor of the Objective, the project team can summarize the total weight of each Objective (column 2 in Figure 29). The total weight is then divided by the lowest common denominator and the weightings of the Objectives thereby established (column 3 in Figure 29). The weights of the Objectives are then used to evaluate the concepts that passed the GO/NO GO criteria matrix in sheet 1, Figure 28. The different concepts are evaluated on how well they fulfill the different Objectives. Once again the scale 1, 3, 9 is used (see Figure 30). The product of the Objective weighting and the fulfillment of the concept is then summarized and normalized on the bottom line and a ranking is presented.
Balancing the number of objectives between design/technical requirements and the producibility aspects is extremely important when using alternative 2. They should both have approximately the same amount of objectives when conducting the evaluation in order to choose the best-suited concept.

### 4.4.3. Alternative 3: OMS in Space Propulsion method

Alternative 1 and Alternative 2 are the two main methods used at GKN when evaluating concepts. There was however one other interesting evaluation model found during the interviews that a Space Propulsion project used, which was a mix of Alternative 1 and 2. This method, from here on referred to as Alternative 3, uses Trade-off Criteria from the external customer early in the concept study phase, as in Alternative 2. Alternative 3 also conducts a Go/No Go analysis on the different concepts found during the project team’s brainstorming activities. The method does not use a matrix as in Alternative 2. Instead, they list a group of example questions that need to be asked to each concept. These are examples of the questions asked:

- Possible to assemble and disassemble?
- Possible to manufacture?
- Possibility to be within interface requirements?
- Possibility to be within mass requirements?
- Possible to perform proof pressure test?
- Possible to measure performance in test?
- Possible to purge?
If the answer to any of these questions are No Go, e.g. if the concept has no possibility of fulfilling one or several of the criteria, even with minor modifications, the concept is excluded.

The Trade-off Criteria given by the external customer is then broken down into Sub Trade-off Criteria, as in Alternative 2. The weight for the Trade-off Criteria are still given by the external customer but is divided into Sub Trade-off Criteria by the engineers in the project team based on experience.

A matrix diagram featuring the Trade-off Criteria and Sub Trade-off Criteria is then used to evaluate the different concepts that pass the Go/No Go analysis (Figure 31). The scale used when evaluating the relationship between the Sub Trade-off Criteria and the concepts is 1, 3, 9. The scale is a reflection of the concepts ability to match the target value, where a “1” being far below target (under -20%), a “3” on target and a “9” far better than target (more than 20%). The concepts gain a score on each Sub Trade-off Criteria through multiplying the relationship value with the weight of the Sub Trade-off Criteria. These scores are then summarized on the bottom line, creating a ranking of the created concepts.

Figure 31, Alternative 3, Concept evaluation matrix
4.5. Challenges when evaluating concepts

During the interviews many different challenges in evaluating concepts were identified. Many interviewees mentioned that the concept evaluation is very dependent on which people who are in the team. One Manufacturing-lead stated that the team members must be able to stand up for their opinions and understand the needs of others in order to deliver an excellent product.

4.5.1. Subjective judgment

Subjective decisions are a problem within the evaluation process. According to all interviewees there are many decisions or “valuations” in this early stage of product development that are made with subjective evaluations from “experts”. This is a problem because the ‘expert’ valuations are inconsistent. For example, one expert may be more conservative with their valuations than another. This applies to both internal experts as well as external suppliers. This inconsistency accumulates if left unchecked. One former Engineer-in-charge stated: “Say you have 10-15 decisions that you need good information on in order to choose the right concept. If the experts are all 90% sure on every decision, the chance of failing is around 70-75%”.

The experts experience a considerable amount of pressure when weighing the different requirements because of time constraints and the company culture. One Engineer-in-charge stated that the experts are encouraged to make decisions, regardless of background, instead of running a series of preliminary tests to better evaluate their decision, often due to time constraints on the project. Another challenge is that there is often certain information that is more complicated to gain, which induces the need of valuation based on subjective judgment. According to a Design-lead from Commercial Aerospace the timing of input can be challenging since different tests can take from a few hours to weeks. In order to save time, the experts will make assumptions based on previous experiences on other projects. This sometimes leads to major complications when projects reach industrialization, often creating a financial loss.

The key is to go from a responsibility and authoritarian driven product development into a data and knowledge-driven product development process. In doing so, the company will gain more information about the quality of the various concepts being considered for production. During the interviews one former Engineer-in-charge stated: “A responsibility and authoritarian controlled development ensures accountability and properly filled in matrixes, but does not give much information about the quality of the different concepts.”

4.5.2. Technical requirements vs. Producibility constraints

Another major challenge when evaluating concepts is balancing the technical requirements with the producibility constraints. Engineers-in-charge, Design-leads and Manufacturing-leads all attest to the need of a good balance between the technical requirements and the producibility constraints. Each of the requirements and constraints are assigned a weighting, which is multiplied by the relationship value of how well the concept fulfilled that requirement or constraint. If the project team used a majority of technical requirements instead of producibility constraints when evaluating the concepts, those would have a bigger impact on the concepts final score. The same would happen if the balance were the opposite, then the producibility constraints would have a larger impact on the evaluation. Maintaining this balance is especially important when using Alternative 2, since there are no fixed categories like in Alternative 1. In Alternative 1 the Steering Group is responsible for ensuring this balance since they decide the weighting of the Top Requirements.
4.5.3. Customer requirements
Interpreting customer requirements is also difficult because customers will often change the requirements after the concept is set. According to one Engineer-in-charge from Commercial Aerospace a “demand” from the customer is sometimes a wish once the right questions are asked.
5. Analyze

This chapter compares the findings from the case study and the theoretical frame of reference in order to find similarities and gaps that can help with improving the balancing of product features within the concept study phase at GKN. This chapter also presents the summarized findings from a workshop held at GKN based on the preliminary analysis.

