Risk Management in Product Development at GKN Aerospace

Challenges of Becoming More Proactive

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Risk Management in Product Development at GKN Aerospace

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Riskhantering inom Produktutveckling på GKN Aerospace

Utmaningar för att bli mer proaktiv

A master’s thesis performed in the subject quality technology and management at Luleå University of Technology and GKN Aerospace Sweden AB.

By
Erik Nilsson and Niklas Månsson, 2015

Supervisors
Sören Knuts - GKN Aerospace Sweden AB
Erik Vanhatalo - Luleå University of Technology
Acknowledgement

This thesis, written at Luleå University of Technology, is the result of a 20-week study, which have linked together the areas of product risk management and quality management. As the integration of these two areas is an emerging research field within quality management, we feel fortunate to have gotten the opportunity of study it. We would therefore first like to thank our supervisors, Sören Knuts at GKN Aerospace Sweden AB and Erik Vanhatalo at Luleå University of Technology.

Sören, your support within this project has been far beyond what can be expected from a thesis supervisor. From time to time you have not only felt like a supervisor, but as an equal team member of the project. Without your guidance we would not have been able to achieve the same result. Erik Vanhatalo, your ability to provide ideas and constructive feedback in the thesis have amazed us several times, especially as product risk management is not part of your research field.

The conclusions and recommendations of this thesis would not have been the same without the benchmarking study with Autoliv and Volvo Construction Equipment. We were able to develop a greater understanding and generate ideas through your help, we would therefore like to thank you for sacrificing your valuable time.

Lastly, we would like to thank our families and friends. Five challenging years in Luleå have flown by in the blink of an eye, and it truly wouldn’t have if it wasn’t for all the fun times with our friends. We would especially want to thank Amanda, Lisa, Ola and Thorbjörn who also have written their thesis at GKN. In less than half a year we became like a family, sharing almost every meal together and the spare time on the weekends. This has been a very special time for us and we hope that we will have as much fun when we meet again in the future.

Trollhättan, June 2015

Erik Nilsson

Niklas Månsson
Division of Work

This thesis was written by two authors and the workload has been evenly distributed. For each chapter a foundation was created in order to get a mutual view of what should be included and all chapters have been written by both authors. However, responsibility of each chapter was divided between the authors in order to ensure the quality and completion of each chapter.

- *Introduction* - Niklas
- *Method* - Niklas
- *Theoretical Frame of References* - Erik
- *Risk Management at GKN aerospace* - Erik
- *Alternative Risk Management Practices* - Niklas
- *Analysis* - Erik
- *Conclusion* - Erik
- *Recommendations* - Niklas
- *Discussion* - Niklas

All interviews have been conducted and analyzed together in order to get a result, which is based on both author's thoughts and ideas. Constructive feedback and support have been given by the university supervisor Erik Vanhatalo at Luleå University of Technology and the company supervisor Sören Knuts at GKN Aerospace Sweden AB.
Abstract

Risk Management is becoming an integral part of Quality Management. For example, in the new revision of ISO 9001, which will be released by the end of 2015, the incorporation of risk-based thinking is considered to be the largest update.

This master thesis have has been conducted as a case study at GKN Aerospace Sweden AB in Trollhättan. The company produces complex high-tech components that can be found in 90% of the civil aircrafts produced today. The strict flight safety requirements and long time-to-market creates a need for effective and proactive risk management practices. GKN Aerospace has therefore been considered as a suitable case to study in order to understand how companies can work with product risk management to become more effective and proactive.

D-FMEA:s and traditional product risk management tools have naturally been given a large focus. However, the study has had an open and exploratory approach in order to identify alternative practices, which reduces uncertainties and creates proactivity. This has led to an investigation of how Robust Design, Design for Manufacturing and Lessons Learned can be integrated effectively to the current Risk Management Processes.

A literature, survey and interview study have been conducted in order to create an understanding of the current product risk management practice at GKN Aerospace. These results have then been used in a less extensive benchmarking study at Autoliv and Volvo Construction Equipment in order compare alternative practices and develop suggestions for improvements. This has lead to the following conclusions:

- In order for risk management to be effective there must be a demand. If there is no demand from the customer it must be created internally.
- Clearly specifying the process, working continuously and increasing the risk management education are ways to avoid a situation where FMECA:s are filled in reactively and therefore loose both their purpose and potential.
- Many at GKN perceive FMECA:s as time-consuming, complex and hard to get a holistic perspective of. This problem decreases by creating a "Master-FMECA" where generic risks are used as input, which allows focus to be directed to where the biggest risks are; new content and changes.
- Increasing the basic educational level within risk management is effective, but not sufficient for those leading the risk management work. An additional educational level of how the work should be managed is needed.
- It is fully possible to include Robust design in the FMECA:s, but complementing parallel process flow is recommended in that case.
- The Manufacturing department should be required to always be involved in the FMECA work, in order to early include a producibility perspective. There should also be a clear process flow between the FMECA and P-FMEA.
- Lessons learnt may effectively be used as input to the risk management process, but it is hard and something all three organisations struggle/have struggled with.
Sammanfattning

Risk management blir en allt mer integrerad del av kvalitetsutveckling. Till exempel, i den nya revisionen av ISO 9001, som släpps i slutet av 2015, ses integrationen av riskbaserat tänkande som den största uppdateringen.

I detta examensarbete har en fallstudie genomförs på GKN Aerospace Sweden i Trollhättan. Företaget producerar högteknologiska och komplexa komponenter som återfinns i 90% av alla nytillverkade civilflygplan. De strikta kraven för att säkerställa flygsäkerhet samt de långa produktutvecklingstiderna skapar ett behov för effektiv och proaktiv riskhantering. GKN har därför ansett som ett lämpligt fallstudieföretag för att undersöka hur företag kan arbeta med produktriskhantering för att bli mer effektiva och proativa.


En litteratur-, enkät-, och intervjustudie har genomförts för att skapa en förståelse för dagens produktriskhanteringsprocess på GKN Aerospace. Dessa resultat har varit utgångspunkt i en mindre benchmarkingstudie med Autoliv och Volvo Construction Equipment för att jämföra alternativa arbetssätt och utveckla förbättringsförslag. Detta har lett till följande slutsatser:

- För att produktriskhantering ska fungera effektivt måste det finnas en efterfrågan. Om det ej finns hos kund behöver den skapas internt.
- En tydligt specificerat process, kontinuerligt FMECA-arbete och utökad riskutbildning är medel för att undvika en situation där FMECA:n fylls i reaktivt och således tappar både sitt syfte och potential.
- Många på GKN ser FMECA:s som tidskrävande, komplexa och svåra att överblicka. Detta problem minskar genom att skapa en ”Master-FMECA” där generiska risker används som input för att tillåta fokus ligga där riskerna är som störst, vid förändringar och nyheter.
- Att utöka den grundläggande utbildningen inom riskhantering är effektivt, men inte tillräckligt för de som ska leda och driva arbetet. En utökad riskhanteringsutbildning behövs för dessa.
- Det är fullt möjligt att inkludera Robust Design i FMECA:s, men ett kompletterande och parallellt processflöde rekommenderas i så fall
- Lessons Learnt kan användas som en effektiv input till riskhanteringsprocessen, men det är svårt och något samtliga fallföretag kämpar hårt/ har kämpat med.
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### Concepts and Abbreviations

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<th>Meaning/Definition used in the thesis</th>
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<tr>
<td>AS9100</td>
<td>An aerospace standard issued by the International Aerospace Quality Group. It sets quality management requirements for the aerospace industry and has a strong focus towards risk management and the assurance of flight safety.</td>
</tr>
<tr>
<td>ARDIM</td>
<td>Autoliv Robust Design Improvement Methodology</td>
</tr>
<tr>
<td>Autoliv</td>
<td>Autoliv Sweden AB, Vårgårda</td>
</tr>
<tr>
<td>D-FMEA</td>
<td>Design FMEA</td>
</tr>
<tr>
<td>DFM</td>
<td>Design for Manufacturing</td>
</tr>
<tr>
<td>DfR</td>
<td>Design for Robustness</td>
</tr>
<tr>
<td>DfSS</td>
<td>Design for Six Sigma</td>
</tr>
<tr>
<td>FMEA</td>
<td>Failure Mode and Effect Analysis</td>
</tr>
<tr>
<td>FMECA</td>
<td>Failure Mode, Effect and Criticality Analysis</td>
</tr>
<tr>
<td>GKN</td>
<td>GKN Aerospace Sweden AB, Trollhättan</td>
</tr>
<tr>
<td>ISO 9001</td>
<td>The ISO 9001 is an international standard within the ISO 9000 series, which is a family of quality management systems standards</td>
</tr>
<tr>
<td>ISO 31000</td>
<td>ISO 31000 is a family of standards relating to risk management issued by the International Organization for Standardization</td>
</tr>
<tr>
<td>KC</td>
<td>Key Characteristic</td>
</tr>
<tr>
<td>OMS</td>
<td>Operational Management System, the management system at GKN’s intranet which defines all processes and operations</td>
</tr>
<tr>
<td>PDP</td>
<td>Product Development Process</td>
</tr>
<tr>
<td>P-FMEA</td>
<td>Process FMEA</td>
</tr>
<tr>
<td>Producibility</td>
<td>The general engineering art of designing products that are easy to manufacture. In other words, this means designing products that do not exceed estimated product cost and are outside the manufacturing capabilities.</td>
</tr>
<tr>
<td>Program</td>
<td>Large product development project conducted over a long period of time</td>
</tr>
<tr>
<td>R&amp;T</td>
<td>Research and Technology</td>
</tr>
<tr>
<td>RPN</td>
<td>Risk Priority Number</td>
</tr>
<tr>
<td>TRL</td>
<td>Technological Readiness Level</td>
</tr>
<tr>
<td>Volvo CE</td>
<td>Volvo Construction Equipment AB, Eskilstuna</td>
</tr>
<tr>
<td>VRM</td>
<td>Variation Risk Management</td>
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1 Introduction

This chapter introduces the research area and provides a problem discussion, which is followed by the aim of the thesis. Thereafter, the scope, delimitations and thesis disposition is presented, as well as a brief background to GKN Aerospace Engine Systems.

1.1 Background

The world's leading quality management standard, ISO 9001, is currently under revision and at the final draft stage. The new version can be expected by the end of 2015, where the major change is the incorporation of risk based thinking (ISO.org, 2015-05-19). According to Dr. Nigel Croft, chairman of the ISO 9001 committee, the new standard will be built upon three cornerstones; the process approach, the PDCA-cycle and the newly added risk based thinking (ISO.org, 2015). He motivates the incorporation of risk based thinking by stating that:

"A quality management system is about prevention of problems by anticipating what might go wrong and doing things to avoid producing non-conforming products. We have to recognize that not all processes are equal (...) and understand how different processes may affect the outcome that we want to achieve."

The link between quality management and risk management has according to Perkins (2011) been a growing topic of conversation, where risk management is sometimes entitled as "the future of quality management". He further discusses a shift from reactive approaches of controlling variances, to proactively eliminating potential sources of failure. Popescu et al. (2011) view risk management and quality management as two sides of the same coin; quality is the measure of satisfying the requirements, whereas risk measures the weight of unfavorable situations and deviations from the requirements. However, the area of risk management is not only evolving through the integration of quality management. According to Anderson (2009), sustainability is a newly emerging risk area and will be one of the critical areas of the 21st century. He argues that even though excellent books have been written on sustainability, no one has approached it using a risk management framework or recognized that it needs to be approached in this manner.

As a research area, risk management receives much attention within product development since risk reduction is a method to control costs, schedule and technical performance (Oehmen et al. 2014). Cooper (2003) argues that in order for new product development to be successful, effective strategies for reducing risk are required. The extent to which risk management needs to be implemented is according to Croft (2015) governed by the context of the organization. Demanding organizations, within a high-tech environment, may need a full risk management approach while others only need a partial implementation. One industry, which Hobday (1998) categorizes to have high-tech and complex products/systems is the aerospace industry. New and uncertain technologies are a commonality, which is
also confirmed by Altavilla and Garbellini (2002). In addition they characterize the industry as having long development schedules and high risks, due to the severity of the consequences in case that something goes wrong.

Dostaler (2010) argues that the failure of one single component in an aircraft could have catastrophic consequences and cause fatal casualties. The industry is therefore highly regulated and new aerospace vehicles must go through a rigorous and detailed certification process. This means that considerable efforts are needed to produce defect-free aircrafts and assure flight safety. Dostaler (2010) further argues that despite this, companies within the aerospace industry lack efficiency within risk management. They tend to rely on various safety nets and non-value adding activities to ensure that the quality objectives are met. Further, Lee et al. (2009) argues that the aerospace industry needs to take issues of variation into account better. Designing structures for robustness will increase the survivability of the products. These conditions make this specific industry interesting from a risk management perspective, and suitable to study further.

One of the world’s largest first tier suppliers in the aerospace manufacturing industry is GKN Aerospace. At the facility in Trollhättan, Sweden, most of the product development of the subdivision GKN Aerospace Engine Systems take place. At this site engine components for the commercial and military sector, as well as components within space propulsion, are produced. This makes them a well-suited subdivision to investigate and will be the chosen main object of investigation for this study.

GKN Aerospace Engine Systems (henceforth referred to as GKN) is regulated by the SAE Aerospace Standard AS9100C, an international standard that sets quality management requirements for aviation, space and defense organizations. The standard incorporates the requirements of ISO 9001, but primarily focuses on flight safety. In the standard, risk is defined as:

>A undesirable situation or circumstance that has both a likelihood of occurring and a potentially negative consequence."

In contrast to the AS9100 standard, the risk management standard ISO 31000 has a more opportunistic view and defines risk as:

>"Effect of uncertainty on objectives", where effect is defined as a "deviation from the expected, and can be either positive or negative".

The ISO 31000 standard has recently been implemented at GKN and ISO’s definition of risk will be used henceforth in the thesis when discussing risk management.
1.2 Problem discussion

According to Cooper (2003), only in a perfect world would it be possible to manage all risks within a project. Due to limited resources, the author argues that we have to decide which risks to explore and reduce. Effective risk management is therefore of great importance. The aerospace industry is characterized by Altavilla and Garbellini (2002) as a complex industry, with long development schedules and high risk due to the severity of consequences. At GKN the development of a new product for the civil aircraft industry typically takes 5-7 years, and up to 20 years within the space programs. The long time to market causes difficulties to determine the severity of future risks, as the knowledge and technology maturity is low in the early phases of technology and research. (GKN, 2015)

This situation causes risk management to become a central element within product development, and the need for proactive practices is clear. Proactivity is in this thesis defined as

"Preventative measures taken in advance in order to reduce uncertainties and mitigate risks. These measures can be either be tools, practices or a general mindset."

Furthermore, Thornton (2004) emphasizes that the commitment to future costs in projects are increasing as the project progress. In other words, the costs of changing from one concept to another become higher the further you move into a project. Oehemen et al. (2014) states that most of the risks are not detected until they have an impact on project’s performance. In other words, it becomes a reactive approach similar to a contingency plan.

To summarize, there seems to be a both a great need and opportunity for organizations to be more proactive within risk management, especially in complex industries as the aerospace industry. Academic databases verify that risk management is a rather explored research area, but research that focuses on proactive approaches within risk management appears to be scarce.
1.3 Aim of the Thesis

The aim of the thesis is to – in the different phases of product development – understand how a company in the aerospace industry can work with risk management in order to become more effective and proactive. The thesis does not only focus on the traditional risk management tools, but also to identify alternative proactive practices which are used to reduce uncertainties and mitigate risks. In order to develop a better understanding and get ideas, alternative practices will be investigated. This will create a foundation of how the risk management practices at GKN can be developed. The following research questions have been formulated to fulfill the aim of the thesis

RQ1 – How does GKN work proactively with risk management in their product development processes?

RQ2 – How can manufacturing companies work proactively with risk management within their product development processes?

RQ3 – How can the risk management practice be developed at GKN in order to become more proactive in their product development processes?

1.4 Scope and delimitations

The thesis does not focus on creating new proactive approaches and tools within risk management, but to identify those which creates proactivity within product development. Therefore, the study will be limited to identifying practices that can complement risk management, in the pursuit of becoming more proactive. The whole product development phase must be taken into consideration, but the main focus will be from the “conceptual design” phase to the “final design” phase of the product development process. This is where the majority of the product risk management activities at GKN are carried out and therefore where the greatest potential of improvements lies. The study will have a primary focus on product risk management, but additional activities such as project risk management is also needed to be taken into account. Lastly, the study will not give a large focus on the implementation of the recommendations.
1.5 Background to GKN Aerospace

Worldwide GKN Aerospace has over 12,000 employees and is part of the global group GKN plc. The subdivision GKN Aerospace Engine Systems grew considerably in 2012 by acquiring Volvo Aero Corporation in Trollhättan. Mike Beck, previous CEO of the subdivision, stated that

“GKN plc has had a strategy of growing the engine business by acquisitions and doing that organically to the same size as the aero structure division would take too long time. Volvo Aero came with some excellent capabilities from an engineering standpoint is very respected by their customers and creates a partnership relationship with original equipment manufacturers.” (Beck, 2012)

In total, GKN plc employs approximately 51,400 people, operates in 32 countries and within four divisions; GKN Aerospace, GKN Driveline, GKN Powder Metallurgy and GKN Land Systems. GKN Aerospace develops a variety of complex and high-performance components within the aerospace industry. The products cover areas from metallic/composite assemblies for aero structures and engine products to glass and polycarbonate transparency systems. They mainly supply customers within the civil aircraft industry, where their components can be found in over 90% of all new airplanes. Other customers are found within the military aircraft industry and space industry. At the production site in Trollhättan combustion chambers and nozzles are produced for Ariane 5 rocket as well as the RM12-engine for the JAS 39 Gripen. (GKN plc, 2015)

As mentioned before, the aerospace industry is characterized by a combination of high safety demands and advanced solutions in a number of areas, often placing them in the frontier of technological development and production methods. One of these areas is fabrication, where GKN claim themselves to be one of the leading companies in the world and uses the slogan “make it light”. The fabrication method of using welded structures, consisting of a combination of different materials, means
that the traditional, heavy and casted structures can be replaced. However, using fabrication means that the number of production steps increase for fixturing, welding and inspections. This causes increased variability and a need to early address these issues in the research and development phase to create a robust design and manage the risks.