In this chapter, the author presents the findings from comparing the case study to the theoretical frame of reference regarding the methodology areas of Design for Quality, such as Concurrent Engineering, Platforms and Robust design. The author also analyses which quality tools were used when balancing products at GKN and how other quality tools mentioned in the theoretical frame of reference were applied in the design process. Table 4 gives a brief summary of the main analysis findings for each of the areas in the study. The different areas are analyzed in more detail further down in this chapter. A small summary of each area is given in italics before being analyzed.

Table 4 Analysis summary of how GKN is working with different areas within Design for Quality, Evaluation tools and Quality tools

<table>
<thead>
<tr>
<th>Area</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design for Quality</strong></td>
<td></td>
</tr>
<tr>
<td>Concurrent engineering</td>
<td>Problems with balancing producibility and technical requirements in evaluation of concepts. GKN works in cross-functional teams leading to improved product development.</td>
</tr>
<tr>
<td>Platforms</td>
<td>Benefits include reduced risk, reduced product development cycles, etc. GKN projects have reported results that match theory. GKN does not use a People and Relationship platform.</td>
</tr>
<tr>
<td>Robust design</td>
<td>Differentiated view of Robustness within GKN. The organization lacks focus on variation, which is important according to theory.</td>
</tr>
<tr>
<td><strong>GKN concept evaluation tools</strong></td>
<td></td>
</tr>
<tr>
<td>Alternative 1</td>
<td>Basic Pugh matrix combined with a matrix diagram.</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>Based on 3 steps: step 1 is a basic Pugh matrix, step 2 uses QFD influences when translating Trade-off Criteria to Objective weight, step 3 is a matrix diagram using weights from step 2 to evaluate the concepts.</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>Uses a matrix diagram with Sub Trade-off Criteria used as evaluation criteria.</td>
</tr>
<tr>
<td><strong>Quality tools</strong></td>
<td></td>
</tr>
<tr>
<td>Pugh matrix</td>
<td>Used frequently in comparing concepts to Absolute Requirements.</td>
</tr>
<tr>
<td>Matrix diagram</td>
<td>Used frequently when evaluating concepts and balancing product features.</td>
</tr>
<tr>
<td>QFD</td>
<td>Alternative 2 uses it to translate Trade-off Criteria to Objective weights. It is however an extremely simple application of the method.</td>
</tr>
<tr>
<td>FMEA</td>
<td>Frequently used at GKN. Used in risk identification of chosen concepts. Not used in balancing of product features.</td>
</tr>
<tr>
<td>Design of Experiments</td>
<td>Sometimes used when studying concepts to be able to make decisions based on facts, however, mostly used at GKN in problem solving, rather than preventive measures or platform development.</td>
</tr>
</tbody>
</table>
5.1. Design for Quality

In order to achieve quality, one needs to fulfill and if possible exceed the customer’s expectations. This can be achieved partly by having the right design of the product. The theoretical frame of reference defines the objectives of Design for Quality to be designing a product that meets the spoken and unspoken customer requirements and focuses on managing or minimizing the effect of variation in both production and usage of the product. This can be done through continuously improving the product’s performance, reliability, and technology in order to exceed the customer’s expectations and offer superior value.

Working with design to make was new within certain areas of GKN. Within Commercial Aerospace, there has been a long history of make to print, and therefore, major parts of the company still are trying to improve their design responsibility. GKN has taken several large steps within growing as a design to make organization, working with breaking down customer requirements and translating those into design features. However, it appears that there is still much work to be done in order to really have total control of their requirement management. There is quite a divided picture of what robust design is within GKN today, where the employees actually working within projects are mainly concerned with applying it within production. GKN has more and more been focusing on Concurrent Engineering, working with platforms as well as improving their tools for i.e. evaluating concepts, through using quality tools such as mentioned in the theoretical frame of reference.

5.1.1. Concurrent Engineering

Working with Concurrent engineering can make the design process more complex since there are more constraints to be taken into consideration. The benefits however in improving customer satisfaction through faster product development, improved quality, reduced cost, and shorter time to market, outweigh many possible downsides.

GKN has gone from working with a more traditional product development, where the design determined everything further down the line, to working with a more Concurrent Engineering inspired approach. When starting a new project, GKN have continuously emphasized the importance of people from different areas of expertise to sit together in order to ease communication and to better assist each other. There was however still mistakes being made in design that later on need mending, products that need reworking, manufacturing techniques that need extensive testing, time plans that are postponed due to various reasons i.e. industrialization periods, welding problems, supplier problems, etc.

There were also still problems specific to evaluating concepts. In Alternative 2, it was up to the project team to find the balance between design/technical requirements and the producibility aspects. According to the interviewees, the balance should be about 50/50 in order to choose the “right” concept, but in the end, producibility aspects were often disregarded. Alternative 2 uses the external customer’s Trade-off Criteria in order to calculate and decide the weighting of the criteria that was used to evaluate each concept. However, one Engineer-in-charge from Space Propulsion claimed that the weighting from the customers was not what really mattered. It was more the number or ratio between design/technical requirements and the producibility constraints that really made a difference in the end. According to the interviewee, it was however a mix of both, but the latter has a bigger impact.
5.1.2. Platforms
According to the theoretical frame of reference, a platform can be divided into four different sub-categories: components, processes, knowledge and people and relationships. Some of the potential benefits a company can gain from working with platforms are reduced development time and costs, lowered risk, reduced manufacturing costs, reduced production investments, and reduced support function costs.