*Further information about GKN regarding risk management can be found in chapter 4. Risk Management at GKN Aerospace.*

### 1.6 Thesis Disposition

The disposition of the thesis is explained in further detail in Table 1.1.

**Table 1.1 - The disposition of the thesis**

<table>
<thead>
<tr>
<th>Section</th>
<th>Describes…</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Introduction</td>
<td>… the background to the chosen research area, the problem discussion and the aim of the thesis. This is followed by the scope and delimitation, some brief background information about GKN Aerospace and the thesis disposition.</td>
</tr>
<tr>
<td>2. Method</td>
<td>… how the thesis was conducted in terms of research purpose, strategy, approach, data collection, sample selection, data analysis, reliability and validity.</td>
</tr>
<tr>
<td>3. Theoretical frame of reference</td>
<td>… the theory and literature which is used to build the framework that will be used in order to answer the research questions, by comparing the findings in the case study.</td>
</tr>
<tr>
<td>4. Risk Management at GKN Aerospace</td>
<td>… the empirical findings from the case study at GKN Aerospace in Trollhättan.</td>
</tr>
<tr>
<td>5. Alternative Risk Management Practices</td>
<td>… the findings from benchmarking interviews at Volvo Construction Equipment and Autoliv.</td>
</tr>
<tr>
<td>6. Analysis</td>
<td>… the similarities and differences between the empirical findings and the theoretical frame of reference.</td>
</tr>
<tr>
<td>7. Conclusion</td>
<td>… a summary of conclusions drawn from the analysis</td>
</tr>
<tr>
<td>8. Recommendations</td>
<td>… recommendations based on the analysis and conclusion</td>
</tr>
<tr>
<td>9. Discussion</td>
<td>… the evaluation of the used methodology, the result and whether the research questions have been answered. Finally a discussion regarding validity, reliability and suggestions for further research will be brought up.</td>
</tr>
</tbody>
</table>
2 Method

This chapter presents the research purpose and research approach, which together with the research strategy were used to answer the research questions. A discussion of the data collection, sample selection and analysis method is also covered, followed by a discussion regarding validity and reliability.

2.1 Summary of Method

Saunders et al. (2009) state that the research design is the general plan of how the researcher will go about answering the research questions. This plan contains clear objectives, derived from the research questions, and includes strategies for how data will be collected and analyzed in order to fulfill the purpose of the research. Table 2.1 presents a summary of these choices.

<table>
<thead>
<tr>
<th>Method Overview</th>
<th>Chosen Method</th>
</tr>
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<tbody>
<tr>
<td>2.2 Research Purpose</td>
<td>Exploratory</td>
</tr>
<tr>
<td>2.3 Research Approach</td>
<td>Abductive, Qualitative</td>
</tr>
<tr>
<td>2.4 Research Strategy</td>
<td>Case Study, Survey</td>
</tr>
<tr>
<td>2.5 Data Collection Methods</td>
<td>Primary Data: Semi-structured Interviews</td>
</tr>
<tr>
<td></td>
<td>Secondary Data: Archival Research</td>
</tr>
<tr>
<td>2.6 Sample Selection</td>
<td>Non-probability sampling: Judgmental, Convenience</td>
</tr>
<tr>
<td>2.7 Analysis method</td>
<td>Within-case analysis, Cross-case analysis</td>
</tr>
<tr>
<td>2.8 Research Credibility</td>
<td>See chapter 2.8 for detailed descriptions</td>
</tr>
</tbody>
</table>

2.2 Research Purpose

According to Saunders et al. (2009) the most common classification of research purpose is the threefold one of exploratory, explanatory and descriptive. Ghauri and Grønhaug (2005) argue that an exploratory research problem can be seen as unstructured, in contrast to an explanatory and descriptive purpose, which is structured. The research purpose does not have to be singular, according to Saunders et al. (2009), as the research might have questions addressing problems at different depths. Yin (2003) similarly emphasizes that even though the purposes may have different characteristics, the boundaries between them are not always clear and may overlap. Robson (2002) argues in a similar way, but underlines that the purpose may change over time as the enquiry of the study changes.
Ghauri and Grønhaug (2005) state that in a descriptive research, the problem is structured and well understood. Saunders et al. (2009) further argues that it is necessary to have a clear picture of the phenomena on which you wish to collect data, prior to the collection of the data. An explanatory study instead seeks to explain the causal relationship between two or more variables (Ghauri & Grønhaug, 2005). For this study, the research problem was neither structured, nor well understood. Furthermore, the objective was not to determine any causal relationships between variables, but rather to identify proactive practices within risk management.

The purpose of this study was exploratory due to the lack of knowledge within the research area. An exploratory study can according to Saunders et al. (2009) be compared to the activities of a traveler or an explorer, with the great advantage of being flexible and adaptable to change. They further argue that the flexibility does not mean absence of direction to the enquiry. The focus is initially broad and becomes narrower as the research progresses. Within this thesis a similar process was used, which initially had a broad focus within the product development process and approaches of handling risks. As the study progressed, this focus was narrowed down into more specific phases of the product development and specific approaches within risk management.

### 2.3 Research Approach

Ghauri and Grønhaug (2005) state that there are two approaches of drawing conclusions and establishing what is true or false; induction and deduction. However, both Björklund and Paulsson (2003) and Saunders et al. (2009) argue that these can be combined, creating an abductive approach, which in some cases can be advantageous. The research approach can further be divided by the kind of data collected, where a deductive technique usually uses quantitative data and an inductive uses qualitative (Saunders et al. 2009).

A qualitative method is often used when the researcher seeks to develop a deeper understanding within the research area or when data cannot be measured or evaluated in numbers (Björklund & Paulsson, 2003). However, Saunders et al. (2009) clarifies that both a qualitative and quantitative research approach can be combined within the same study. Surveys and mathematical models are better suited for a quantitative method, whereas interviews or observational studies are more appropriate for a qualitative approach (Björklund & Paulsson, 2003).

The deductive approach has its origins in the natural science and uses existing theories as a foundation to formulate the research problem (Saunders et al. 2009; Björklund & Paulsson, 2003). Based on this foundation, the researcher forms predictions around the research problem, which he or she then seeks to verify by empirical findings (Björklund & Paulsson, 2003). Conversely, an inductive approach starts by the collection of empirical data to investigate a problem or situation (Saunders et al., 2009). Björklund and Paulsson (2003) clarifies that this means that
a subject can be studied without any prior knowledge or collection of theory, instead new theory is formed based on the conclusions from the empirical findings.

The third alternative of using an abductive approach combines the other two approaches and moves from one abstraction level to another (Björklund & Paulsson, 2003). According to Saunders et al. (2009), the researcher alternates from collection of empirical data and explanation of patterns with the objective of generating new theory, which again is tested against additional data.

This study was conducted with an open mind, using conventional theories within risk management as well as other theories/practices in the pursuit of finding ways to become more proactive. The thesis can therefore be considered to have used an abductive approach, as theories were studied parallel to the data collection and the theoretical framework was developed as data were collected. Furthermore, the thesis is mainly built on qualitative data collected from interviews and internal documents but a survey was also conducted with both quantitative and qualitative questions. The survey was used in order to map the current situation and the more qualitative questions gave the opportunity to compare different departments, roles, etc. within the product development.

2.4 Research Strategy

According to Yin (2003), the research strategy is dependent on the research purpose, but most importantly on the formulation of the research question. Saunders et al. (2009) emphasize the importance of a choice that sufficiently meet the objectives of the research and answer the research questions. Both Yin (2003) and Saunders et al. (2009) stress that no research strategies are superior or mutually exclusive, even though this seems to be a common misconception. Furthermore, these authors argue that it is possible to use multiple strategies within one study and there are no limitations to which strategy works with which research purpose. Yin (2003) suggests five research strategies - experiment, survey, archival analysis, history, and case study - which are described in detail in Table 2.2.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Form of Research Question</th>
<th>Requires Control of Behavioral Events?</th>
<th>Focus 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>
As all research questions in this thesis were formulated as “How”-questions, none of the strategies could initially be excluded based on the suggestions from Yin (2003). However, since this study did not require control over behavioral events and the focus was not on contemporary events, the experimental and historical strategies were excluded. This left survey, archival research and case study as potential research strategies to use.

In the thesis, a case study was used as the main focus was on one specific company and process. Saunders et al. (2009) describe case study as a study involving an empirical investigation of a contemporary phenomenon within its real life context, which makes this strategy appropriate for this thesis.

Ejvegård (2003) explains that the purpose of a case study is to examine a specific process in a larger context, which can be used to draw conclusions and make generalizations. However, Ejvegård also stresses that there is a great risk of letting one case be representative for the whole situation. The conclusions from cases can rather be seen as circumstantial evidences, which do not gain a true value until other case studies come to similar conclusions. In order to overcome this obstacle, two other manufacturing organizations within related industries were studied parallel to the case at GKN. These were Volvo Construction Equipment in the construction equipment industry and Autoliv in the automotive safety industry. This gave an opportunity to investigate how different companies work with risk management. It also gave the possibility to find similarities and positive elements in different approaches.

As organizations within the aerospace industry are governed by the requirements of the aerospace standard AS9100, they can be seen as suitable for a case study within the research area. They are forced to work in similar ways in accordance to the quality management system of the standard. This increases the external validity as the conclusions become more generalizable to the aerospace industry.

2.5 Data Collection Methods

Yin (2003) states that there are six important sources when collecting data in a case study; documentation, archival records, interviews, direct observation, participant-observation and physical artifacts. According to Yin (2003) and Saunders et al. (2009) the different techniques are often used in combination.

Ghauri and Grønhaug (2005) and Saunders et al. (2009) categorize data into primary and secondary data, where primary data is collected for the purpose of the study and secondary data is information collected by others. In this study both primary and secondary data have been used. Furthermore, data were collected through a survey, interviews and search of literature to find variables relevant to the research area, which according to Saunders et al. (2009) is a suitable way to conduct an exploratory study. Figure 2.1, describes how data were collected,
CHAPTER 2 - METHOD

processed and its connection to the research questions, which is further described in this chapter.

Figure 2.1 – Data collection process in relation to the research questions

2.5.1 Primary Data

Saunders et al. (2009) states that there are three ways of collecting primary data; interviews, observation and questionnaires, whereas Ghauri and Grønhaug (2005) in addition mention experiments. Björkund and Paulsson (2003) describe interviews as way of collecting primary data through different forms of questioning and Yin (2003) entitles it as the most important source in a case study. Both Ghauri and Grønhaug (2005) and Saunders et al. (2009) bring up three types of interviews; structured, semi-structured and unstructured interviews. The difference between the types are in the way they are conducted. A structured interview is according to Saunders et al. (2009) often used to collect quantitative data and therefore best suited for a survey strategy. The authors further argue that both semi-structured and unstructured interviews can be useful in an exploratory study when collecting qualitative data. The difference between the forms is, according to Ghauri and Grønhaug (2005), how the interview has been determined in advance.

The main method of collecting data within this thesis was through interviews, conducted at both GKN and the benchmarking organizations. The interview templates can be seen in Appendix 3-4. At GKN 16 interviews were conducted with the purpose to help answer RQ1, whereas the benchmarking interviews gave input to RQ2. In the benchmarking, a single extensive interview was conducted at each organization. However, since it just was one interview the focus was not to go in depth but to cover areas of interest for the study.

Before the interviews, a survey was conducted at GKN, which gave a better understanding of the problem and was also used in order to answer RQ1. The survey was sent out within GKN’s intranet to four different departments connected to product development. In total 87 employees received the survey and 45 of these
answered (52%). The result also gave input for the interviews as the survey was not anonymous, which meant that specific responses could be traced to certain employees who could be interesting to interview further. In other words, this information was used in the sample selection of the interviews and as an input to construct the interview questions.

For the interviews conducted in this thesis, topics and questions were prepared in advance. During the interviews all topics were covered, but the focus of the interview was allowed to vary dependent on the answers of the interviewee. The interviews could therefore be categorized as semi-structured, since they were prepared but also gave opportunities for follow-up questions and discussions. In addition, informal conversations were held at different occasions with employees at GKN, similar to unstructured interviews.

2.5.2 Secondary data

According to Ghauri and Grønhaug (2005), examples of secondary data are books, journal articles and online data sources. Using these sources can save considerable amount of time and money, as well as a mean to get a better understanding of the research problem and to find information to solve the problem. Saunders et al. (2009) have constructed three groups of secondary data; documentary data, survey-based data, and data compiled from multiple sources.

For this thesis books, journals and databases were used, which according to Saunders et al. (2009) can be categorized as documentary secondary data. Literature and scientific articles were used to add an academic perspective when building the theoretical framework. In order to build the empirical collection, industry standards, internal documents and GKN’s internal Operation Management System (OMS), were used. This primarily gave a foundation and understanding of the practices at GKN, which was needed in order answer RQ1.

2.6 Sample Selection

Saunders et al. (2009) argue that non-probability sampling is often used for exploratory and qualitative research, while probability sampling is associated with survey and experimental research strategies. Limited resources and short time frames often forces researchers to choose non-probability sampling techniques. As time and resources were constraints within this thesis, convenience and judgmental sampling were combined in the collection of primary data. Ghauri and Grønhaug (2005) state that in convenience sampling the researcher creates a sample based on what is most convenient, whereas a judgmental sample is based on the researcher’s judgment of the selection criterion that creates a representative sample.

Using these sampling techniques raises some concerns regarding whether or not the sample will be representative. Therefore, the supervisor and reference group at GKN played a role in the selection of a sample. They ensured that the chosen sample
was representative for different roles and departments. They also ensured that the interviewees had worked at GKN for a while and had experience and knowledge within the research area. The survey was however handed out to all employees within four different departments, all connected to the product development process. Employees whose tasks did not involve product risk management could be redirected to the end of the survey by using “branching logic”.

Lastly, the less extensive cases in the benchmarking study were selected using a judgmental sampling technique. Both companies naturally have a large focus on safety and risk management; Autoliv develops and manufactures safety solutions within the automotive industry and Volvo CE use "Safety" as one of their three core values.

2.7 Analysis method

According to Yin (2003) and Saunders et al. (2009) there are several ways of analyzing a case study. The process of analyzing qualitative data occurs according to Saunders et al. (2009) many times during the data collection and it can be seen as an interactive procedure. In order to support meaningful analysis they further promote three types of processes to group data; summarizing, categorizing and structuring of meanings using narrative. The different types can be used individually or in combination.

Summarizing is a method of reducing data from interviews or organizational documents, with the purpose of identifying potential relationships between different themes. Categorizing is a method of sorting data into different categories. By doing this it is possible to recognize relationships and further develop categories, making it is possible to develop and test propositions. The narrative approach is often used to analyze data collected from unstructured interviews. (Saunders et al., 2009)

Yin (2003) addresses the importance of both having a clear strategy when analyzing a case study and knowledge of what to analyze and why. Further, he discusses five analytic techniques; pattern matching, explanation building, time-series analysis, logic models and cross-case analysis.

A cross-case analysis is relevant when the research consists of more than one case where each case should be treated as a separate study. It is then possible to create word tables that describe data from the different cases. Patterns and differences from the word table can then be investigated. (Yin, 2003)

Yin (2003) states that the different techniques cannot be used straight off, they need to be adapted. In this thesis the interviews were analyzed by a combination of what Saunders et al. (2009) describe as summarizing and categorizing. The interviews were first transcribed and after that summarized in order to point out the most relevant information. Data from different interviews were then categorized into four
areas; Product Risk Management and FMECA, Robust Design, Design for Manufacturing and Lessons Learned. Since the case at GKN was more extensive, opinions from different roles were also separated with the purpose to investigate differences within the organization.

After the data had been processed, a cross-case technique was used even though the scope of the cases were not fully comparable. The method was used in order to investigate differences and similarities, in an attempt to find stepping-stones to develop the current risk management practice at GKN. The analysis also had input from theory with the purpose to get a wider approach and an academic perspective.

Since the survey was both qualitative and quantitative it was analyzed with two different approaches. The quantitative data were analyzed by using pivot tables in MS Excel, in order to investigate patterns and correlations between employees’ views in risk management and their background. The qualitative data, collected from the open text questions, were analyzed by using an affinity diagram. According to Klefsjö (1999) this is a useful tool when a big amount of verbal information needs to be structured in order to identify or describe a problem. Klefsjö (1999) describes the process of using an affinity diagram as a team activity, in this case however the answers from the survey are represented by the team’s opinions. Different opinions concerning difficulties and obstacles of performing risk management were categorized and given headlines, which was used when mapping the current situation at GKN. This result was then used in a workshop, where design leads ranked the different headlines.

2.8 Research Credibility

Bell (2006) emphasizes that no matter which research design that has been used it has to be critically reviewed in order to determine if it is reliable and valid. Saunders et al. (2009) argues that findings can never completely be proven and all that can be done is minimizing the risks of getting the answer wrong. Therefore, the researcher must address issues regarding reliability and validity of the research design.

2.8.1 Reliability

Reliability is a measurement of the extent to which an instrument will give the same findings over time, performed during the same circumstances (Bell, 2006; Yin 2003). Therefore, the goal of reliability is to minimize the errors and biases in a study (Yin, 2003). According to Saunders et al. (2009), this can be achieved by questioning; if the measurements will yield the same results on other occasions, if similar observations will be reached by other observers and if there is transparency in how sense was made from the raw data.

In this study the primary data were the survey and transcriptions from the semi-structured interviews. Saunders et al. (2009), points out that the lack of standardization in unstructured and semi-structured interviews, may lead to
concerns regarding reliability and interviewer bias. After transcribing the recorded interviews, the raw data needs to be reduced, categorized and sorted in order to become comparable. In order to avoid issues regarding reliability, the interviewees were given the possibility to review the transcription. Furthermore, Saunders et al. (2009) argue that interviewee bias often become an issue in case studies within organizations, as interviewees may answer what they believe their bosses want them to say. In order to reduce this risk the interviewees were anonymous and they were also told that they would not be mentioned by name in the report.

Some measures were taken in order to address issues concerning the reliability of this study. First of all, a number of questions prior to the actual interviews were asked in order to define the business area of the interviewee and experience within risk management etc. Secondly, triangulation - defined by Björklund and Paulsson (2003) as method of increasing reliability - was used in the theoretical frame of reference and method. It was also used within the empirical study by combining different data collection methods. Further, conducting multiple interviews with different employees with the same role at GKN increased the credibility. In order to gain different perspectives of product risk management, interviews were held with a number of different roles within the whole product development process.

2.8.2 Validity

The validity of a research refers to which extent the research actually measures what it was intended to measure (Yin, 2003; Ejvegård, 1995; Saunders et al., 2009). Saunders et al. categorizes it further into two separate types; internal and external validity, whereas Yin (2003) and Ghauri & Grønhaug (2005) also discusses a third type, construct validity. These can be described as

- **Construct validity**: The extent to which an operationalization measures the concept which it intends to measure (Yin, 2003)
- **Internal validity**: Extent to which we can infer that a causal relationship exists between two or more variables (Ghauri & Grønhaug, 2005)
- **External validity**: Establishes the domain to which a study’s findings can be generalized (Yin, 2003)

As this study had an exploratory purpose and did not seek to find and measure causal relationships, internal validity was only partially taken into consideration. Yin (2003) points out that internal validity is solely discussed within causal and explanatory studies, not exploratory.

In order to increase the validity, Björklund and Paulsson (2003) emphasize the importance of creating questions that are well-formulated and unbiased. Saunders et al. (2009) further argues the importance of finding a representative sample. This study used a judgmental sample selection technique in an attempt to create a representative sample where the supervisor at GKN had a major role of contacting the most suitable employees. In order to broaden the perspective, each interviewee
were also asked to recommend other employees which may have interest in being interviewed. This can be seen as a way of trying to strengthen the external validity, which Moutinho and Hutcheson (2011) define as the quality of a research design, such that the results can be generalized from the original sample and is representative to the whole population.

Some of the measures taken to increase the reliability of the study did also increase the validity, e.g. to send the transcriptions to each respondent in order to give them an opportunity to explain and change inaccuracies. Similarly, interviewees were in some cases contacted after the interview in order to elaborate on vague answers. Methods of triangulation were used with the intent of increasing the validity, as Björklund and Paulsson (2003) argue is a way of achieving this. Finally, construct validity was taken into account by following the recommendations of Yin (2003); usage of multiple sources of evidence, establishing a chain of evidence and letting key informants go through the case study.
3 Theoretical Frame of Reference

This chapter presents a theoretical frame of reference which creates an understanding for the research area and a foundation used in the analysis in order to draw conclusions about the research findings. The chapter starts by describing chosen theories and its connection to the research area.

3.1 Introduction to theories used in the thesis

This thesis was conducted with an exploratory research purpose and the theoretical frame of reference was therefore developed along the way. Figure 3.1 is a mind map used in the development of the theoretical frame of reference. All areas have been investigated in the initial phases of the study, but the underlined ones are those who were used and are covered in this chapter. The risk management circle cover the traditional risk management tools whereas the proactivity circle cover areas that are seen as proactive within the product development process. In the center of the figure lies the standards, ISO 31000 and AS 9100, with requirements that GKN must fulfill.

![Mind map used in the development of the theoretical frame of reference. The underlined headings are the areas covered in this chapter](image-url)
3.2 Product Development

Thornton (2004) defines product development as missions performed to bring products to markets that satisfy a customer need. The process includes the whole process of developing, from gathering of customer requirements and designing, to manufacturing and shipping. Cooper (2003) similarly defines it as a process to create or improve a product. He further states that one of the biggest challenges within product development is to reduce the time and development cost without sacrificing innovation. The process is often divided into several phases where Thornton (2004) describes a typical process with the steps seen in Figure 3.2.

Bergman and Klefsjö (2012) address the importance of creating conditions for product quality during the product development. They also emphasize the importance of avoiding late changes in the design, especially in production phase as costs of implementing changes increase for each phase. This is illustrated in Figure 3.3 by Thornton (2004), which shows the product development teams' possibility of affecting cost and quality by the "cost reduction opportunities" and the "cost of implementing change". The early design phases are therefore crucial, which is also pointed out by Kerley et al. (2011) who estimate that 70%-80% of life cycle costs are determined during the design phase.

![Figure 3.2 - Typical phases of a product development process, adapted from Thornton (2004)](image)

![Figure 3.3 - Product development teams' possibility of affecting cost and quality by the "cost reduction opportunities" and the "cost of implementing change", Adapted from, Thornton (2004) s.6](image)
3.3 Risk Management

According to Ammar et al. (2007), unexpected events often cause deviations from the project plan, which can either have a positive or negative effect. This causes a need of risk management, which Oehemen et al. (2014) describe as a method to improve cost, schedule and technical performance within product development. Baxter (1995) argues that risk management is a way to get products to market and ensure that; it satisfies the customer, is for its intended purpose, fulfil its expected lifetime and can be produced at an acceptable cost.

3.3.1 ISO 31000

The International Organization for Standardization (ISO) is a worldwide federation of national standards. ISO is an independent, non-governmental membership organization, which is based on a collaboration between 163 countries. The risk management standard ISO 31000 was published in 2009 and can be applied in many different ways, areas and at any time in entire organizations to specific projects and activities. It is a generic guideline for managing any form of risk and the relationship between the principles, framework and process is shown in Figure 3.4 (ISO.org, 2015)

![Diagram of ISO 31000 principles, framework, and process]

*Figure 3.4 – An overview of the principles, framework and processes of the ISO 31000 standard. Adapted from ASQ.org, 2015*
The ISO 31000 is based on a number of principles, which guides organizations towards effective risk management. It also consists of a framework that, according to ISO, will help organizations to integrate risk management to the overall management system. Finally, the standard presents a process, which is the actual practice to work with and handle risks. It starts with establishing the context followed by risk assessments that involves identification, analysis and evaluation. The process ends with risk treatment and all this should work as an iterative procedure. In each stage of the process there is an input from external stakeholders and plans for communication should be developed in an early stage. (ISO.org, 2015)

3.3.2 The Swiss Cheese Model

According to Reason (2000) the cause of human errors can be viewed in two ways; either with a person approach or a system approach. The person approach focuses on the errors of individuals, where they are blamed for their forgetfulness, inattention or moral weakness. The system approach instead originates from the basic premise that people are fallible and errors are to be expected. Reason (2000) further argues that:

“We cannot change the human condition, but we can change the conditions under which humans work”

Therefore, the system approach tries to create defenses, barriers and safeguards within the organization to avert errors or mitigate their effects. Reason chose to illustrate these defensive layers with the so-called Swiss Cheese Model, see Figure 3.5. In an ideal world each defensive layer would be completely intact, but rather like slices of Swiss cheese they have many holes. However, unlike the cheese these holes constantly shift position, open and close. Holes in one layer do not normally cause a bad effect, but when holes from many layers momentarily lines up a trajectory of accident opportunity appears. (Reason, 2008)

![Swiss Cheese Model](image)

Figure 3.5 The Swiss Cheese Model. Adapted from Reason (2008, p.76)

The holes may appear for two separate reasons; either because of active failures or latent conditions. Active failures are unsafe acts performed by employees who are in direct contact with the system. One example of this is in the Chernobyl accident of
1987, where operators violated plant procedures and switched of successive safety systems (Reason, 2000). Latent conditions are the circumstances which may cause potential failures in the future. These could be caused from the organizational processes or culture within the company, or simply arising from decisions taken by e.g. designers, top level management. (Reason, 2008)

3.4 FMEA

FMEA is an acronym for Failure Mode and Effects Analysis and is described by Thornton (2004) as a tool to identify and assess possible failure modes and causes. The tool was, according to Bergman and Klefsjö (2012), developed in the 1960s and has been used in the Swedish aerospace industry since. However, they also mention an extended version of the tool called FMECA, where a Criticality Analysis is added. This tool is common in the aerospace and military industry and today many companies involve the criticality analysis but still calls it FMEA. As these two tools have grown together and all three cases of this study include the criticality analysis in their FMEA:s, these terms are used synonymously henceforth in the report.

Bergman and Klefsjö (2012) describe FMEA as a useful tool for reliability analysis, as well as a systematic approach of reviewing a product or process, from the perspective of its functions, failure modes, causes of errors and consequences. Figure 3.6 illustrates an example of a FMEA flow.

![FMEA workflow](image_url)

**Figure 3.6** – FMEA workflow. Adapted from Hassan (2007, p. 224)
Both Thornton (2004) and Bergman and Klefsjö (2012) states that a FMEA mostly is conducted in a qualitative way when failure modes, causes and consequences are analysed. The purpose is according to the authors to proactively identify potential problems and assess how to avoid or reduce the consequences. Thornton (2004) defines the process as a brainstorming phase where failure modes are identified and ranked based on the criticality, which can be determined by the severity, occurrence and possibility of detection. Severity concerns the degree of impact to the customer, occurrence is the likelihood of the failure event occurring and detection is the possibility to detect the failure before impact. These three aspects are multiplied after they have been ranked from 1-10, which gives a Risk Priority Number (RPN) that can be used to effectively priorities the risks.

According to Thornton (2004), the evaluation and selection of design concepts should consider the ability to achieve quality targets, such as technical requirements. Thornton further states that a preliminary FMEA is often made at the concept phase in order to identify failure modes for both the product and manufacturing processes. Britsman et al. (1993) describe that a FMEA should be conducted when there is a change in the product or a process and the work should be based on an effective management of experience, available data and competence.

A FMEA can according to Bergman and Klefsjö (2012) be divided into a Design-FMEA (D-FMEA) and Process-FMEA (P-FMEA). The D-FMEA focuses on the product and its ability to fulfill customer requirements were the P-FMEA focus on the manufacturing process and its impact to the product. Britsmana et al. (1993) further explain the work as a team activity where employees with different experiences and competences are gathered. The team should include employees with technical knowledge about the system, knowledge about FMEA-method and a person defined to lead the work. Furthermore, Britsman et al. (1993) states that it is preferable if the result from the D-FMEA is available when performing a P-FMEA. Actions to avoiding failures coming from the P-FMEA can then result in design changes. Here, employees with knowledge about the process can be involved in the D-FMEA as well as designers can be involved in the P-FMEA.

Finally, Thornton (2004) addresses some limitations with applying FMEA to variation sensitive issues. These are:

- The ability to handle complex situations when a single source can impact several failure modes. In this kind of situations it is difficult to document and trace effect from a system failure to part dimension.
- The RPN can sometimes be misleading due to the probability of detection factor. For example; If a critical problem has a high consequence and high probability to occur but is easy to detect, it will gain a relatively low RPN-number. Therefore the design team will not prioritize a redesign which lowers the severity and occurrence factor.
- The variation-specific issues are not separated from other design related issues.
3.5 Robust Design

Bergman and Klefsjö (2012) states that all products are exposed to different forms of variation during the product life-cycle. It may be variation caused from different customers’ use, variation from use in different environments or variation in the production and assembly processes. Designers and product developers must therefore seek to use their own and others´ experiences to make trade-offs with regard to such variations, in order to create a robust design. The term robust design refers to various different practices, with the common goal of reducing the occurrence and impact of variation during the whole product life cycle. (Bergman and Klefsjö, 2012)

The state of Robustness is defined by Taguchi et al. (2000) as:

“Where the technology, product or process performance is minimally sensitive to factors causing variability (either in the manufacturing or user’s environment) and aging at the lowest unit manufacturing cost.”

In order to address these issues of variability, these factors are classified as either controllable or uncontrollable (noise variables). The aim is to find the setting for the controllable variables that minimizes the variability transmitted to the response from the uncontrollable variables (Montgomery, 2013). Yang and El-Haik (2003) argue similarly, but emphasizes that it is in general impossible or too expensive to eliminate noise factors. However, the effect of the noise factors can be reduced through the use of robust design.

During a whole life-cycle a product system is exposed for various sources of variation. Bergman and Klefsjö (2012) have divided these into five different sources of variation.

Variation from unit to unit - This is derived from the different sources of variation of the production processes. It is the variation between different units produced using the same specification.

Variation caused by use - The variation caused by wear and tear of the product and changes to the product during its use.

Variation caused by misuse of the product - It can both be the variation of how one specific customer uses the product from time to time and how different customers use the product. This also includes the misuse, the differences from what is intended by the producer.

Variation caused by the environment - Changing the circumstances in the environment where the product is use causes variation, e.g. temperature, humidity and vibration.
Variation caused by system interaction - This is especially important in today’s pursuit of modularization within organization. One module must work flawless in different system environments.

According to Bergman and Klefsjö (2012), organizations have traditionally argued that as long as the parameters of their products are held within the tolerance interval, the economic loss is equal to zero. An economic loss does not occur until the parameter is outside the tolerance interval. This viewpoint was already questioned by Dr. Walter Shewart in the 1930s and was developed by Genichi Taguchi in the 1950s. He argued the loss from a deviation of the target is quadratic to the size of that deviation. This has been entitled as Taguchi’s loss function, which is illustrated in Figure 3.7.

Figure 3.7 – The traditional view of costs related to process variation (to the left) and the Taguchi loss function (to the right). Adapted from Bergman and Klefsjö (2007, p.216)

3.6 Variation Risk Management

According to Thornton (2004), variation in processes impact many aspects of operational efficiency and lead to increased waste and reduced profit. Thornton further describes variation risk management (VRM) as an approach that will help to allocate limited resources to variation control in order to improve quality and reduce cost as effectively as possible.

VRM can according to Thornton (2004) be used both proactively within product development and to an existing product. Furthermore, the method is based on the ideas of a holistic view of variation and a process that involves identification, assessment and mitigation. The holistic view will help to select and identify the most critical process to control and the working process leads to selection of the right problem and utilization of limited resources. When working with VRM the focus is to find the most critical issues that have largest impact on cost, performance and quality. The issues are often related to critical system requirements and are named
key characteristics, which is described in the next section. Finally, when using the VRM method it is preferable to have participants from all functional groups that have influence over product quality. (Thornton, 2004)

3.7 Key Characteristics

Hassan et al. (2007) argue that it is not economical to control all tolerances within a product’s drawing set, and in order to address this problem organizations are using Key Characteristics (KC). The authors further describes the use of KC:s as a method to identify where variation will have the most affect in the product quality and where product features and tolerances require special attention in manufacturing.

Hassan et al. (2007) bring up a definition of KC that describes it as product and process valuable properties that has a major impact in the final cost, performance or safety of the product when the KC vary from its target. Thornton (2004, p.35) has a similar definition that describes it as:

“A quantifiable feature of a product or its assemblies, parts, or processes whose expected variation from target has an unacceptable impact on the cost, performance, or safety of the product.”

The definition of Thornton (2004) adds the expected variation and the author further points out four important concepts:

- The target value and the acceptable variation of the KC should be quantifiable
- At any level of product, system, assembly, part or process, a KC may be identified
- The expected variation must have a significant impact
- The expected variation must be likely to occur

Thornton (2004) is also using Taguchi’s loss function to describe KC:s, illustrated in Figure 3.8. The x axis represents the variation from target and y axis represents the cost due to the variation. The Figure 3.8 demonstrates Taguchi’s ideas of an exponential increasing cost associated with deviations.
The aim of using the KC approach is according to Hassan et al. (2007) to manage the variation and their impacts to ensure manufacturability assessment, to predict end quality of design and to improve robustness of the product. Thornton (2004) views KC:s as a central element in the method of VRM where FMEA can be a source of information when identifying KC:s.