GKN defines platforms as Product, Production, and Technology, which can be compared to the definitions of components, processes and knowledge found in the literature framework. GKN does not however work with platforms concerning people and relationships. Many of the potential benefits that were mentioned in literature have been confirmed by the case study at GKN. Reduced development time and costs have been experienced, especially regarding the mentioned project where they were building the 7th version of the same product platform. Lowered risk was something that many of the interviewees described since the platforms allowed the group to base their decisions on facts. Reduced manufacturing costs and production investments were also reported within GKN since they were able to use known methods and tools within manufacturing. Support function costs have not been discussed during the interviews. But as one interviewee said: “Platforms support the project team to do the 30-40% new needed with an as low risk as possible”.

5.1.3. Robust design
In the theoretical frame of reference, there are four different areas described that need to be considered when working with Robust Design Methodology: creating awareness of variation, creating insensitivity to noise factors, understanding that robust design is only a methodology, and focusing on the entire development process.

The competence center Design for Robustness (DfR) was only three years old and was still struggling with the cornerstones found in the theoretical frame of reference. There was, according to a recent performed study made at GKN, quite a large gap between how the DfR and the people working with the product development projects, perceived robust design. When speaking to employees from DfR, they confirmed that there was much work to be done in creating awareness of variation. They further expressed the importance of handling it within the entire product development process. Robust design was perceived by the project teams as “easy manufacturing of products”, with focus being on production.

5.2. Balancing of product features
Since design requirements are conflicting by nature, no final design can be perfect. It is the responsibility of the designer to compromise and determine the degree of “failures” within the product. The theoretical frame of reference describes the conceptual design phase as a phase where design objectives are identified, functional requirements are specified, and concepts are generated, evaluated and selected.

According to the interviewees, the balancing of product features at GKN mainly takes place in the evaluation of the concepts. During the case study, three different tools were identified, which now have been analyzed and compared to the quality tools described within the theoretical frame of reference.
**Alternative 1: OMS**

The OMS matrix is a mix between a Pugh matrix and a basic matrix diagram. First, the concepts are evaluated towards the Absolute Requirements in the top of the matrix. This can be compared to a Pugh matrix, although the team only uses a grading scale with two levels, 1 (passed) or 0 (failed). If a concept has a “0” they are not evaluated further. The concepts that pass all Absolute Requirements are then evaluated, in a basic L matrix diagram, towards the Sub Requirements that were broken down from the Top Requirements. The grading scale for determining how well the concept is performing towards the target value of each Sub Requirement is rated on a scale from 1-5 (see Figure 27).

**Alternative 2: Space Propulsion**

This alternative that is used by Space Propulsion is divided in to three different sheets. On the first sheet, the concepts are evaluated on a Go/No GO basis in a Pugh matrix, where they are graded on a scale with three values: - (no), 0 (maybe), and + (ok). If the concepts fail on one of the Go/No GO requirements, they are eliminated from the evaluation.

Sheet 2 is used to translate the Trade-off Criteria set by the external customer into the weighting of the objectives, which is then used in sheet 3. This can be compared to the first house of quality within QFD where the voice of the customer, the Trade-off Criteria in this case, is translated into the engineering characteristics and the most important ones are identified. The only difference being that the “Voice of the customer” (Trade-off Criteria) is placed on top of the matrix and the “engineering characteristics” (objectives) on the left hand side, which is reversed from the original house of quality. The objectives, gathered by customer requirements and internal know-how, are evaluated on a scale of 1,3,9 on how much they affect each Trade-off Criteria. This is a commonly used scale in many of the quality tools, but it is also one of the drawbacks mentioned with i.e. QFD.

The concepts that passed sheet 1 are now placed on the top of sheet 3 and the objectives with their newly calculated weighting from sheet 2 are placed on left side of sheet 3. This makes for a classic L shaped matrix diagram. The concepts are then evaluated on a 1,3,9 scale on how well they fulfill each of the objectives, and by summarizing the total score for each concept, a ranking is established.

**Alternative 3: OMS in Space Propulsion method**

Alternative 3 consists of two parts. First, the developed concepts are evaluated on a Go/No Go basis with a specific question that can be viewed in chapter 4.3.3. This step can be compared to sheet 1 in alternative 2 where the same technique was used, although they differ in the questions asked. In Alternative 2, the absolute requirements for evaluation, according to an interviewee, was set mainly by customer requirements while Alternative 3 more clearly considers both the external customer and the internal customer when evaluating the Go/No Go criteria, with the question focusing on producibility and feasibility.

The concepts that are approved by the first step are then evaluated by the Trade-off Criteria broken down into Sub Trade-off Criteria. The methodology of Alternative 3 is quite similar to Alternative 1 since they are both based on a basic matrix diagram. The main difference is that Alternative 3 uses the Trade-off Criteria from the external customer to define the criteria on which the concepts are evaluated, while Alternative 1 uses a mix of external criteria such as life and weight, and internal criteria such as business case and producibility (for more details see Alternative 1 Figure 27).
5.3. Quality tools

The theoretical frame of reference describes a group of quality tools that are commonly used when working with design for quality. The tools described include the Pugh matrix, Matrix diagram, QFD, FMEA and Design of Experiments. This part of the analysis will describe how these tools are used throughout the concept development, and not only within the concept evaluation as described above.

Pugh matrix
GKN used this mostly when evaluating absolute or Go/No Go requirements in order to exclude the concepts that are not suitable, or that they do not know enough about, in order to use in a new product. The ones that passed were then evaluated towards other objectives and criteria.

Matrix diagram
The matrix diagram was used frequently in different aspects by GKN. It is a basic tool that gives structure to different choices made, such as the concept evaluation in the different methods described above.

QFD
According to the theory companies with a robust development process, they tend to use QFD more simplistically. Within GKN, QFD was not a commonly used tool. The only application found was when evaluating the concepts in alternative 2, more specifically when translating the Trade-off Criteria determined by the customer into the weighting of the different objectives. The only part of QFD used in that “translation” was the relationship matrix, which leaves many other functions unutilized. GKN is thereby arguably using QFD in a simplistic manner; whether that means that they have a robust development process or not is hard to establish.

FMEA
FMECA was commonly used within GKN. However, it was not used in order to balance product features, at least not if the balance occur where the interviewees claimed it did, in the evaluation of concepts. The FMECA was applied on the two or three concepts chosen after the evaluation process. Then there is a combined analysis of the concept evaluation, the FMECA and other specific circumstances before choosing the final concept. The concept evaluation was only to be viewed as a recommendation.

Design of Experiments
Design of Experiments was not a required step when balancing product features but was used sporadically when gathering information regarding the different concepts in order to make decisions based on facts and not on subjective judgment. It has also been used when trying to find the root cause to different problems within manufacturing.

5.4. Validation of the study findings – A workshop within GKN
After the initial case study and analysis of the findings was conducted by the author, a workshop was held to validate the results and to further evaluate how the different methods used at GKN today can benefit from each other and theory. The group consisted of seven people, three of which were included in the interview study. The author and his supervisor at GKN handpicked the participants in order to get a good balance between Commercial Aerospace and Space propulsion, see Figure 32.
5.4.1. Findings

The most important aspects that were discussed during the workshop can be summarized in the following areas:

- Balancing was not limited to the evaluation of concepts.
- A solution was often predetermined when starting the concept evaluation.
- Use maturity analysis as a compliment to better analyze the concepts, and evaluate risk.
- The same evaluation tool can be applied to all departments.
- Document the weighting keys when evaluating concepts.

The thesis title is "Balancing product features in complex concept design", and according to the interviewees the main balancing occurred during the evaluation of the concepts. The workshop however showed that even though there was balancing taking place during the evaluation, there are other phases that contributes just as much. The participants described three phases within new product development where balancing occurs:

1. When gathering customer requirements and establishing the business approach.
2. During the evaluation and comparison of the concepts.
3. In deciding details and managing changes.

The participants thereby validated that balancing of product features takes place within the evaluation of concepts, but that the subject was not as simplistic as the answers from the interviews might have implied. Instead, there were other aspects that also needed to be taken into consideration as described in the list above. They further described a major issue being that the project team members often already have a “hidden agenda” or a solution already predetermined. According to the Design-lead from Commercial Aerospace, this sometimes leads to the selected criterion for evaluation being chosen to “suit” their alternative, which could lead to an incorrect evaluation. This could be hard to handle since the project group sets the Sub Criteria for evaluation and a strong leader could quite easily get his or hers favorite concept selected.

The Manufacturing-lead from Commercial Aerospace stated that in order to make better concept choices, the project teams needed to start determining and documenting what correlations that were based on facts and which were not. The Engineering Design specialist at GKN gave the idea of measuring the maturity of each concept evaluated, and referred to a study made at GKN regarding knowledge maturity (Johansson, 2009). He drew a basic model, illustrated in Figure 33, on how
concept maturity could give more information about the concepts. In the proposed model, the team members or specialists would, next to the evaluation of how well they fulfill the criteria in terms of design merit, also determine “how sure” they are in their valuation.

![Figure 33 Concept evaluation chart displaying Design Merit (DM) and Concept Maturity (CM)](image)

By defining if the valuation was a guess, made by an expert or was based on validated fact, the project team could analyze both the design merit and the maturity of each concept. They would thereby have more information when choosing a concept, and more importantly have a better understanding of the risk associated with the chosen concept. If two concepts have similar design merit although one has much higher concept maturity, the one with higher maturity would probably have less risk involved. Using that method would also give an opportunity to quantify the risk, by assessing the concept maturity score.

The different alternative tools used for evaluating concepts were presented to the workshop participants. They all agreed that alternative 2, used in Space Propulsion, was a good way to structurally make sure to weigh the requirements after what the customer wants. They confirmed what the interview study showed, that the different input led to the use of different tools. The workshop participants did however see the benefits of having predetermined Trade-off Criteria set by the customer, which in the Commercial Aerospace case would be the internal customer. They confirmed that having Trade-off Criteria set by the customer was not something that was used by Commercial Aerospace today; however, they did not see any problems with having a dialog with the internal customer in order to develop such criteria. They on the contrary agreed that there was great value in establishing such criteria and thereby better match the weighting of the requirements to what the customer wants, and also have similar tools for all departments.

Lastly, there was a discussion during the workshop regarding the use of different weighting scales within the evaluation tools and the weighting keys used to translate the meaning of the numbers into the context of the criteria. According to OMS, Alternative 1 uses 1-5 as a weighting scale, with a weighting key referring to the target value. A “1” represents that the concept is 20% below target, a “3” defines the concept as meeting the target value, and a “5” represents 20% above target. The members of the workshop all agreed that the weighting scale 1-5 was most of the time replaced with a 1, 3, 9 scale in all alternatives, since it gives a greater effect on the end result which makes it easier
Analyze
to evaluate. They further described that there seldom was a target value appointed and that the weighting key, described in alternative 1, often was not used. They do however emphasize the importance of using and documenting the keys for each criterion. The group needs to ask the question, what does a 1, 3, 9 mean for this specific criterion?
6. Results and recommendations

This chapter presents the results and recommendations found in the study. First, a summary of the results and recommendations is given, followed by a more detailed description featuring the different topics analyzed within the study.