Figure 3.8 – Model of what defines a KC based on Process Output (Blue) and Variation Cost (Yellow). Adapted from Thornton (2004, p. 37)
3.8 Design for Manufacturing

Anderson (2014) states that in the old days, before the concept Design for Manufacturing (DFM), a common view within many organizations was “I designed it; you build it”. The design department often threw the design over the wall, leaving the manufacturing people with a difficult dilemma. Either they struggle to launch a product that was not designed for manufacturing or they object, even though it is too late to redesign the product. In today’s competitive environment, organizations need a flexible, adaptive and agile approach and one way of achieving this is by Design for Manufacturing (Pullan et al, 2010). According to Anderson (2014):

“DFM is the process of proactively designing products to optimize all the manufacturing circumstances while assuring best cost, quality, reliability and time-to-market.”

DFM is often mentioned together with terminologies like concurrent engineering. According to Anderson (2014), these are proven design methodologies working for any size company. By early considering manufacturing issues it is possible to shorten the product development time, reduce the development cost and ensure a smooth transition into manufacturing, which results in a quick time to market. Further, Anderson (2014) emphasize that design determines cost. Figure 3.9 illustrates that by the time a product has been designed, only 8% of the total product lifecycle-cost has been determined by the chosen design.

![Incurred costs in the product development](Adapted from Anderson, 2014, p.53)
Knowledge management is defined by Koenig (2012) as the process of capturing, distributing and effectively using knowledge. Mårtensson (2000) similarly describes it as a management tool that collects and stores employees’ knowledge and makes it accessible within the organization. By gathering and processing knowledge from internal and external sources, knowledge management systems can, according to Cooper (2003), be a support in risk reduction. Cooper further argues that the complexity within product development is continuously growing, which requires greater width and depth of knowledge that need to be acquired from outside the core project team.

Koenig (2012) states that making data available to members of the organization is the most obvious approach within knowledge management and suggests three actions. These are lessons learned databases, expertise location and communities of practice. Dikmen et al. (2008) suggest that lessons learned with risk related information can be used in order to facilitate learning from risk events. For example lessons learned about effectiveness of response strategies and factors that affected the risk consequences can be stored. The authors further argue that learning as a part of risk management can enhance the benefit of the work.

Dikmen et al. (2008) also points out several barriers to knowledge sharing. Examples are time and budget restrictions, which may result in limited time for employees to document the lessons learned. The authors further discuss that the organizational culture can become a barrier for effective knowledge management if it becomes a “blame culture” where employees will not admit their mistakes. The likelihood of knowledge being reused will according to Cooper (2003) be affected by:

1. Knowledge of the recipient
2. Search approach used by the recipient
3. The willingness to share knowledge
4. The relationship between the source and recipient, a closer relationship will facilitate the transfer
5. The ability to adopt and use previous knowledge
6. The presence of an independently party that can establish credibility of the knowledge
7. The existence and availability of shared artifacts

Cooper further argues that it has to be willingness in knowledge acquisition and systems must address factors that increase the probability that relevant knowledge will be reused. Koenig (2012) argue that one common reason for knowledge management failures is the separation of project teams, as project members are reassigned to new projects before after-action documents are written. The author further emphasize that organizations need to be aware of this issue and have a plan for how projects should be finished.
Finally, Cooper (2003) argues that new tools or systems can add new risks into projects due to e.g. learning curves. Since the aim of using knowledge management systems is to add relevant information, the risk is linked to the way knowledge can be applied. Cooper further argue that it can be risks due to misunderstanding and misusing of knowledge which require the user to understand how the knowledge was generated and potential problems with using it.
4 Risk Management at GKN Aerospace

In this chapter the collected data of the thesis are presented, which describes the current situation at GKN. The current risk management practice is described and followed by a description of how GKN includes issues regarding robust design, producibility and lessons learned.

The empirical findings in this chapter are a summary mainly based on 16 semi-structured interviews conducted at GKN during the spring of 2015. In Table 4.1, the different disciplines of the interviewees and their roles within the product development process are described, as well as the number of interviews with each role. In addition to this a survey has been sent out to 4 different departments across the design organization, reaching a total of 87 employees with a response rate of 52%. The main focus was on how employees work with FMECA today as this is the main tool for managing product risks at GKN. Note that employees from the manufacturing department are not included in the survey. For a further description of the data collection, see section 2.5.

**Table 4.1 – Disciplines of the interviewees and their responsibility**

<table>
<thead>
<tr>
<th>Interviews</th>
<th>Discipline/Function</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Concept Developer, R&amp;T</td>
<td>To develop and explore new technologies up to TRL 5 or 6 for coming products</td>
</tr>
<tr>
<td>4</td>
<td>Engineer in Charge</td>
<td>Responsible for the construction/design aspects in a project</td>
</tr>
<tr>
<td>3</td>
<td>Chief Engineer Deployed</td>
<td>Responsibility for a development program or product in production</td>
</tr>
<tr>
<td>4</td>
<td>Chief Manufacturing Engineer</td>
<td>To take responsibility and lead work regarding manufacturing process development in Product Development</td>
</tr>
<tr>
<td>2</td>
<td>Manufacturing Lead</td>
<td>Responsibility for the producibility aspects of a project</td>
</tr>
<tr>
<td>1</td>
<td>Knowledge Management</td>
<td>To support programs regarding quality related issues in Product Development</td>
</tr>
</tbody>
</table>

4.1 Current Situation at GKN Aerospace

Today, the majority of the GKN Aerospace Engine System’s product development takes place within the facilities in Trollhättan. The division is specialized in developing, manufacturing and maintaining engine system components, which are mainly delivered to customers like Rolls Royce, Pratt and Whitney and General Electric (GKN plc, 2015). During the last decades Volvo Aero (now GKN) began a transformation from being a “make-to-print” organization to both developing and manufacturing their own designs. One employee, who has worked within the organization in Trollhättan for over 30 years, states that
"Today we live in a completely different world with different circumstances, even if we just compare with the situation in 2007. During that time, we could live on our good reputation of high quality. Today’s competition is fierce, the capital has shifted to Asia and the rate of globalization means that everyone has equal possibilities of acquiring advanced production equipment. This is one of the reasons behind GKN Aerospace focus towards using complex fabrication methods and the “make things light”-slogan. However the new, lighter and complex solutions increase product risks and decrease margins of error."

4.1.1 Regulatory requirements affecting GKN’s practice

Due to the catastrophic effects one single component failure can cause, the aerospace industry is strictly governed by various different standards and requirements within risk management. These can be categorized into governmental requirements and customer requirements. Since GKN’s customers are large global actors operating under different governmental requirements, these are projected down at GKN as suppliers. The situation is illustrated in Figure 4.1.

![Diagram](image)

Figure 4.1 – Illustration of the different standards and requirements GKN have to operate under

4.2 Product development process

Product development at GKN is characterized by being highly complex, which is common in the aerospace industry. This means long time-to-markets and the products are developed in close cooperation with a few number of customers. A
typical program within the civil aircraft department usually takes 6-7 years, while programs in the space industry can take up to 20 years.

In order to shorten the long lead times, ensuring producibility and low product cost, GKN uses concurrent engineering. This means that manufacturing processes are developed simultaneously with the design phase. GKN use a model called the Global Development Process, which is divided into six different stages and can be seen in Figure 4.2. The steps are; Pre-study, Conceptual Design, Preliminary Design, Detailed Design, Final Design, and Industrialization. Each stage is followed by a review stage, where different area experts examine and question the developed design concept.

![Figure 4.2 - The product development model used at GKN, called the “Global Development Process”](image)

However, before the first stage can be entered, sufficient research and technology (R&T) processes must have been carried out in order to ensure that technologies are mature enough to move into product development. This work is done by using methodology originated from NASA, called Technological Readiness Level (TRL), also shown in Figure 4.2. Using TRL and evaluating the products maturity, is one way of addressing uncertainties and create proactivity. This is built upon nine different levels where the sixth level requires that the system/subsystem model has been demonstrated in a relevant environment, either in the space or on the ground. This level is required for all technologies before the pre-study phase of the GDP can be initiated. Table 4.2 describes the different phases in more detail.
Table 4.2 – Description of each product development phase at GKN

<table>
<thead>
<tr>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Study Phase</td>
<td>The purpose of this phase is to investigate technical and commercial possibilities as well as conduct technical feasibility studies. Functional system requirements should be identified and sufficient amount of data should be compiled to start the development work. The first risk management initiatives are required here.</td>
</tr>
<tr>
<td>Conceptual Design</td>
<td>The programs at GKN are linked to the development programs of the customers, who provides GKN with a technical specification. This specification includes requirements of interface measurements, performance, forces, cost, reliability etc. Requirements on a system level are broken down into product requirements, system risks are identified and concepts are developed and assessed. The contracts with customers are normally not signed until a satisfactory concept is presented.</td>
</tr>
<tr>
<td>Preliminary Design</td>
<td>A preliminary product definition is developed and verified, which will be used for manufacturing of development hardware. The first interface features against other systems are frozen and cannot be modified without customer approval. The first producibility and DFM issues should here be lifted for discussion. A FMECA should have been created, risks closed, updated and reported to CED.</td>
</tr>
<tr>
<td>Detailed Design</td>
<td>The product definition is developed and verified, which will be used for manufacturing of development hardware. More product features are frozen and definitions set in order to be certified by aerospace authorities. The manufacturing department tests their processes further to determine capabilities and ensuring cost efficiency. Work with the FMECA is required in the beginning and end stages of the phase.</td>
</tr>
<tr>
<td>Final Design</td>
<td>In this phase the final definition should be developed and verified, which is used for serial production. Further documentation for maintenance and usage should be created in this last phase before the final review, which releases the product into production. Work with the FMECA is required in the beginning and end stages of the phase.</td>
</tr>
<tr>
<td>Industrialization</td>
<td>The last product validations are made within this phase, where the transition of manufacturing tests move on to full-scale serial production.</td>
</tr>
</tbody>
</table>

GKN operates within a high-tech industry and therefore have focused on building an organization with high competence within engineering. Advanced simulation and analysis is part of their core competencies, which becomes a proactive measure of early handling uncertainties within product development. Cross-functional teams are set up for each program with engineers from departments like design, aero/structural/thermodynamic analysis, definition, manufacturing and quality assurance. However, there seem to be some rivalry between programs and some interviewees have pointed out that there is competitiveness between programs when it comes to acquiring the best engineers.
4.3 Product Risk Management and FMECA

Managing risks seems to be a part of the daily work within product development at GKN, where the FMECA can be considered the main tool. In general much of the FMECA work is done just before reviews and gates, where performed risk actions are summarized. In other words the tool is used reactively, instead of proactively identifying, assessing and mitigating potential future problems. The majority of the employees state that they work with FMECA a few times per year and about ten percent are working with it every month (see Figure A4). Overall there does not seem to be a clear picture throughout the organization of how much time should be allocated for the FMECA and how frequently one should work with the tool. The affinity diagram from the survey (Appendix 2), which was graded by the EiC:s, show that one of the major difficulties at GKN lies in working continuously with the tool. The general explanation is that there is not enough time/resources and it is not prioritized. One employee claim that:

“The problem is that we are working with risks when they have occurred and not proactively. It becomes more of a fact than a risk.” – Chief Engineer Deployed

The attitude towards FMECA as a tool is however positive. The survey show that almost all employees report that they understand the purpose of the tool, but some still question how user friendly it is and to which extent it is value creating (see Figure A5-A7). A breakdown of these results, shown in Table 4.3, reveals that 42% of the survey respondents with FMECA education seem to have a more positive attitude towards FMECA than other employees. The table also shows that the EiC:s attitude towards FMECA as a tool is more positive than the Definition engineers, especially when it comes to perception about FMECA as being value creating. However, a larger amount of the EiC:s have a FMECA education.

<table>
<thead>
<tr>
<th>On a scale from 1-6, to which degree do you...</th>
<th>FMECA education</th>
<th>EIC</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>... understand the purpose of the FMECA?</td>
<td>5,6</td>
<td>4,8</td>
<td>5,6</td>
</tr>
<tr>
<td>... find FMECA user friendly?</td>
<td>4,6</td>
<td>3,9</td>
<td>4,4</td>
</tr>
<tr>
<td>... perceive FMECA as a value creating tool?</td>
<td>5,0</td>
<td>3,7</td>
<td>4,7</td>
</tr>
<tr>
<td>Average</td>
<td>5,1 vs.</td>
<td>4,1</td>
<td>4,9 vs.</td>
</tr>
</tbody>
</table>

Functions that are present in creation of FMECAs are primarily EiC:s, Analysis Structure and Definition (see Figure A15). It is the EIC that has the overall responsibility to run the job, which is requested and later approved by a Chief
Engineer Deployed. The degree to which extent the manufacturing department should be involved in this work or not varies. However, it is clear from the interviews that the manufacturing side express a great interest for them being present, while the opinion on this matter varies in the design organization:

"Unfortunately the manufacturing department is only to some extent involved in the FMECA work today. The design department would benefit from early getting a production perspective." – Manufacturing Lead

Apart from that, the connection between FMECA and P-FMEA is not clear, where manufacturing emphasize that there should be a clear link between the tools. One employee states that some risks from the FMECA should be transferred to the P-FMEA, but the flow of information is not clear. Requirements should be transferred, and risks that cannot be managed in the P-FMEA should result in re-design. One opinion from the manufacturing side is that:

"It is important to have some boundaries between design and manufacturing, but manufacturing perspectives needs to be lifted in the FMECA as well. Otherwise it is easy to choose the wrong concept." – Manufacturing Lead

4.3.1 Demand and requirements

In general it seems like FMECA documents are not demanded to the same extent as other documents used in the product development process. This is however something that differs within the organization, which can be seen in the space department where the customer requirements are much higher. Customers are highly involved and conduct reviews where they critically examine the FMECA and other documents. In the civil aircraft department there is no customer involvement and they do not impact the product risk management work.

Aspects that affect the work are reviews where FMECAs has to be done in order to pass gates connected to the development process. The general impression among employees is that the work is very extensive and time consuming. Since the work is not done continuously it becomes more of a summary of what have been done instead of a proactive tool to identify risks. Stricter requirements would result in more thorough FMECAs, as it is the requirements that drive the work. The opinion in general is that the FMECA document is not viewed as important in comparison to other documents at reviews.

To summarize, the work with FMECA:s is highly affected by reviews, which requires effort and updates. Since the work is not performed continuously, it often results in a heavier burden before gates, which makes it overwhelming. As the external customers of the civil aircraft department have a lower interest in the FMECA:s than the customers of the space department, there is only an internal demand which drives the work forward in the civil aircraft department. This seems to be one of the reasons why the FMECA-work is much more active within the space department.
4.3.2 Technical aspects of working with FMECA

The majority states that the work with FMECA should start in an early stage at conceptual design, right after the concept is defined. They argue that there is no meaning to start earlier as there is too much changes and uncertainties. This is also shown in the survey (see Figure A30) where the majority seems to initiate the FMECA work at the concept phase. The work often starts by input from old FMECA:s of a product that is relatively similar and the general opinion is that it is essential in order to make the work manageable. The hardest job is to set up the work, which can be seen as an obstacle. Here some of the employees ask for a standardized FMECA with a base structure to use as a starting point, which includes the base risks similar between products. Today the FMECA:s are allowed to differ between the programs, one of the EiC:s admitted that:

"We did not fully understand all parts of how the FMECA should be carried out, therefore we made our own interpretation and made adjustments." – EiC

In other words, this situation allows different programs to work with the FMECA in different ways. As can be seen in Figure A16, some use method support from a super user within the company in order to get started with the right structure, while others avoid it. Some even seem to avoid it as it might lead to big changes of how they currently work with their FMECA, which in the short run would create a heavier work load. Those who have used method support do however seem relatively pleased with the support (see Figure A17).

Furthermore, the input to the work besides old FMECA:s is employee experience and brainstorming exercises with post-it-notes (see Figure A21). Opinions about instructions vary, but some think they are too theoretical and complicated. They are also not applicable for all projects like demonstrators within the space department, which naturally leads to the deviations from the FMECA instructions. Overall, the instructions are good but a sufficient amount of time needs to be allocated to these tasks. How the FMECA is conducted and what is written in instructions are therefore not always the same, and sometimes shortcuts are taken.

The FMECA should result in a priority list over risks connected to the product with an accepted and clearly described mitigation plan. Today, the risks are mostly related to flight safety and ensuring the technical requirements. However, it seems to be highly unclear whether it should involve more risk aspects like robust design and producibility. One of the EiC:s state that:

"The FMECA should handle what is critical for the product. All economical risks, e.g. producibility does not belong there and should be handled in the P-FMEA." – EiC

In contrast, an opinion from the manufacturing side is:

"I think producibility and difficulties linked to manufacturing should be included in the FMECA." – Manufacturing Lead
A similar difference in opinions is seen in discussions regarding if robust design should be included or not. Some claim that it should be handled within the manufacturing department and some state that they do work with it but not through the FMECA. One EiC further states that all risks could be included in the FMECA.

4.3.3 Observed challenges with the FMECA

The survey shows that one of the main obstacles to achieve effective risk management and FMECAs is “Difficulties to get a holistic view, identify and prioritize risks”. The holistic view is related to GKNs product as a part of a bigger system, which leads to issues regarding assessment. Employees also find it hard to identify failure modes, risks “outside the box” which often is missed. This is also one reason to reuse old FMECA:s.

There is no united view of what the FMECA should be based on. The FMECAs are based on technical functions and/or technical requirements. There are also examples of FMECAs based on components and/or interfaces, and confusions are in the FMECAs level of detail. Employees also think it is hard to distinguish failure cause and failure effect, and the feeling is that they sometimes merge.

Due to the heavy workload that the FMECA requires, extra supporting resources have been discussed during the interviews. Some of the employees state that the EiC:s have too many demanding tasks as it is, and therefore have difficulties to push the team to mitigate the risks. They therefore argue that there is a need of an additional resource within the teams, which can support and ease the workload. At the same time, one of the Chief Engineer Deployed claim that it is key to have an authority role while working with these tools, in order to get the commitment and engagement that is needed within the group. One respondent argued that:

“The challenge is to get people understand the proactivity in the work. Today, it is often done in order to satisfy the system.” – Chief Engineer Deployed

To summarize, it is not evident if aspects like producibility and robust design should be included in the FMECA work or not, and this differs throughout the programs. Flight safety is the central risk aspect handled in the FMECA:s and is taken care of well. Some mention that the EiC:s have a too heavy workload and that there is a need of an additional supporting resource. However, as lack of commitment and engagement within the teams is already a problem, this resource must have authority.

4.4 Proactive Practices and Mindset

The connection between the term proactivity and risk management is obvious, as risk management itself is a mean in order to be more proactive. However, many of the employees state that the risk management approach easily become reactive. Instead of listing potential failure modes, FMECA:s are used as a statement of the
risks that fell out and have been handled. This becomes more of a "check in the box"-behavior in order to move on to the next gates, instead of using the full potential of the tool. In these cases it seems risks and uncertainties are identified and mitigated in different ways. In other words there are many different ways of creating proactivity. This seems to be based on the mindset of the teams and differ within the organization. Opportunities lies within other areas like producibility, robust design and lessons learned, which are aspects linked to risk management. One example of this can be to early use geometrical assurance analysis and create fixtures, which can be used to assure that components within production processes are correctly placed during operations and do not move. In other words these are proactive actions that early ensure that tolerances can be met, therefore some robustness and producibility risks decreases.

The result from the survey show that there are no clear answers of what other proactive practices are conducted as complement to the FMECA. The general picture from the organization is vague, common answers are e.g. creating a checklist for themselves, trying to predict and lift producibility issues etc. Very few mention specific tools like Design of Experiments, which can verify and give a better picture of how robust the design is. Several respondents also stated that proactivity is connected to individual traits and one of the interviewees further discusses the importance of the project team. The right composition together with a good mood within the project team can create conditions that encourage proactivity. A key factor is a prestigeless environment where members can admit failures and question each other, which according to the respondent requires good leadership.

Regular meetings can also create proactivity, which was brought up by an employee from the Research and Technology organization. In Research and Technology they have meetings called “pulse meetings”, which becomes a natural forum where different competences can discuss and highlight different problems. The respondent emphasize that the external input can be very helpful in many situations and facilitate to make right decisions. This works well within R&T where the work is agile and iterative, therefore he further states that it may not be suitable and effective within all areas.

Many respondents point out the importance of understanding risk tools like FMECA in order to use them proactively. Many identify themselves in the situation where they are good at identifying risks, but have a hard time to follow through the whole process by planning risk actions, performing them and finally close them. One respondent claims that:

“Proactivity is not just about front-loading and putting a lot of resources in the beginning of the project. It is about doing the right things at the right time, and it is important to know what to do.” – Chief Engineer Deployed
4.5 Robust Design Issues

The robustness of different solutions seem to be widely discussed throughout the organization and perceived as important, but how employees actually work towards achieving robust design is unclear. Furthermore, it is unclear how these issues should be linked to the risk management process and to what tools and analysis should be used to ensure robustness. One respondent states that these issues are often overlooked and it is an area with great potential for improvements. This is somewhat of a paradox, as one of GKN’s most evident strengths lies within their advanced simulations, analysis and mathematical models within the product development. Therefore it should be seen in areas like Design of Experiment as well.

Failure modes related to robustness are not something that is handled in the FMECA, though there was an attempt where FMECA was used in order to identify KC:s. All risks with severity 8-10 were classified as a KC, which resulted in too many characteristics and extensive work. This meant that the efficiency was lacking and the KC:s were not chosen based on their impact on variation and cost.

It is not obvious how robust design should be integrated in the product development process, one respondent emphasize that GKN need a better understanding of the area and a clear plan. One example where the lack of understanding can be seen is in how KC:s and Critical Item are mixed up. KC:s are identified by having a higher variation and impact on product cost than other characteristics, whereas Critical Items can be dimensions with low tolerance requirements set by the external customer.

The general opinion about KC:s is that they should be kept to a minimum, as the need for measuring increases together with administrative tasks. The importance of early working with robust design is lifted and one respondent state that the FMECA could be of support in that case. Some also lifts the need of having a cross-functional team in order to successfully integrate robust design.

One of the manufacturing leads claim that robust design is an issue connected to manufacturing. This is also seen in the survey results, where there is a difference in opinion regarding if robustness issues should be lifted in the FMECA or not (See figure A10). This is also pointed out in one of the recent master thesis at GKN, which also show that it is unclear if the FMECA should be used as the main tool for identifying KC:s.

Some examples can be seen of how Robust Design is integrated successfully. The Research and Technology department started to work with robustness in a more systematic manner by using geometry assurance. One respondent claim that they are satisfied with their current practice and that it will be used to a further extent within future product development projects. They also using KC:s but not to a great extent, instead they are working with Key Process Variables (KPVs), which are related to the manufacturing process.
4.6 Design for Manufacturing Issues

One employee argues that in order to remain competitive on today’s global markets, with competitors in low cost countries, producibility becomes an increasingly important issue. As GKN in the near future may increase their production volume this issue becomes even more essential. Historically speaking the producibility of the products has not been of top priority, the main concern has been in optimizing the aero design. One employee argues that:

“We used to work separately one function at the time. First the aero engineers created a design, sent it over to the structural engineers, then the thermo engineers looked at it and gave it to the definition department. Last in the chain came the production department who were just expected to produce it.” – Chief Manufacturing Engineer

Multiple employees have argued that these scenarios often led to designs far beyond the production capabilities. These issues could have been fixed if it was brought up earlier for discussion across the departments. Different examples of this have been brought up, in one of the cases the design department was praised and given prizes for the innovative and complex aero design. However, when it reached the serial production phase it did not take 370 production hours, which was originally estimated in the business case. Instead it took over 1200 hours per unit. Today this number has decreased to 650 hours through different improvement actions. The producibility of the design was severely underestimated, which have led to some changes in the organization where producibility is questioned earlier. One of the Chief Manufacturing Engineers therefore emphasize the importance of early including all disciplines/functions in order to ensure that no one goes down a design path which later turns out to be outside of the production capabilities.

At the moment GKN is improving within these areas and going through a transformation where producibility is increasingly prioritized. As product cost and profitability is closely linked to producibility, management is requiring that these issues are lifted earlier. One engineer from the manufacturing organization states:

“We can no longer design solely for the sake of designing.” – Chief Manufacturing Engineer

4.6.1 Communication and motivation of requirements

Today the manufacturing department has acquired more influence in discussions regarding e.g. choice of concept. This means that they to a further degree can question why different requirements and tolerances on the drawings are set the way they are. In many cases it has become clear that some requirements do not have a clear motivation behind them and the tolerances can be loosened. In other cases a requirement is set by the external customer and therefore projected downstream to the manufacturing department. Often these are so called interface measurements - which require high precision in order to assemble with other modules at engine level - and are therefore classified as Critical Items (CI:s, not to confuse with KC:s).
In the discussions between design and manufacturing a “Six Sigma engineer” is sometimes included. Statistical analyses are made in order to create forecasts of the outcome, which becomes a basis for what the best cause of action might be. A redesign might be needed, a development of the manufacturing process or just a discussion with the external customers to see if they can change their requirements. One employee stated that:

“In some cases there are no actions that can be taken, instead you need plans of how you are going to live with your risks and deviations.” – EiC

In many cases requirements for thicknesses, dimensions and tolerances are set solely on experience and not on actual facts. One of the EiC:s point out that every time decisions like these are made the designers might remove degrees of freedom from the manufacturing department, freedom that could have been used to improve the manufacturing processes. It is therefore important to early include the manufacturing department. One of the manufacturing leaders argues similarly and states that:

“It is absolutely essential to involve experienced manufacturing engineers early. Manufacturing issues need to be lifted in the FMECA, it cannot just be handled in the P-FMEA. Otherwise the problems will just come bubbling up to the surface in the P-FMEA.” – Manufacturing Lead

According to 45% of the survey respondents (see Figure A15), manufacturing engineers are involved in the initial stages of FMECA work. However the survey further shows that some do bring up producibility issues in their FMECAs, while others do not. The same pattern is seen throughout the interviews, which suggests that it is not fully clear whether it should be included or not. One of the manufacturing leads point out that:

“Someone from manufacturing must be included in the FMECA work, otherwise it becomes like starting off from a white blank page and it is too easy to go down the wrong path.” – Manufacturing Lead

He further argues the need of having sufficient platforms as a basis in order to clearly define the boundaries and constraints for the design department. In the case that a concept lies outside of this mapped design space, this becomes a risk/input to either the FMECA or the P-FMEA. Another employee similarly argue that it is important to establish the design space and the capabilities of the production site in order to make fact based decisions in these situations.

4.6.2 Leadership and Proactivity

It is clear that the issues regarding producibility is getting a larger focus at GKN, but some employees still seem conservative towards lowering the barriers between the design and manufacturing department. In one of the most successful programs, which is now in serial production phase, the number of deviations and problems
regarding producibility has been considerably lower than other programs. One of the engineers of the program argues that one of the main reasons is connected to leadership:

“The leaders of the project made it clear from the beginning that there were three main objectives of the program; Ensuring the technical functions, create a design with good producibility and doing so without exceeding the product cost.” – Chief Manufacturing Engineer

The interviewee further argues that setting these requirements led to many intensive discussions from the beginning, which meant that problems were lifted and addressed early. Often they came to the conclusion that they had found a good compromise when everyone was equally unsatisfied with a solution. This is a contrast to the picture many of the employees give when they describe the situation in the past, when the scales where tilted towards the design department.

The three main objectives above are also included in GKN’s Design Philosophy, see Figure 4.3, but no one else of the interviewees brought it up while discussing these issues. This suggests that this philosophy is not widespread throughout the organization or demanded from the executive management. The figure illustrates that programs should be managed in pursuit of finding an optimal balance between technical requirements, product cost and producibility.

4.7 Issues with Lessons Learned

GKN does not work in a systematic and effective way with lessons learned and it is unclear if it is a requirement and how these documents should be written. Among the required documentation within projects, lessons learned have a low priority and the general opinion seems to be that there is not sufficient time to document this. In general, the lessons learned procedure is perceived as time consuming and a
administrative tasks, and many point out the difficulties of effectively transferring knowledge into a document.

One of the obstacles with saving and making use of experience lies in the way projects are ended. In the final phases of the projects when these documents should be written some members of the project group are already on their way to new projects. Therefore, the possibilities and interest of documenting the project outcome is low. The experience and knowledge of how specific risks have been handled is not used to its full potential. The space department does however differ to some extent, as they see the FMECA as a way of documenting their knowledge. According to one interviewee they are also better at closing their projects. Another employee within the space division describe their FMECA as their “know-how”, with experiences that need to be checked and mines that need to be avoided. The employee further admits that it does become a heavy work load with large amount of information, but it is value creating as it ensures that they do not repeat the same mistakes again.

The general opinion throughout the organization seems to be that documented lessons learned are disappearing within the system and will therefore never be used:

"Often you write a lessons learned document, but there is not that many who actually read it. (...) You know that someone within the program wrote something, but it disappears together with other documents within the company’s database." – EiC

Some employees emphasize that it is hard to find lessons learned in the system. A barrier here seems to be confidentiality between different programs, which is required by the customers and some documents are therefore locked. However some respondents emphasize that the confidentiality issues should not hinder the work with lessons learned. Overall, knowledge sharing also appears to be work better internally within programs than between different programs. Within programs, engineers at different sub-projects today sit close together which enables them to easily share knowledge. Furthermore, several respondents claim that the organizational structure and the way functions are sitting affects how knowledge is shared and it is therefore positive if product knowledge is gathered.

Apart from difficulties in writing and sharing lessons learned, a problem seems to be employees’ willingness in using lessons learned documents. One respondent point out that humans are lazy by nature and seek the easiest solutions. Therefore, employees rather share experiences in a more informal way through conversations, as finding and understanding the content of the documents is very time consuming. In general, this is the way knowledge is shared at GKN today and most find that it works well.

The employees of GKN seem helpful and willing to share their knowledge and many are greatly experienced as the majority has been within the organization for several
years. Instead of searching for knowledge in documents, the projects are choosing the right engineers with the right competence and experience. This leads to dependence in specific employees, which could be seen as a limitation. One respondent argues that it is important to find core competences and secure the knowledge within the organization by documentation or education. It is further discussed that the company has remained in the time when GKN was an “industrial town organization” where employees stayed their whole careers. This is not the case in today’s globalized society and the company cannot risk that valuable knowledge and expertise disappears completely if an employee decides to quit.
5 Alternative Risk Management Practices

This chapter contains the results and findings of the two separate benchmarking cases, which has been conducted at Volvo Construction Equipment and Autoliv. Due to the limited time frame, these are less extensive and have been focused towards general areas that are of interest based on GKN’s situation.

5.1 Risk Management at Autoliv AB

This section is based on a two-hour interview at Autoliv in Vårgårda. The visit included a presentation of Autoliv and their risk management process followed by an interview. Three representatives from Autoliv working with product risk management were interviewed.

In 1997 Autoliv Inc was formed through a merger of Autoliv AB and Morton ASP, the leading airbag manufacturer in North America and Asia. Today they are the world’s largest automotive safety supplier with sales to all the leading car manufacturers in the world. The safety products range from various types of airbags and seatbelts to radar, night vision cameras and pedestrian protection systems. Through these innovative systems they estimate that they save 30,000 human lives every year and prevent 10 times as many injuries (Autoliv, 2015).

5.1.1 The Risk Management Process

Autoliv has a clear process for product risk management where their D-FMEA is one of the tools within their risk management process, see Figure 5.1. All risks in the D-FMECA are connected in some way to the life cycle; from the suppliers’ transport of components to disassembly and recycling. The customers have a certain involvement in the D-FMEA, as some risks in Autoliv’s sub-systems influences the customers systems. It was also due to customer requirements Autoliv started to work with robust design in a more systematic way. In the beginning it was not seen as value creating, but more of a way of satisfying the customer. This situation resulted in the development of a new approach called ARDIM (Autoliv Robust Design Improvement Methodology), which only involves what Autoliv themselves find value creating and what is necessary to satisfy the customer.

The process consists of two process flows, seen in Figure 5.1. The first starts with a boundary diagram, which is connected to a document called "Function definition". The boundary diagram can be seen as a visual map whereas the Function definition is a list of words. Functions are thereafter transferred into the D-FMEA where they are converted into potential failures. The results are functions based on the output from the boundary diagram, instead of just functions created out of thin air, which it used to be. Besides these functions, internal and external customer requirements are moved to the D-FMEA. Furthermore, the work is based on a master-FMEA, which saves time and the focus is therefore in changes on the product.
The second flow handles the robustness issue and starts with a Parameter-diagram, where noise factors are brought up. Noise factors are connected to variation of the product and are divided into different areas. It can e.g. be variation due to ingoing components and variation in usage. Noise is types of deviations that can result in failures, which is therefore also moved into the D-FMEA.

Noise factors are further transferred into a robustness checklist. In the list, relationship between noise and failure modes are studied and ranked. The result is a priority list of noise factors which highlights were the focus should be put. The number of robustness checklists is the same as P-diagrams.

Finally, risks with the highest RPN from the D-FMEA are together with the result from Robustness checklist transferred into what is called "clever test plan". Since it is not economical to test everything, this is the plan that the work is based on.

5.1.2 Lessons Learned

Autoliv has a clearly defined approach of how to handle lessons learned and collect difficulties and problems that occur within different projects. The way Autoliv works today is relatively new and has been developed since they too have been struggling with these issues for a long time. The new IT-solution has been launched globally and they are satisfied with the result.

Autoliv has started a forum where they every second week collect and register incidents, which is stored in a global database. The database is both connected to a tool/program and a flowchart to go through at different decisions, where each product has a separate flow. For example, if a non-standard item is chosen, every lessons learned about that item is presented.