The three different tools used for evaluating products at GKN are the outcome of different inputs into the business processes. Space Propulsion is given Trade-off Criteria by their customers from the start and can therefore, in Alternative 2, in a structured way translate what the customer wants in to which concept to choose. Since quality is defined as the ability to satisfy and exceed the customer requirements, Alternative 2 can be considered as a structured way of achieving quality. The participants of the workshop confirmed this by suggesting Alternative 2 as the main tool for GKN to use, which included the Trade-off Criteria set by the internal customer. Alternative 2 does however have a problem with balancing the technical and producibility requirements. Further it does not consider the business case as efficient as alternative 1, which can give the steering group better control of how to balance the product. This satisfies both the internal and external trade-off criteria.

In order to successfully balance product features, it is important to have facts about the concepts. Every decision should, if possible, be based on facts, and therefore it is important for GKN to continue to develop their platform methodology. GKN is today making many decisions within early phases of product development based on “qualified guessing”. In some cases this has according to the interviewees led to problems later on in the development process, which has resulted in increased cost for the company. When looking at the methods and tools used for balancing product features in the concept design phase, there are certain parts that often are based on subjective judgment. All of the tools used, Pugh matrix, Matrix diagram and QFD, have steps where the user needs to determine a relationship or evaluate how well the concepts are performing towards the different criteria. This creates uncertainty within the present methodology for balancing product features in the concept phase. The main recommendations that the author gives to handle this uncertainty are summarized in Table 5.

Table 5 Summarized recommendations from the study

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continue to focus on platform development</td>
<td>Work with platform development in order to base decisions regarding the concept evaluation on facts.</td>
</tr>
<tr>
<td>Implement Maturity analysis</td>
<td>An easy way to gain more information when choosing the concept. The Concept Maturity score can also help in taking calculated risks within a project.</td>
</tr>
<tr>
<td>Implement Alternative 2 in OMS</td>
<td>By using this tool the project group can, in a structured way, chose the concept that best suits what the customer wants, thereby creating a qualitative product.</td>
</tr>
<tr>
<td>Develop weighting keys</td>
<td>By discussing and documenting weighting keys for each criterion, the group can improve the valuation of the concepts and ease potential follow-up.</td>
</tr>
<tr>
<td>Further investigate Fuzzy Logic</td>
<td>Do further research on how fuzzy logic can be implemented within the evaluation tools to better handle the current crisp weighting scale 1,3,9.</td>
</tr>
</tbody>
</table>


6.1. Design for quality

Table 6 presents an overview of the results from the study focusing on the different methodologies under Design for Quality. More detailed descriptions of the results and recommendations are found further down in this chapter.

Table 6 Summary of results and recommendations from the study regarding Design for Quality

<table>
<thead>
<tr>
<th>Area</th>
<th>The analyze show…</th>
<th>Which can lead to…</th>
<th>Therefore GKN should…</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concurrent engineering</td>
<td>Problem with balancing producibility and technical requirements.</td>
<td>Financial loss through re-work, delayed time plan, scrap etc.</td>
<td>Develop a balancing method that works for all departments that is indifferent to these balancing problems, with a focus on platform development.</td>
</tr>
<tr>
<td>Platforms</td>
<td>Multiple benefits reported from GKN projects, although still not completely implemented.</td>
<td>Less risk taking, shorter lead-time, etc. within product development and more decisions in concept evaluation can be based on facts.</td>
<td>Keep on working with implementation of platform methodology throughout the organization.</td>
</tr>
<tr>
<td>Robust design</td>
<td>Difference in the understanding of the robust design within GKN.</td>
<td>Unnecessary variation designed into the products, causing variation in production.</td>
<td>Continue to support and inform projects on the benefits of e.g. geometry assurance and early risk identification.</td>
</tr>
</tbody>
</table>

6.1.1. Concurrent engineering

GKN has improved their work with Concurrent Engineering over the years but there is still room for improvement. By sitting together in cross-functional teams when working on projects, they are more likely to understand and reflect on all the important aspects throughout the product development process. GKN has also started to understand the importance of balancing requirements, especially between technical and producibility requirements, which have not been clearly defined in earlier projects. However, GKN has learned from their mistakes during earlier projects, and are about to improve many of the tools used in critical phases within projects, such as the concept evaluation. There are still improvements that can be made to further improve how GKN is working with Concurrent Engineering. One possible improvement would be to better map what input the different projects have when starting a concept study phase, and also to better define who is responsible for the internal requirements.

6.1.2. Platforms

The platform methodology at GKN is not completely developed and functional yet, but the organization has taken big steps during the last year. Working with platform development, not releasing products, processes or technologies before they reach a TRL 6 is a recipe for success. GKN has lost money with platforms not being developed in the pace that the initial estimates showed. Despite these setbacks, many of the projects have pushed GKN’s technology development to reach levels they might not have been at now if they would have waited until the platform had reached TRL 6 before using it in a product. If GKN can get better at working with platforms and platform development, they will most likely be able to produce better products, in a shorter timeframe and with less risk involved. Working with platform development will also help with eliminating much of the subjective judgment that exists within concept evaluation today. GKN needs to understand the solution space surrounding their current know-how in order to be more efficient and less risk-taking
within concept development projects. Further the organization needs to spend more money earlier within the product development process, thereby minimizing the product lifecycle cost.

### 6.1.3. Robust design

GKN has a lot to gain from working with robust design in a structured and organized way. The true value of robust design can be found when implementing ways to handle variation in the design of the product instead of solely focusing on the manufacturing process. Within the department Design for Robustness, they are aware that the organization needs a change in mentality, and hopefully they will be able to teach the organization on how to truly design for robustness.

### 6.2. Balancing of product features

In Table 7, the major strengths and weaknesses regarding the different tools used for evaluating concepts at GKN today are summarized. These are then discussed in further detail on the following page.