The program consists of questions and requirements. The requirements describe both unchangeable parameters and tunable parameters, which can be changed within certain boundaries. If it is not possible to stay within the boundaries it leaves the preferred flow and goes into the non-standard flow. This procedure is done three times for every project and the result is a summary, a non-confirmed list.
which is brought to tollgates. The summary contains deviations from standard, which automatically become uncertainties and risks:

“\textit{The non-conformance list is not about decreasing the rate of innovation, companies are dependent on that. It is about handling risks and point out new items that we must be considerate with. It might be that more tests are needed. The way of work becomes business related, where risks are viewed from the opposite perspective and seen as opportunities.}”

The summary is then something management need to accept and consider if the risks are handled, for example what actions are needed, extra resources, conducted or planned tests. Autoliv argue that this is a way to point out uncertainties and involve employees in observing risks, and claims that:

“\textit{At the end of the day, everything is about whether you are red or green. If you are red, you have risks and you need to describe how you will manage them.}”

If something is new it can start up a new non-standard flow, but some continuous recurrent mistakes will be avoided. Finally, Autoliv argue that they have struggled with different databases and developing this approach and today they have something that works. It is easy to use, but they further argue that it sometimes can be a bit time consuming. For example, it can take three hours to find a lessons learned document, but in relation to what potential mistakes that can be avoided it is a small sacrifice. It is therefore important to have a clear agreement within the organization where everybody knows the standard. This way of working prevents personal assumptions and decision based on gut feeling.
5.2 Risk Management at Volvo Construction Equipment

This section is based on a two-hour interview with a representative for Volvo Construction Equipment, Volvo CE. The representative works as a process leader and is method owner of the product risk management process at Volvo CE. Every year he educates about ten to fifteen new product risk managers within the company and coaches these after the education is finished.

Volvo Construction Equipment it part of the Volvo Group, which Volvo Aero in Trollhättan also was until GKN’s acquisition in 2012. The group is built upon three core values - Safety, Quality and Environmental Care - and has the common goal of developing and delivering efficient transport solutions. All product developed and manufactured by Volvo CE have two things in common, they are classified as machines and are in some cases allowed to drive on roads. The vehicle types range from articulated haulers, wheel loaders, excavators, compactors, paving machines to backhoe loaders. These products are sold globally under three different brands; Volvo CE, Shandong Lingong, Terex Trucks. The production site in Eskilstuna has around 2000 employees and both design and manufacture transmission and axles for wheel loaders and articulated haulers.

5.2.1 The risk management process

According to the interviewee, Volvo CE’s approach with FMEA:s and proactive practices is key to ensure that the products are mature. As an original equipment manufacturer, their risk management process becomes slightly different in comparison to GKN and Autoliv, which are supplying companies. Each machine is built upon many different sub-systems, and consequently the FMEA:s also need to have a sub-system structure. Besides the FMEA, the other primary tool used is Fault Tree Analysis. The FMECA works bottom up while the fault tree analysis is performed top down. Therefore they complement each other well, but at the moment Volvo CE does not have a standardized practice for Fault Tree Analysis. Primarily the risk management work is focused within product maintenance and new product development, where FMECA:s are started at the concept phase and are active throughout the life cycle of the product.

All product risk management activities have a connection to the core values of the Volvo group and are built upon a classic SIPOC-structure. In other words the connections within the whole process are shown in relation to Supplier, Input, Process, Output and Customers. A simplified flow is shown in Figure 5.2, where the process starts off by defining the system-of-interest and its boundaries, system specification, the level of new content and updating the hazard list. This, together with historical FMEA:s and a standard list of typical failures creates the input for the new FMEA.
The new content analysis in the Figure is used to objectively determine the degree of change in a new or modified product, evaluating impact on Form-, Fit-, Function and Performance of Function. Through this approach the amount of proactive measures and required FMEAs, can be established. A proactive plan is created including FMEA:s. Normally there is a need to prioritize proactive plan and actions (e.g. due to project constraints), therefore each proactive action can be weighed against “cost of poor quality”-documents and warranty analysis. Actions are thereby justified and this determines the best cause of action. Note that this is only done for risks linked to costs of poor quality, safety risks must always be eliminated or mitigated to a approvable residual level.

There is a clear process description/standard for how employees should work with D-FMEA and P-FMEA. This describes the general requirements of; what should be included in the FMEA:s, in which cases the FMEA should be performed, the connection to the product development process and who is required to participate in the work. Furthermore there is an “Engineering Baseline”, which sets the minimum requirements of which documents that have to be included in the product risk management process. Volvo CE act under safety requirements and directives similar to those GKN have to follow. In order to ensure that they fulfil their requirements, Volvo CE uses a type of approval stair. If a residual risk has a Risk Priority Number ≥ 60 the system owner has to approve it. If S>8 and RPN ≥ 150, the design is not seen as a robust solution. This is not negligible and therefore must be approved by both the system owner and the highest ranked Quality Manager. Safety risks, risks with high severity, must always be handled and reduced, but this is a
way of deciding which other residual risks they are willing to live with. The interviewee further states that

“Safety is more of a mandatory qualifier, but profitability lies within robust design and producibility”

The representative argues that continuity can become an issue as it is hard to define how often one should work with these documents. It all depends how the system changes. Therefore, they avoid this issue by stating in the product risk management process that

“A FMEA shall/must always be created or updated if there is a change that impacts either form, fit or function of a system. The one who decides or drives to make the change is also responsible to prove that the change is safe.”

In general Volvo CE have this philosophy with all FMEA:s, where they instead of questioning if something is safe enough, require their engineers to prove that it is safe enough. As the systems interact and affect each other, clear boundaries have to be set for each system limits, otherwise the FMEA-scope is unclear and thereby workload for each change becomes overwhelming.

5.2.2 Other aspects of Risk Management

In order to ensure the producibility of the products, Volvo CE requires that a representative from the manufacturing engineering department is present during the initial phases of the FMECA work. As the FMECA matures and the P-FMEA is started up it is important to reach a level where product development and manufacturing engineering department can shake hands and agree on a design where no more design changes will be required. Another way ensuring the producibility and technological maturity issues is by using Technological Readiness Levels as also used by GKN. These are used to determine the maturity of sub-systems and see if they are ready to be integrated within larger systems in the products.

Volvo CE try to unlink knowledge from specific projects and instead link it to the product type, therefore the FMEA follows the product within the data-systems. The interviewee does not personally believe that white books are the solution. Instead he claims that the most important issue is that the team performing changes to a product must have access to all vital data and documentation for the product. The FMEA is a historical view of what risks have been dealt with previously and how they have been verified. If changes are made to a system this gives an indication of which risks to be observant of, which verifying actions might be needed and which approaches will be suitable to solve the problems.

Volvo CE has a standardized way of handling their Special (key) Characteristics (SC) within the FMEA, which is presented in a Volvo Standard regarding Special Characteristics. Only in extreme cases, where a characteristic cannot be changed
through a re-design of product or process solution, they classify something as a SC. The SC-standard requires that SC:s need to be quality assured and traceability is of great importance. In the D-FMEA potential SC:s are classified and are either verified in the D- / P-FMEA or eliminated through mitigation actions. The standard only allows a SC classification if they cannot be reduced in any other possible way. The standard further states that if there is a SC, there is a need for statistical process control, which ensures that the process is in statistical control.

5.2.3 Leadership and Education

The interviewee states that they have identified two specific success factors, which have lead to major improvements in their product risk management. The first one is to assign the responsibility of the FMEA work to the system owner. The persons assigned this role have an internal responsibility to safeguard that the product risks are managed and ensure that a sufficient FMEA for the specific system are delivered and traceably document managed, throughout the systems Life cycle. The second success factor has been to create a role called Product Risk Manager. It is up to each system owner to assign this position to someone within their group, but the interviewee emphasizes that

“Those who are smart assign this position to their Design Leader, who is sent on to an extensive internal education lasting several days. A FMEA is about safeguarding that the risks are reduced/eliminated through planning and managing the mitigation actions, which should be carried out by the whole team. Who else but the design leader could do this as effectively?”

The interviewee further argues that educational level of the product risk managers must go beyond just how the tool works and how FMEA-meetings should be carried out. The product risk managers must learn how to lead the risk reduction actions, coach the team members, assess the remaining risk levels and manage this work throughout the product’s whole life cycle. Besides that they are required to know the basics within root cause analysis, problem solving techniques and preferably have a six sigma green belt training. The interviewee argues that since they focus on educating their Product Risk Managers to this level, the need of method support is not required. Besides the extensive education of product risk managers, a basic level of FMEA education must be held throughout the organization as well. The interviewee states that this is a major challenge, since many employees have not seen a successful FMEA and therefore does not perceive it as value creating work.

The interviewee himself works with educating the product risk managers and continuously provides coaching after the Product Risk Managers have been educated. The coaching is often about how to move from identifying potential risk actions to actually performing them, as this requires a new type of toolbox. The toolbox must secure that:
1. Risks are identified and evaluated, supporting a risk prioritization and risk reduction
2. Root Cause Analysis of prioritized risks are performed
3. The identified Root Causes are solved – often by re-design of product and/or process
4. The modified design and/or process, to be verified to be safe / risk reduced to in FMEA identified risks but also analyzed for potential new risks. Design of Experiments is one example of a tool to verify design and process changes.
5. The performed and risk reduced FMEAs to be updated and documented through-out the systems life cycle, to safeguard continuous learning and knowledge management.

“We are able to verify a risk and the severity of the risk, as well as understand which changes we need to do in order to improve the product or process design and thereby mitigate that risk. Many companies are happy with identifying a risk and blindly change to a solution they think is better, but how do they verify that the risks are reduced with the new solution, what is the objective evidence of performed risk reduction and effect there-of?”
6 Analysis

In this chapter the current product risk management practices at GKN are compared to the theoretical framework and the alternative practices at Autoliv and Volvo CE. The similarities and gaps are analyzed in four different sections; FMECA, Producibility, Robust Design and Knowledge Management. Within each area the level of proactivity in different practices is discussed.

As mentioned in the empirical findings from Chapter 4, proactivity as a term is often discussed within different contexts throughout GKN. However, what employees actually do and what practices actually creates proactivity within the product development programs is harder to establish. This analysis therefore seeks to identify different aspects of proactivity within each area and compare it towards the theoretical frame of reference. This creates the foundation, which the recommendations to GKN will be based on.

As the organizations are from different industrial areas and act under different circumstances, this must be taken into consideration. These circumstances have therefore been summarized in Figure 6.1, together with the different tools, processes and approaches that set each of the companies apart.

Figure 6.1 – Illustration of the different circumstances the three companies act under. The outer layer represents the different tools, processes and approaches that set each of the companies apart.
First off we see that the production volume differs greatly between the three cases, where Autoliv and GKN are on opposite sides of the spectra. However, they have in common that both are companies supplying subsystems, which will become a part in a larger system. Volvo CE on the other hand design, develops and manufacture complete systems. Product safety is of great importance within all three organizations, but naturally it has an even higher focus at GKN and Autoliv. Lastly all three companies are large global actors with development and manufacturing spread out globally.

6.1 Product Risk Management and FMECA

All three cases within the thesis uses D-FMEA and P-FMEA within their product risk management process. However, the processes and used tools differ and in general it seems like the practices at Volvo CE and Autoliv are more structured and have a clearer flow. ISO 31000 also emphasizes the importance of having a systematic, structured and timely approach to risk management. Note however that the FMECA practice in the benchmarking cases have been described by experts and method owners, while it has been described by employees who actually work with it at GKN. This might not give a fair picture of the reality. Table 6.1 presents a short summary of how the different organizations are using FMECA, which will be discussed in this section.

<table>
<thead>
<tr>
<th>GKN</th>
<th>Volvo CE</th>
<th>Autoliv</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Basic FMECA-education</td>
<td>- Product Risk Manager</td>
<td>- High focus on simple flow of processes</td>
</tr>
<tr>
<td>- Partly using historical FMEA:s as base</td>
<td>- Historical FMEA:s as base</td>
<td>- Master-FMEA</td>
</tr>
<tr>
<td>- Different practices are allowed</td>
<td>- Risk specialist distributed across organization</td>
<td>- Clear flow between risk tools/processes</td>
</tr>
<tr>
<td>- Space Department as best practice</td>
<td>- Clear Product Risk management process &amp; Process Owner</td>
<td>- Boundary Diagram used in order to identify functions</td>
</tr>
<tr>
<td>- Primary flight safety included in the FMECA</td>
<td>- Volvo CE core values are included in the FMECA</td>
<td></td>
</tr>
</tbody>
</table>

Both Volvo CE and Autoliv have a clear process with tools for identification of failure modes. This is more of a problem at GKN as subjective interpretations of the instructions are allowed to a further extent. Autoliv and Volvo CE are using boundary diagram in order to identify functions. At GKN there are examples where FMECA:s have been based on functions, requirements and interfaces. Autoliv are also explicitly using a “master-FMEA” which always is used like a base and focus is therefore in changes and updates. At Volvo CE change in form, fit and function requires updates in the FMECA and new FMECA:s always get input from historical FMECA:s. At GKN the space department are always using old FMECA:s as a base, but
this varies within the civil aircraft department. The general opinion among the three
organization is that re-use of old FMECA:s is essential in order to make the work
manageable.

GKN is positive to risk management education and it seems to affect the attitude in a
positive way. Volvo CE are also seeing the importance of FMECA education through
the organization. However, they have identified the success factor of creating the
role product risk manager, which in a greater extent is educated in FMECA. It is
according to Volvo CE preferable to have the design lead as product risk manager. In
interviews at GKN it has similarly been lift that it is of great importance that the
role leading the risk management work have authority. There is not the same need
of method support at Volvo CE, as the product risk manager leads the work and gets
coaching from the process owner. At GKN the utilization of supersers varies,
whereas Autoliv have made an attempt to make the standard as simple and clear as
possible, which means that the same need for support will not be needed.

The general perception at GKN is that the space department has a good risk
management approach, which many see as the best practice within the company.
Others state that this is not a coincidence, as they have more resources and much
longer development times than the civil aircraft department. Either way, their work
with FMECA works well and they have thorough old FMECAs that are used as
foundations for new projects. They are working more actively with these tools and
the main reason seems to be linked to the customer requirements, as the customers
are highly involved and demand thorough FMECAs. The opinion at the civil aircraft
department is that the FMECA is a document with low priority, which is filled in
reactively in order to satisfy the system. The demand therefore has a big impact in
how the work is performed, which Volvo CE also indicates. Indications of connection
between cost of poor quality and risk management caused a higher internal
demand. It resulted in more focus in risk management and a changed risk approach.

All organizations start up their FMECAs within the conceptual design phase. The
literature however states that preliminary FMECA:s can be used in concept
evaluation (Thornton, 2004). This has not been seen within this thesis, instead
employees at GKN state that they see no meaning to start before the concept is
defined.

GKN primarily addresses flight safety within their FMECAs. What other risk
perspectives should be involved is however relatively unclear. The opinion at Volvo
CE is that their core values, Safety, Quality and Environmental Care, should always
be addressed. Note that this differs from GKN and Autoliv, where environmental
issues do not seem to be addressed within product risk management.

6.2 Robust Design

At GKN there is no system for integrating robustness issues into risk management
and there is no evident connection to the FMECA. However, this section analyzes
how the different companies addresses robust design and its connection to risk management, where Table 6.2 gives a short summary of each company.

**Table 6.2 – Summary of the different Robust Design Practices in the three cases**

<table>
<thead>
<tr>
<th>GKN</th>
<th>Volvo CE</th>
<th>Autoliv</th>
</tr>
</thead>
<tbody>
<tr>
<td>- No clear integration of Robust design into the risk process</td>
<td>- KC indicates a need for statistical process control</td>
<td>- Systematic work with robust design in the risk process</td>
</tr>
<tr>
<td>- Attempts to use KC:s</td>
<td>- KC only in extreme cases</td>
<td>- Noise factors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- P-diagram, RCL, Test plan</td>
</tr>
</tbody>
</table>

There are however attempts in using KC:s, which literature states as part of Variation Risk Management and can be used in order to develop and produce more robust products (Thornton 2004). The author further argues that FMECA can be used in order to identify KC:s, which also was the case at GKN. The attempt was however not that successful, since variation was not taken into account in the identification of KC. The reason for that seems to be that there is a great confusion between the terms KC and Critical Item. KC:s are characteristics influenced by variation and result in high deviation costs, whereas critical items are important characteristics based on specific customer requirements, such as interface measurements for the customer’s engine modules. This confusion was also portrayed during the interviews and also lifted as one of the main issues in a previous master thesis at GKN.

According to Thornton (2004) it becomes a limitation when the FMECAs are used in a way where variation risks are not separated from design risks. A condition in order to include robust design into the work with risk management is to take variation into consideration, either in the FMEA or in a separate process flow. Autoliv handle this by having a separate flow for robustness issues within their risk management process. In the flow they have tools for both identification of noise factors and ranking how these factors are connected to failure modes. Finally, the flow results in what they call a clever test plan, which gives an indication of which are the most important tests to perform caused by variation in the product.

To summarize, it is important to have a clear strategy of how robust design issues should be integrated into the risk process. This is of even greater essence at GKN with their low production volumes. Volvo CE and especially Autoliv have larger amounts of data from their greater production volumes, giving them better opportunities to correct mistakes by using statistical process control. Furthermore, it is a need for both understanding of robust design as concept and tools that address the task and take variation into consideration. To limit the amount of KC:s and critical items to a minimum is also something all three organizations agree on, since increasing the number of measures results in more administration. Volvo CE states that only in extreme cases, where no redesigns and process changes are
possible, they choose to classify a characteristic as a KC. Furthermore they state that addressing something a KC automatically implies that statistical process control is needed.

### 6.3 Design for Manufacturing

As seen in Figure 6.1, the three organizations within this thesis act under very different conditions because of their varying production volumes. Autoliv produces up to a million items of the same product, in other words achieving a producible design from the beginning result in large savings in the long run. The high production volumes also result large potential for improvements, as larger amount of production data gives more feedback for six sigma improvements, statistical process control etc. This is considerably harder at GKN where production volumes can vary from a couple of hundred items in the civil aircraft department down to just a few items when it comes to nozzles within the space department. Volvo CE is positioned somewhere in between GKN and Autoliv, with production volumes varying around 1000 – 10 000 items per product. Table 6.3 summarize the major differences between the organizations’ approaches in their pursuits of designing for manufacturing.