#### Table 7 Major strengths and weaknesses of the tools used for evaluating concepts at GKN

<table>
<thead>
<tr>
<th>Tool</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>Focused on the internal customer. The Steering Group decided the balance between e.g. producibility and technical requirement weighting.</td>
<td>Uncertain how the “voice of the customer” has been satisfied in a structured way.</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>A structured way of translating what the customer wants into the evaluation of the concepts.</td>
<td>Up to the project team to manage the balance of objectives. Producibility vs. Technical</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>Focused on the Trade-off Criteria from the external customer when evaluating concepts.</td>
<td>Not enough considerations were taken to the internal customer in terms of business case and producibility.</td>
</tr>
</tbody>
</table>

Alternative 1 was officially recommended by GKN to use during this activity. The reason behind other projects using different tools the author believes was because of the input to the processes. Commercial Aerospace and Space Propulsion received different input from the customer in terms of requirements, time plan and desired business model. Space Propulsion received Trade-off Criteria’s from the customer that helped the team in weighting the objectives, which then each concept was evaluated on. This was however only the criteria set up by the external customer. The internal customer requirements, e.g. producibility and business case, were accounted for when the engineers defined the Objectives. These Objectives were then weighted towards the external customers Trade-off Criteria. Quality was defined in this study as the ability to satisfy and exceed the customer’s needs and expectations, but the project team still needs to make sure that the “internal customer”,...
Results and recommendations

business case and the producibility of the product also are considered in order for the company to be profitable and secure long-term quality.

Alternative 1
This alternative was supposed to be the standard way of working, since it was the only one presented in the Operational Management System (OMS). The alternative suggested a different weighting scale than the other alternatives that used 1, 3, 9. The weighting scale 1-5 gave less impact on the different requirements and was seldom used. The tool tried to reduce subjective judgment by using a weighting key that compared the concept to a target value. The reality was that the engineers did not always have facts to base their decisions on, which lead to a great deal of uncertainty when using this tool. Another important aspect of this tool was how the steering group defined the weights of the Top Requirements. These weights were essential when the concepts were evaluated since they controlled the weights of the Sub Requirements. Therefore, it was of vital importance that the steering group understood how much their decision of the Top Requirement weightings affected the evaluation of the concepts. The tool that was displayed within OMS had very few characteristics within producibility and a new updated tool was on the way with more detailed examples of the Sub Requirements for manufacturing. The biggest issue, besides the fact that current tool not focusing on producibility enough, was lack of structure when handling external customer requirements. The tool could not handle the Trade-off Criteria that were set by the external customer in Space Propulsion.

Alternative 2
Space Propulsion used this method because they had different input to their concept evaluation process than the other departments. They received Trade-off Criteria from their external customer that they needed to use when choosing concept. These Trade-off Criteria affected the balancing of the product features. However, it was hard to say how big effect they had on the final concept choice. The balance between the technical and producibility requirements was probably the one aspect that mattered the most, even though they all contributed to the final result. By using the Trade-off Criteria to weight the Objectives, Space Propulsion in a structured way managed to translate what the customer wanted into which concept to choose. By using three sheets it was easy to follow the procedure and separate each step. However, there can still be a great deal of uncertainty in the tool since it relies on the engineers when balancing the numbers and ratio of technical requirements to producibility requirements. This tool used the weighting scale 1, 3, 9 when describing the relationship. This was preferable since it resulted in a greater impact on the end result, however there is still subjective judgment involved when using these crisp values.

Alternative 3
The third alternative was used by Space Propulsion and was quite similar (methodologically) to alternative 1. It used the Trade-off Criteria from the customer to evaluate the concept directly by breaking down the Trade-off Criteria into Sub Trade-off Criteria. This could be one way of uniting under one methodology, but it was unclear how this alternative would be able to handle the internal requirements. Since the external customer sets the weight of the Trade-off Criteria, and the weight of the Sub Trade-off Criteria was just a breakdown of the Trade-off Criteria’s total weight, the project lacks the control of handling the requirements from the internal customer in areas such as business case and manufacturing. The engineers did weight the Sub Trade-off Criteria’s, and can affect the weighting in the favor of the internal customer.
One method for all
When presenting the different tools used for evaluating concepts to the participants of the workshop, they believed that the same evaluation tool, alternative 2, could be applied to all departments. In order for alternative 2 to work, all departments need to have better communication with their customers and develop Trade-off Criteria’s together with them. For Commercial Aerospace, the person responsible for ordering the product development internally should be responsible for designing the Trade-off Criteria. That person should take responsibility for design, producibility and the business case. This will give structure to GKN’s work within quality, since they could base their choice of concepts on what the customer actually wants.

6.2.1. Handling uncertainty
Within certain areas at GKN there was “qualified guessing” taking place when using the evaluation tools. In some projects there have been “qualified guesses” that have led to financial losses due to testing and delayed production starts. These guesses also created great uncertainty when evaluating concepts. There are different methods that can be used in order to handle this.

Maturity analysis
GKN were only analyzing “design merit” when evaluating the concepts with their current tools. By adding a “maturity” analysis, which analyzes the quality of the information used in order to grade the “design merit”, GKN would be able to visualize how well developed a concept is, and take calculated risks. Adding “concept maturity” to the evaluation tools is a simple feature that would help the project teams in choosing the right concept.

Fuzzy Logic
If the project team can’t base the decisions on facts, there are other alternatives that can help when handling uncertain or approximate reasoning, and make decisions with estimated values under incomplete or uncertain information. One alternative frequently discussed within the scientific world was a method called ‘fuzzy logic’. It can help to model vagueness in relationships and data by manipulating fuzzy qualitative data in terms of linguistic variables. This means that it can help with handling the subjective judgment that was involved in many of the tools used at GKN. The matrix diagram, QFD, Pugh matrix and FMECA, all use some form of weighing scale that uses crisp numbers when describing a relationship. Examples are risk priority number in FMECA and the relationship matrix of the QFD. They might use different scales such as 1, 3, 9 and 1-5, but they all use crisp values, making the engineers choose one set value. By using fuzzy logic, the vagueness of a relationship can be better modeled to describe a real situation. Unfortunately, there might be employees who find working with fuzzy logic to be too complex. Therefore, GKN should continue to examine how it can be implemented in the evaluation tools in a way that makes it easy for the project team to use.

Weighting keys
If GKN keeps using crisp values and working with the old tools, one thing that can be done in order to improve the evaluation of the concepts is to discuss and document the weighting key for each of the criterion. Alternative 1 still suggests that the evaluation should be based on how the concept relates to a target value set for each criteria. According to the participants of the workshop, there was usually no target value established. By discussing and documenting what a 1, 3 and a 9 means to a certain criteria, GKN will not only make better valuations, but also be able to go back and evaluate
the process. If a requirement or circumstance would change, it can also help others understand what has been done before when restarting the concept evaluation process.

### 6.3. Quality tools

Table 8 presents an overview of the results and recommendation from the study focusing on the different Quality tools evaluated, followed by a more detailed description of the results and recommendations found.

**Table 8 Summary of results and recommendations from the study regarding Quality tools**

<table>
<thead>
<tr>
<th>Area</th>
<th>The analyze show...</th>
<th>Which can lead to...</th>
<th>Therefore GKN should...</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quality tools</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pugh matrix</td>
<td>Was used frequently within evaluation of Absolute Requirements</td>
<td>The concepts not applicable are excluded.</td>
<td>Keep using the tool; apply earlier in process to avoid unnecessary evaluations of concepts.</td>
</tr>
<tr>
<td>Matrix diagram</td>
<td>Was often used in concept evaluation.</td>
<td>A structured approach to analyzing i.e. concept evaluation.</td>
<td>Keep using the tool, but be aware that there was uncertainty regarding the subjective judgment in the valuation</td>
</tr>
<tr>
<td>QFD</td>
<td>Was used to translate the Trade-off Criteria to weighting of objectives.</td>
<td>The concept evaluation being structurally derived from what the customer wants.</td>
<td>Try to implement in all concept evaluations, which would also require Commercial Aerospace to start dialogs with customer regarding Trade-off Criteria.</td>
</tr>
<tr>
<td>FMEA</td>
<td>Was commonly used when the concepts were already evaluated.</td>
<td>Resources spent studying concepts that are not applicable based on a too high risk involved.</td>
<td>Consider implementing FMECA in an earlier stage of the concept development.</td>
</tr>
<tr>
<td>DoE</td>
<td>Was sparsely used at GKN, often used in late in the problem-solving process.</td>
<td>GKN not using the full potential of the tool, which can be achieved when finding the best combination of factors prior to the final concept design is set.</td>
<td>Educate more employees of the opportunities that working with DoE can bring, especially in platform development.</td>
</tr>
</tbody>
</table>

Most of the tools were frequently used except for Design of Experiments (DoE) and Quality Function Deployment (QFD). To some people, DoE can appear as a very complex tool, and can be hard to understand, use and interpret. Many projects would greatly benefit from using DoE to help analyze how multiple factors affect each other, instead of only looking at one factor at a time. There was help to get regarding the use of the tool from GKN specialists, but these resources were seldom used.

QFD is commonly used in other companies to help design products and weigh characteristics. Despite the wide use of QFD, the tool was not commonly used at GKN. One possible explanation could be that GKN received very specific technical requirements from their customers and no breakdown of the “voice of the customer”, to more specific technical aspects, was therefore necessary. That reasoning is strengthened by the difficulty of finding relevant literature regarding the use of QFD in complex design. GKN does use parts of the House of Quality when evaluating concepts in Space Propulsion, using the tool Alternative 2. In order to increase effectiveness and efficiency, GKN needs to apply a structured translation of what the customer wants to the weightings of the criterion in all departments in order to improve quality within their products.
7. Conclusion and discussion

This chapter reflects on the strengths and weaknesses of the study by examining the method of the research and discussing the impact of the findings. This is followed by a concluding discussion regarding the results and the validity and reliability of the study. Finally the chapter discusses further research within the area.

Many recommendations are relatively easy to implement. Adding the maturity analysis could really help make better concept evaluations with little effort. This study might help GKN understand why there are different tools used to evaluate concepts. The study has also helped to shed a light on how quality tools are used within concept evaluation, and where the balancing of product features take place at GKN. The evaluation tools used at GKN all use some form of quality tool, which is showed in the Analyze chapter. The problem seems not to be within the evaluation tools used; rather it is in the uncertainty within the tools. The recommendations made are mainly focusing on handling this uncertainty. The problem areas found regarding balancing of product features at GKN are likely to be found in many different industries outside of the aerospace industry. This study may be of interest for any company that has a complex product in need of manufacturing.

7.1. Method

The case study was based on nine interviews, many documents, unstructured observations and a validation workshop. The interviews, together with the documents related to them, were the main source of information for this study. The different interviewees were selected strategically together with the supervisor at GKN, and focused on finding people from the department’s Commercial Aerospace, Space Propulsion and Military. Those selected all were or had recently worked as Engineer-in-charge, Manufacturing-lead or Project manager. This gave diversity to the interviews and provided insight on how employees were working with balancing product features throughout the company.

A questionnaire template was used during the interviews. Since this was conducted as an abductive process, the interview template changed over time. The original template can be found in appendix A. This can cause problems in terms of repeatability of the study, but was necessary in order to work with continuous analysis. The theoretical frame of reference grew as the interviews progressed and upon evaluating the process. The unstructured approach of the interviews and letting the theoretical frame of reference grow during the study also helped with getting to the bottom of certain problem areas that had a big influence on the major conclusions.