<table>
<thead>
<tr>
<th>GKN</th>
<th>Volvo CE</th>
<th>Autoliv</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Partly involve manufacturing engineers in the D-FMEAs</td>
<td>- Always include manufacturing in the D-FMEAs</td>
<td>- Effectively use lessons learned as input for new projects</td>
</tr>
<tr>
<td>- GKN Development Philosophy</td>
<td>- There is a clear connection between P-FMEA and D-FMEA</td>
<td>- Use standard concepts if possible</td>
</tr>
<tr>
<td>- Unclear how these issues should be handled</td>
<td>- Handshake/Agreement between design and manufacturing</td>
<td>- Line and product design workshops</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Pre study projects</td>
</tr>
</tbody>
</table>

At GKN the barriers still seems to be high between design and manufacturing in some cases. In other cases it seems like the collaboration between the departments work considerably better, which suggests that this is dependent on individuals within the project group. This issue is also brought up in a number of interviews. Some teams involve manufacturing in the creation and early phases of the FMECA work, while others avoid it. In general the manufacturing department seems more open to this type of involvement within the FMECAs than the design department. One manufacturing lead even stated that he takes initiatives himself to be involved as early as possible to lift important questions regarding producibility, which otherwise creates problems in the P-FMEA. In contrast to this, Volvo CE instead demands a representative from the manufacturing department to be involved in the FMECA work. The practice at Autoliv is unclear, but in general they seek to simplify
and standardize their processes. Furthermore, their structured and standardized lessons learned database provides input in the FMECA regarding several of these issues that have occurred in the past.

Volvo CE have appointed a process owner for their risk management process and created a product risk management standard, which is considerably more specific and detailed in comparison to the policy used at GKN. Volvo CE’s standard states a clear flow and relationship between the D-FMEA and the P-FMEA and requires the manufacturing department to play an integral part in the D-FMEA. In addition Volvo CE’s risk management process, they require the two departments to come to an agreement on the design solution. A handshake is required when the manufacturing department deems the solution producible. A similar process has not been seen at either GKN or Autoliv.

GKN has a development philosophy, see which is reoccurring in the conversations regarding producibility. This illustrates how each program should seek to fulfill three main objectives and the programs should be managed in order to find equilibrium between these objectives. Similar philosophies have not been seen at either Volvo CE or Autoliv. However, Volvo CE has managed to link their risks to costs of poor quality documents.

The literature emphasizes the importance of a close connection between the design and manufacturing department. Concurrent engineering is based upon that different development processes are not initiated in sequences, but are simultaneously overlapping. All three cases implement this to some extent.

### 6.4 Lessons Learned

As mentioned in the theoretical frame of reference, lessons learned can provide good support within the management of risks (Cooper, 2003). However, lessons learned are not utilized to a great extent at GKN and is not clearly included within their risk management process. There are also problems using lessons learned which are similar to those stated in literature. This could e.g. be limitations due to time restrictions and problems caused by an early separation of the project members in the end of the projects. Literature is therefore pointing out the importance of having a plan for how projects should be finished. Table 6.4 give a short explanation of how the organizations in this thesis are using lessons learned.
Table 6.4 – Summary of the different lessons learned practices in the three cases

<table>
<thead>
<tr>
<th>GKN</th>
<th>Volvo CE</th>
<th>Autoliv</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Not systematically using lessons learned</td>
<td>- Not systematically using lessons learned</td>
<td>- Global IT-solution for lessons learned in order to find out uncertainties and risks</td>
</tr>
<tr>
<td>- Informal discussions, org. structure becomes important</td>
<td>- Linking the FMECA:s and other documents to the product, not the projects</td>
<td>- Lessons learned is continuously updated and used as input in new projects</td>
</tr>
<tr>
<td>- Confidentiality limitations</td>
<td>- FMECA is partly used as know-how, linked to product types</td>
<td></td>
</tr>
<tr>
<td>- Space department use FMECA as know-how</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

At GKN many interviewees discuss that confidentiality between different programs lead to difficulties of sharing knowledge, whereas other state that there are ways to move around such issues. The confidentiality leads to problems of making data available through the organization, which according to Koenig (2012) are the most obvious within knowledge management. It also affects the willingness of use lessons learned, as it is both time consuming to understand the documents and find the information you are looking for. This calls for a simple system where the documents are easy to access.

Autoliv state that they have experienced similar problems with lessons learned, which lead to a global initiative where they introduced a new IT-solution. This data base which includes all lessons learned in a structured and easy way means that lessons learned can become a better complement and input to their risk management processes. If the design teams use new content in their solutions, it is pointed out as uncertainties and risks. This means that a separate more extensive process flow must be followed in order to ensure that all risks are handled. However, a simpler process can be followed if known content is used in the design choices. This creates incentives to only take higher risks in the situations where it is really needed. In addition, choosing new items results in a list of risks with mitigation activities, which have to be accepted by management. Autoliv consider this as one of their core strengths within their product development, but also point out that finding the right documents can be very time consuming. However, if it can prevent redoing easy mistakes it is worth it.

All three cases within this thesis point out that it is challenging to work with lessons learned in an effective way. It seems to be a conflict between what can be seen as good enough and effective in the short run versus the long run. Volvo CE argue that it easily results in a lot of administration, but all three cases agree that it can prevent many mistakes and problems.

At GKN much knowledge is shared in a more informal way through conversations between employees, but the general opinion is that lessons learned can be used in more structured approach. Old FMECAs at GKN can however be seen as one way of saving and sharing knowledge. However, both Autoliv and Volvo CE are reusing their FMECAs in a greater extent and having so called master-FMECA for different
products. This is also something that is requested at GKN and it is seen as a condition for doing the work more manageable.

Cooper (2003) also brings up risk with using new tools and stored data. It is therefore important that relevant data is used which is applicable to the issue. Finally, the possibility of using lessons learned as a tool within risk management is probably highly affected by the organization and its conditions, maybe it is not suitable for all organizations. It might be more useful when products are homogeneous and it is important to consider barriers such as confidentiality.
7 Conclusions

In this chapter the general conclusions and findings from the study is presented. These are divided in the four different main areas that have been covered in the study; Product Risk Management and FMECA, Robust Design, Producibility and Lessons Learned.

7.1 Product Risk Management and FMECA

In order to get a proactive risk management approach and use the full potential of the FMECA, it is important to have a clearly specified process. Otherwise the FMECA easily becomes a document that is used reactively to summarize already carried out actions. Using it this way does not fulfill the purpose of the tool.

It is not just important to have a clearly specified process, but to ensure that the employees understand how the tool should be used and that they have a positive attitude towards it. The survey shows that employees at GKN with FMECA education are prone to have an overall positive attitude towards the tool. Therefore, raising the basic educational level does not only increase the understanding of the tool, but may also create a better attitude towards risk management within the organization.

However, the basic level of education might not be enough for those appointed to lead the work. Creating a Product Risk Manager role and giving these employees a more extensive education of how to lead the team’s risk reducing actions is a possible solution. This also decreases the need of having super users who are appointed to support those who lead the work. A super user can instead be appointed to be process leader and focus on educating employees and coaching the Product Risk Managers.

In order to get employees to put enough effort into product risk management activities there must be some kind of demand. An external demand from customers naturally has the greatest effect, but the demand can also be generated internally within the organization. However, if the demand should be created internally the support from the executive management is of great importance, since sufficient resources must be provided in order to prioritize these issues.

Finally, the work with FMECA:s usually start at the conceptual design phase and many point out that it is not value creating to start earlier. In order to save time and make the work manageable, it is beneficial to use historical FMECA:s as foundation. There are also examples of organizations that uses a “Master FMECA” as a basis for new FMECAs.

7.2 Robust design

The study shows that it is possible to include robust design issues into the risk management process. Including this risk perspective creates proactivity as variation issues are handled at an early stage. However, including robust design issues in the
FMECA and use it as the only tool might not be enough to identify all types of variation risks. In order to not increase the complexity of the FMECA, there needs to be a plan of how variation risks should be separated from design risks and adjustments might be needed in the FMECA-template. However, it might be of even greater importance to create a separate process flow, similar to the one used at Autoliv. The separate process gives a more detailed action plan for variation risks, whereas the FMECA give a holistic view of all risks.

Lastly, robust design issues and variation risks do not seem to be included from the initiative of employees. Therefore this must be demanded by the process. If the customers do not require it, the demand must be created internally and be requested from the executive management.

7.3 Producibility

It is clear that the collaboration and dialogue between design and manufacturing is key in order to early create a producible concept. How risks regarding producibility should be included in the FMECA is not obvious, but one important aspect is to early include manufacturing engineers in the discussions. At GKN the manufacturing side is in general very open to be included in the FMECA-work, which enables this collaboration to start from the beginning of the projects.

In order to effectively work with producibility issues there needs to be a clear connection between the FMECA and the P-FMEA. There needs to be a flow where risks and uncertainties can be transferred between these two documents and solved either by changing the design or the production process. However the first step lies within establishing the limitations and capabilities within the manufacturing facilities and understand these from the start of the product development projects.

7.4 Lessons Learned

One of the simplest ways of sharing knowledge and experience is through discussions and conversations. But if too much knowledge and expertise is locked to specific employees the organization becomes very dependent on these individuals. When they leave the organization or transfer to other positions they take their knowledge with them. The organization becomes sensitive to these changes and a structured approach for how the knowledge should be retained is needed.

According to literature lessons learned can be a natural part of the risk management process, which is also seen at Autoliv. Collecting the shared knowledge of the company becomes a way of proactively ensuring that mistakes are not reoccurring within the organization. This means that the mistakes that are made at least are value creating to some extent, as the lessons learned from these become valuable input for new projects. However, all cases and literature show that working with knowledge management and lessons learned is very challenging. Simplicity within the databases and systems are therefore of greatest importance.
8 Recommendations

This chapter presents our recommendations to GKN of how they may proceed in order to gain a more effective and proactive product risk management processes.

8.1 Support and Demand from Executive Management

In order to implement any of the recommendations in this thesis, support from the executive management is required. Product risk management at GKN is of top priority when it comes to ensuring flight safety, but besides that it seems like risk management has a low priority compared to other activities and documents, which are required before gate reviews.

However, this study shows that this situation is different when there is a demand from the external customer. At GKN, the risk management within the space department is at a higher level, but one of the major reasons is probably that the customers review and questions the FMECAs in detail. Similarly Autoliv includes variation risk management and robust design to a much higher degree, but the changes to today’s system were not made until the customers required them to implement these perspectives.

As there is no external demand in the majority of GKN’s programs, an internal demand must be created in order to achieve similar effects. At Volvo CE the executive management gave increased support and allocated more resources to develop the risk management processes, after they managed to show the value of risk management by linking it to future costs of poor quality. Therefore GKN should try to find a way to link their risk management activities to the monetary savings it results in, in order to show how value creating it is.

8.2 Appoint process lead

At the moment GKN does not have a process lead for the product risk management process. However, there is a specialist within product risk management, who in many cases performs these types of tasks and informally takes this position. Appointing this employee or someone else the position of process lead would give more authority and a possibility to standardize and even out the risk management practices, which are allowed to vary between programs today.

8.3 Develop a more specific standard/instruction

In general, the product risk management process at GKN is less specified and structured in comparison to the ones at Volvo CE and Autoliv. The survey show that 66% do not know whether they work in accordance to the instructions of OMS or not. With this in mind one might question the effects of developing these instructions. However, if there is support from the executive management for these
changes, the process lead has more authority to implement these changes. The same goes for EiC:s who are backed up by specific instructions as they are likely to meet some resistance in the implementation. Therefore, the following adjustments are recommended for an updated standard.

8.3.1 Decision of risk aspects which should be included in the FMECA

At the moment it is unclear which specific risk aspects should be included within the FMECA. Forcing in risk aspects like producibility and robust design into the tool will contribute to one of the major problems already identified; the tool is too complex, time-consuming and hard to get a holistic view of. Therefore, GKN needs to decide on an approach of how these issues should be included. If producibility and robust design issues are included in the FMECA, a complementary process flow similar to Autolivs will be needed. The issues and mitigation actions are handled in the separate process flow, but they are also documented in the FMECA in order to give a holistic view of all risks. A similar approach is also suggested by Thornton (2004) regarding how KC:s should be integrated within the FMECA-tool. A suggested Robustness flow will be discussed further in section 8.4.

8.3.2 Requiring manufacturing to be included within FMECAs

Through the interviews it is evident that there are still some barriers between design and manufacturing, and in some cases manufacturing is not included in the FMECAs. However, the manufacturing side seems open to be involved earlier and point out that some producibility risks otherwise go unidentified until the P-FMEA is conducted. Therefore, a recommendation is to make it a basic requirement that manufacturing is involved from the start of all FMECAs. Whether risks should be mitigated trough re-designs or process improvements may vary between cases. However, in order to have a proactive approach with FMECAs, all potential risks should be identified as early as possible and followed up.

8.3.3 Clarification of the continuity issue

The second largest difficulty is the continuity issue, according to the grading of the affinity diagram by the EiC:s. The question of how often one should work with the FMECA is hard to determine. It differs between cases and is dependent on the current phase of the program. However, the survey results show that the majority of the employees work with the FMECA one time to a few times per year, which cannot be considered frequent enough. A minimum requirement similar to the one used at Volvo CE is therefore suggested, where the FMECA needs to be updated in the case when either form, fit or function is changed. Furthermore, Volvo CE uses an attendance list to follow up which employees who have been present during FMECA meetings. This can be one way of increasing the number of participants during the meetings.
8.3.4 Create a clear flow between the FMECAs and P-FMEAs

The standard does not at the moment include a clear flow of information between the FMECAs and P-FMEAs. Through the interviews it is clear that some risks are connected and appearing in both documents. Therefore if they are not handled in the FMECA, they might reappear in another shape within the P-FMEA. The flow between these two documents therefore needs to clearly be structured where issues are first identified in the FMECA, handled if possible and used as input within the P-FMEA.

8.3.5 General updates of the instruction

*The following updates are recommended to be adjusted and clarified in the product risk management instructions.*

- Similar to Volvo CE require that FMECAs are started at a conceptual level when initiating the concept phase. In most cases at GKN the FMECA is started during this phase, but at the moment it is not required. This is where the highest risks are identified as well as potential “show stoppers”. Questioning and discussing concepts in terms of “potential show stoppers” is a way of having a proactive mindset.

- At the moment the same FMECA instructions in OMS is used for all phases of the product development process. In other words if someone is viewing the FMECA instructions within the final design phase of the PDP, they get an instruction focused on how an FMECA is created at the initial phases instead of how risk actions should be followed up and closed at the final stages. By customizing the instruction to the different phases, the employee gets the information he/she is looking for in an easier way. The complete FMECA instruction can conveniently be linked at the bottom of the page.

- In general, the FMECA instructions are focused on the initial phases of the FMECA work and needs to be clarified and developed for how risks should be followed up, mitigated and closed.

- The term “FMECA-maturity” is used at Volvo CE in order to discuss how far along the team has come with the reduction of the total number of risks. Introducing this term at GKN throughout the instructions could be effective, especially since e.g. maturity of technologies and Technological Readiness Levels are commonly used within the organization.

- In general, the disciplines required to participate in FMECA exercises should be clearly specified in the instruction, as well as the number of employees preferred.

8.4 Include Robust Design in risk management and develop a “Robustness Flow”

In order to include robust design aspects within the risk management process there needs to be a sufficient understanding within the area throughout the organization, as well as a clear approach of how it should be involved. This needs to be clarified at
GKN, as it is clear that e.g. critical items and KC (Key Characteristics) are mixed up. Furthermore, as been discovered in this thesis, it is possible to include robustness in risk management and a recommendation is to consider this opportunity at GKN. However, this requires a lot from the organization and changes are needed.

In order to include robust design effectively, tools that take variation into consideration is a condition. It is not recommended to blindly integrate it in the FMECA, as it is already perceived as complex and overwhelming. The recommendation is therefore to develop a separate flow that handles robustness. This could be similar to how Autoliv work, with a tool that point out variation and a tool that evaluates the severity by connecting it to failure modes. Finally, this recommendation requires changes in both the process and the standard. A “Robustness Flow” needs to be added to the process and it needs to be expressed in the standard.

### 8.5 Clarification of connection between Producibility and Risk Management

This recommendation is connected to previous recommendations; Develop a more specific standard/instruction. By having guidelines in the standard that address how producibility should be included in the risk management and FMECA will create conditions for a more effective work regarding this issue. Furthermore, by including employees from manufacturing in a larger extent in the FMECA will give a stronger manufacturing perspective. Questions regarding the design and its conditions to be produced can therefore be raised in an early stage. Finally, the process and the connection between the FMECA and the P-FMEA need to be clarified, which will create possibilities transfer and solve uncertainties by collaboration.

Today, the work with developing producible products is done by collaboration and a dialogue between design and manufacturing. The recommendation here will not imply any bigger changes but it will lead to a more structured approach when handling issues regarding producibility. It will clarify the work and facilitate the collaboration between design and manufacturing. The purpose is to create better conditions and an approach where these problems are solved together.