All of the interviewees attested to the complexity that lies within balancing of product features. The interviewees were asked to bring an example where they had been working with balancing product features, and the quality of the interview depended quite substantially on the example. For this research, the applied method was a good fit with regards to the information that was available from the start of the project.


**7.2. Results**

The aim of the project was to improve the balancing act of product features in a complex concept design phase using quality tools in order to meet and exceed customer expectations, thus generating quality. GKN’s current work with balancing product features within the concept design phase (RQ1) is described in chapter 4, with main focus on the evaluation of concepts. The methods by which quality tools are used to balance product features in a technologically complex concept design phase (RQ2) is answered in chapter 3 and by analyzing the gaps towards GKN today. Chapter 6, results and recommendations, describes how GKN can use quality tools within the conceptual design phase in order to improve the balancing of product features (RQ3) and handling of uncertainty within the tools. Quality tools can be used to better balance product requirements in order to meet and exceed the customer expectations and needs. GKN has used parts of the results from this study to update their current practices.

This is a case study made at GKN Aerospace in Trollhättan, and the chapter 4 findings are to be viewed as specific for this organization. The general methodology and findings are considered applicable to many different business areas working with complex product development. Few similar studies have been conducted in this kind of complex product development, and hopefully, this thesis will inspire more research within the field. GKN’s goal of minimizing their product weights can be accomplished by using quality tools to improve the balancing of product features in complex designs. Finding ways to evolve and develop more fuel-efficient engine parts at a lower cost and risk, will be beneficial not only for GKN, but also for the entire world population who together need to take responsibility in order to reach a sustainable community.

**7.3. Validity and reliability**

A workshop was held at GKN in order strengthen the validity of the case study. The findings from the case study were presented and a discussion regarding its validity took place, the summary of which can be found in chapter 5.4. The validity of the findings was further strengthened through the supervisors, both from the university and GKN, continuously reviewing the study and work material. The two supervisors at GKN have been kept up to date on the progress of the study, and have made important decisions on going forward with the study along the way. Interviewing a wide variety of people from different departments and different roles enforced the internal validity, but could have been improved by increasing the number of interviews. Familiarity with GKN’s complex processes and products would have also increased the effectiveness of the study.

A reliable study is a study that if repeated by another researcher would produce similar findings. Even though the research has been conducted in an abductive loop, with the theoretical frame of reference growing during the process, the findings from the study would probably be the same if the study was conducted again. Whether the next researcher would end up with the same recommendation however, that is hard to establish.

**7.4. Further research**

One of the main recommendations of this study was to further look into how Fuzzy Logic can help with handling the uncertainty that was found within the concept evaluation process regarding the weighting scales, such as 1, 3, 9.
Conclusion and discussion

It would also be interesting to further look into how the different business methodologies influence the input to the balancing act and how the different departments can learn from each other in order to create better products and increase profit for GKN.

Finally, this study has only focused on one organization and it would be interesting to compare the findings from this study to how other similar organizations balance product features. It would also be interesting to look into how much the actual weighting matters in the tool and how robust the tools really are.
8. List of References

8.1. Bibliography


9. Appendix A

Interview sheet – Balancing product features

Background and experience of interviewee
   a. What business unit do you belong to?
   b. How many conceptual design have you done?

Balancing features
   c. According to you, where does the balancing of product features take place?

Collecting requirements and objectives
   d. How do you gather all requirements and objectives (internal and external) before generating concepts?
   e. How are the requirements and objectives documented?

Generating concepts
   f. Do you today use any tools or certain methodology when generating concepts?
   g. How do you acquire and insert requirements and objectives into the Concept generating process?
   h. Do you today use any tools or certain methodology in order to balance product features/requirements/objectives in concept generating?

Concept evaluation matrix
   i. Do you today use any tools or certain methodology when evaluating the concepts?
   j. Describe a specific project?
   k. If you are using a method/tool, do you always use it? Or are there certain times you specifically use it or don’t use it?
   l. How do you make sure that you have fulfilled all customer demands with the choosing of a concept?

Input from Production/Inspection/Product cost
   m. How do you make sure that the product design you are suggesting is possible and efficient from a …. Both in concept generating and evaluation?
      i. Production perspective
      ii. Inspection perspective
      iii. Product cost perspective
      iv. Reliability/Safety perspective

Visualization of features regarding correlation and tradeoffs
   n. Do you in any way try to visualize the different features when working with concept generation? Why? Why not?
   o. Does it help to visualize the features?
   p. Do you visualize correlation and tradeoffs between features?
      i. If yes, how?
      ii. If no, how do you take into account tradeoffs and correlation?

Weighting
   q. Do you use any kind of weighting when analyzing/balancing/choosing design?
Appendix A

i. If yes - How do you go about doing that?
   1. What kind of scale do you use?
   2. Is it based on subjective assessment or facts?

ii. If no – Why not?

Challenges/problems according to interviewee
   r. What is the biggest challenge according to you when generating concepts?
   s. What is the biggest problem according to you when evaluating concepts?

Changing of conceptual design
   t. How often do you tend to go back and alter a conceptual design that has already been approved?
   u. What is the most common reason for doing that? (Can you see any pattern?)

QFD
   v. Do you know what QFD is?
   w. Have you used it? When?
   x. Positive aspects?
   y. Negative aspects?

Set based Concurrent Engineering
   z. Do you know what Concurrent Engineering means?
      i. - If yes – Do you use that when choosing design?
      ii. - If no – (Explain what it is in general) could you see any benefits in using that when choosing design?

Platform aspect
   aa. What does platform technology mean to you?
   bb. Do you reuse technology or process solutions?
   cc. When working with balancing product features, do you ever use the terminology of platforms?
      i. If yes – How? When? Where?