### 8.6 Organizational Risk Management structure inspired by Six Sigma Belts

The basic risk management education provided to the EiC:s is today at the same as for other employees. Volvo CE has another solution, where their design leads (EiC:s) are given a much more extensive education lasting a couple of days and focusing on how to lead the team to effectively mitigate their risks. The design leads take the role as Product Risk Managers/Risk Responsible and this structure is seen by themselves as one of their success factors. A similar system could be created at GKN, which is visualized in Figure 8.1.
The idea is to still provide the basic education, which all employees involved in the FMECA work should receive. The survey has showed that this has a positive effect on the attitude of the employees and those with risk management education perceive the FMECA as more value creating. Having employees who understand the tool and how it can work proactively means that the discussions can be lifted to another level within the teams and work more effectively.

However, in order to lead the teams effectively and follow through with the mitigation action might require a more extensive education with another focus. It is therefore recommended to appoint the role of Risk Responsible within the teams, preferably the EiCs, and then provide a more extensive education for these employees. As mentioned before, this is seen as one of the success factors of Volvo CE and this type of education would take a couple of days.

Finally, the recommendation involves a risk coach at the top of the pyramid. This employee would be the process lead, described in recommendation 8.2, which is a specialist within product risk management. This employee would provide all educations and then continuously support/coach the Risk Responsible in their work.

Implementing this type of structure would give a possibility to even out the varying product risk management practices seen at GKN today. As new standards and processes are updated this structure would be of big help in the implementation process. This creates conditions similar to the Six Sigma Belt structure. Increasing the level of Green Belts within the team means that the discussions can be held at higher level, problems are identified easier and the level of commitment becomes higher. Having experienced Black Belts leading the teams means that projects can be managed more effectively and with better results. Finally, having a Master Black Belt at the top means that Black Belts can be coached and supported.
Lastly it will create conditions for a more effective risk management since there will be a better FMECA-knowledge within the teams. The attitude will also be better and effect the commitment that will help the work to be more continuously.

8.7 Develop a “Master-FMECA”

One of the most common complaints regarding the FMECA is that it is time consuming, complex and not enough resources are available to handle this. One reason why it becomes complex is that the inputs are not clearly specified, some even start from a white blank page every time. Therefore it is recommended to create a Master-FMECA as the main input, as many state that the basic structure and risks are generic for the same product types. This means that risks that are identified in previous projects together with chosen mitigation actions are gathered in this document, which becomes a way to summarize lessons learned. This enables the focus to be on what is new and what is different from the generic design, in other words a “Delta-FMECA”.

8.8 Investigate the opportunity to utilize Lessons Learned into Risk Management

In order to be proactive and prevent reoccurring mistakes, lessons learned can be utilized in the risk management process. However, this in not an easy task and it requires a lot of efforts from the organization. The recommendation is therefore to investigate the possibilities to work with lessons learned at GKN in a more structured way and use it in risk management. Besides the fact that lessons learned is challenging, GKN also needs to consider how the confidentiality between programs can affect the work.

8.9 Measuring of risk mitigation in the FMECA

Today the structure within GKN’s FMECA template requires risks to be mitigated to a certain level, for example RPN<75. This is linked to governmental requirements and standards, and is a way of ensuring that no residual risks are too large. However, by only requiring risks to be lowered to a specific level where it is considered safe, does not give incentive to lower the risk as far as possible. Neither does this structure give incentive to work as effectively and proactive as possible at the current phase of the product development. One way of improving this situation could be to create complementing performance measurement, which is illustrated by an example in Table 8.1. The two columns on the far right are added to the current FMECA-template. After all risks have been identified at the initial identification phase, the RPN numbers are summarized and this is deemed as 100% of the risks. As the team starts their effort of mitigating the risks by different actions, these two columns give a complementing view of the contribution and progress. In the example, mitigating risk Y results in a much larger decrease in the total RPN than mitigating risk X. Which risks are best to mitigate first depends on the amount
of effort and difficulty required for each specific action. This is a judgment call and up to the engineers to estimate. Introducing this also gives a simple key performance indicator of how mature the FMECAs are and this is easy to follow up on the weekly team-meetings.

Table 8.1 - Example of performance measurement columns to add to the current FMECA-template

<table>
<thead>
<tr>
<th>Risks</th>
<th>S</th>
<th>P</th>
<th>O</th>
<th>RPN</th>
<th>Action</th>
<th>S</th>
<th>P</th>
<th>O</th>
<th>New RPN</th>
<th>Delta-RPN</th>
<th>Total Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk X</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td>140</td>
<td>Action X</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>75</td>
<td>65</td>
<td>11%</td>
</tr>
<tr>
<td>Risk Y</td>
<td>9</td>
<td>6</td>
<td>5</td>
<td>270</td>
<td>Action Y</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>60</td>
<td>210</td>
<td>35%</td>
</tr>
<tr>
<td>Risk Z</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>192</td>
<td>Action Z</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>60</td>
<td>132</td>
<td>22%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>602</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>195</td>
<td>407</td>
<td>68%</td>
</tr>
<tr>
<td>RPN</td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>32%</td>
</tr>
</tbody>
</table>
9 Discussion

This chapter contains a discussion regarding the result of the thesis and the credibility of the findings. Reflections of the thesis process are given together with suggestions for further research.

9.1 Generalization of the findings

The generalizability of the thesis is improved since two separate benchmarking cases within completely different industries are included. The contrast these cases provide gives a better picture of what findings might be specific for the aerospace industry. Furthermore, the conclusions are generalizable for most types of product development cases; like how teams can be managed, education of employees and leaders and how it must be demanded from the top-level management.

9.2 Measures to ensure reliability

In order to ensure the reliability of the thesis, a number of preventive measures have been taken. All 16 interviews at GKN and the benchmarking interviews have been recorded and transcribed. At the same time, many informal conversations have been held with different employees of the organizations, which have not been recorded or transcribed. The trustworthiness of these as well as their contribution to the final conclusions is hard to determine. These have however mainly been used to generate a better description of the organization and leads of where to continue the investigation.

The response rate of the survey, 52%, is relatively low considering the number of reminders that have been sent out. As the survey is not anonymous this might suggest that those who work actively with risk management and follow the instructions are more prone to answer the survey. Therefore the situation at GKN might be different from what is portrayed in the survey. Through the interviews and discussions it is evident that many interpret the instruction in their own way and rarely work with the FMECAs. Measures to counteract these reliability issues have been difficult to find, however one way have been through letting the EiC:s grade the affinity diagram in Appendix 2. This gave good hints of what the majority perceived as the main issues regarding the work with FMECA:s.

9.3 Measures to ensure validity

To some extent, product risk management seems to be a sensitive issue. Due to the severity of the consequences within the aerospace industry, not fulfilling one’s requirements of the risk management process becomes a serious issue. As the survey furthermore is not anonymous the trustworthiness of the survey answers can be questioned. There might be a gap between what the employees state that they do and what they actually do. The interviews have however provided a better
possibility to understand how people actually work, as follow-up questions can be asked.

The analysis, which attempts to compare the three separate cases equally, may provide a skewed picture of the reality. The data collection process for the benchmarking cases is far less extensive than the one at GKN. Furthermore, there is no clear benefit for the companies from the benchmarking, besides the long-term collaboration between the companies. Therefore, they may have been providing a picture that shows more how they set out to handle their risks, instead of how they actually handle their risks. However, the purpose of the benchmarking study has not been to provide an equal comparison of the three cases, but to generate contrast to the case studied in depth at GKN. That has definitely been achieved and it has provided many good ideas of how issues at GKN might be solved.

9.4 Implications on sustainability

As mentioned previously in the thesis, sustainability is more and more becoming an integral part of product risk management. GKN have very recently started a collaborative research project within sustainable product development together with University of Blekinge and Volvo CE. Sustainability risk management is one part within this research and may in the future become a given part of GKN’s product risk management process.

Even though the importance of sustainable solutions cannot be emphasized enough, blindly integrating these issues into the additional product risk management process is probably not the solution either. GKN is at the moment struggling with involving producibility and robustness issues within the product risk management processes. Literature e.g. advises against including variation risk into the FMECA without also treating them separately. The same advice could probably be seen with sustainability risks, where this needs to be treated in a separate process as well. Adding more risk perspectives to the current process will most likely lead to more confusions and result in FMECA:s, which are perceived as even more complex.

A more realistic illustration of what might be better to pursue is illustrated in Figure 9.1. Lifting producibility issues has been of great focus at GKN during the last decades and the majority points out that large improvements have been made. However, it can be seen that making these organizational changes take long time. At the moment robust design is slowly being incorporated to a further extent, mainly through the practice of KC:s. Incorporating sustainability risks is far from impossible, but GKN should be aware that it might be a challenge and will take some time.
Figure 9.1 – Illustration of different risk aspects to include over time in order to gain a risk management process that completely handles the array of different risk aspects

9.5 Suggestions for further research

As the process have been explorative and included many different perspectives, it leaves behind many possible future research questions. Discussions regarding proactive measurements have been brought up from the beginning of the thesis. Trying to create measurements that are easy to understand while giving the right incentives is a great challenge. Therefore it would be interesting to investigate this area of product risk management further.

Another insight that has been developed during the thesis process is the question of how product risks can be transformed into actual costs for the company. Volvo CE has managed to link “costs of poor quality” documents to their product risk management processes. This illustrating the risks from a cost perspective to the management, which means that the benefits of implementing improvements can become clearer. Finding ways to link costs and risks better therefore has great potential.

Finally, it is evident that practices within GKN vary, where some teams handle risks, robustness and producibility issues better than others. In other words, there are different best practice examples within the walls of the company that can be used as base for improvements in the risk management processes. Therefore it would be a possibility to appoint an investigation to further research the differences between programs and departments further.
10 References


http://www.gkn.com/aerospace/aboutus/Pages/default.aspx


Appendix 1 – Result from the Survey

This appendix contains the result from the quantitative questions of the questionnaire. In total 87 questionnaires have been sent out across four different departments. In order for GKN to gain a greater understanding of the current situation the questionnaire has also been sent out to the RoT- and Analysis-department, however those results are not included in this appendix.

Sent out questionnaires: 87
Total number of responses: 45, 52%
Number of respondents suited to answer all questions: 29, 63%

* Indicates a required question. Therefore 100% of the respondents have answered these questions.

1. What is your responsibility within product development at GKN? *

![Bar chart showing responses to question 1](chart1.png)

**FIGURE A1 – TWO MAIN GROUPS HAVE ANSWERED THE SURVEY, 36% FROM DEFINITION AND 27% FROM ENGINEER IN CHARGE (EIC). THE EICS ARE OF SPECIFIC INTEREST FOR THIS THESIS AND ARE TREATED SEPERATELY IN SOME OF THE FOLLOWING QUESTIONS.**

2. How many years have you worked at GKN /Volvo Aero? *

![Bar chart showing responses to question 2](chart2.png)

**FIGURE A2 – A LARGE NUMBER OF EMPLOYEES HAVE WORKED AT GKN FOR A LONG TIME, 56% FOR OVER 10 YEARS**

3. Have you gone through any Risk Management education at GKN? *

*Multiple choices is possible*

![Bar chart showing responses to question 3](chart3.png)

**FIGURE A3 – ALMOST 50% DO NOT HAVE ANY RISK MANAGEMENT EDUCATION. FURTHER ANALYSIS SHOW THAT THERE IS NO EVIDENT CORRELATION BETWEEN THE NUMBER OF YEARS EMPLOYEES HAVE WORKED AND THEIR RISK MANAGEMENT EDUCATION.**
4. How often do you work with FMECA?  

![Bar chart](image)

**FIGURE A4** - ALL EIC'S STATE THAT THEY WORK WITH FMECA, ABOUT TWO THIRDS WORK A FEW TIMES PER YEAR. ONLY 5 OUT OF 46 EMPLOYEES WORK WITH THE FMECA ON A MONTHLY BASIS. IN THE DEFINITION DEPARTMENT ALMOST 50% NEVER WORK WITH FMECA AND 75% HAVE NO FMECA-EDUCATION.

*Note* that the questionnaire uses a branching logic. The 16 respondents who never work with FMECA are not deemed suitable to answer the remaining questions. Therefore the total number of responses per question is henceforth 29.

5. I understand the purpose of working with FMECA  

*To which extent do you agree with the statement, on a scale of 1-6; 1 = Do not agree at all 6 = Completely Agree*

![Bar chart](image)

**FIGURE A5** – QUESTION 5-7 MEASURE THE OVERALL ATTITUDE TOWARDS FMECA, WHICH IS ALSO SUMMERIZED IN TABLE A 1.

6. FMECA is a user friendly tool for working with risks  

*To which extent do you agree with the statement, on a scale of 1-6; 1 = Do not agree at all 6 = Completely Agree*

![Bar chart](image)

**FIGURE A6** - QUESTION 5-7 MEASURE THE OVERALL ATTITUDE TOWARDS FMECA, WHICH IS ALSO SUMMERIZED IN TABLE A 1.

7. FMECA is a value creating tool  

*To which extent do you agree with the statement, on a scale of 1-6; 1 = Do not agree at all 6 = Completely Agree*

![Bar chart](image)

**FIGURE A7** - QUESTION 5-7 MEASURE THE OVERALL ATTITUDE TOWARDS FMECA, WHICH IS ALSO SUMMERIZED IN TABLE A 1.

**SUMMERY QUESTION 5-7.**

<table>
<thead>
<tr>
<th>On a scale from 1-6, to which degree do you...</th>
<th>FMECA-education</th>
<th>EIC</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>... understand the purpose of the FMECA?</td>
<td>5,6</td>
<td>4,8</td>
<td>5,6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4,7</td>
</tr>
<tr>
<td>... find FMECA user friendly?</td>
<td>4,6</td>
<td>3,9</td>
<td>4,4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3,9</td>
</tr>
<tr>
<td>... perceive FMECA as a value creating tool?</td>
<td>5,0</td>
<td>3,7</td>
<td>4,7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3,3</td>
</tr>
</tbody>
</table>

| Average | 5,1 vs. 4,1 | 4,9 vs. 4,0 |
8. How important do you consider the following risk aspects to be in the creation of a FMECA? *

Value the importance on a scale from 1-6;  
1 = Not at all  
3-4 = Partly  
6=Very

Flight Safety

Ensuring Technical Functions

Robust Design

Productibility

Shared Risks

Maintenance

TRL-Level

FIGURE A8 - MEAN = 5.5  EIC_{MEAN}=5.9

FIGURE A9 - MEAN = 5.3  EIC_{MEAN}=5.5

FIGURE A10 - MEAN = 4.4  EIC_{MEAN}=4.7

FIGURE A11 - MEAN = 4.2  EIC_{MEAN}=4.1

FIGURE A12 - MEAN = 4.2

FIGURE A13 - MEAN = 4.1

FIGURE A14 - TRL-LEVEL, MEAN = 3.9
9. Which disciplines/functions are usually present in the team when creating a new FMECA? *

Multiple choices are allowed

![Graph showing the distribution of disciplines/functions present in the team creating a new FMECA.]

**FIGURE A15 – DISCIPLINES/FUNCTIONS PRESENT IN THE TEAMS CREATING NEW FMECA:s**

10. Do you use method support when creating a FMECA? *

*Answer on a scale from 1-6; 1 = Never 6=Always*

![Graph showing the distribution of responses to the question of method support usage.]

**FIGURE A16 – 64% OF THE EIC:S CLAIM THAT THEY NEVER, OR ALMOST NEVER, USE METHOD SUPPORT WHEN WORKING WITH FMECA. THERE SEEMS TO BE A SPLIT INTO TWO GROUPS AS THE REMAINING EIC:S IN CONTRAST OFTEN USE THE SUPPORT**

11. If you have used method support, rate on a scale from 1-6 how you found it? *

*Answer on a scale from 1-6; 1 = Very Bad 6=Very Good*

![Graph showing the distribution of responses to the question of method support satisfaction.]

**FIGURE A17 – NUMBER OF RESPONSES: 17, 59%. WITH A MEAN=4,3, THOSE WHO USE METHOD SUPPORT SEEMS FAIRLY SATISFIED**
12. Have any of the following partners been involved in the creation of the FMECA? *
Multiple choices are allowed

![Partners Involved in Creation of FMECA](image)

**FIGURE A18 – PARTNERS INVOLVED IN CREATION OF FMECA:**

13. When identifying risks for the FMECA, to which extent do you use the following methods? *
*Answer on a scale from 1-6; 1 = Never 6=Always*

**Update from an Old FMECA**

![Update from an Old FMECA](image)

**FIGURE A19 – MEAN = 4.7**

**Systematic Approach Based on Functions and Technical Requirements**

![Systematic Approach Based on Functions and Technical Requirements](image)

**FIGURE A20 – MEAN = 4.6**

**Post It - Technique**

![Post It - Technique](image)

**FIGURE A21 – MEAN = 4.0**

**Fault Tree Analysis**

![Fault Tree Analysis](image)

**FIGURE A22 – MEAN = 2.3**
14. How do you experience the attitude towards FMECA at GKN? FMECA is... *

To which extent do you agree with the statement, on a scale of 1-6; 1 = Do not agree at all 6 = Completely Agree

**An Effective way of Prioritizing Risks**

![Bar Chart](image1.png)  
**FIGURE A23 – MEAN = 4,3**

**A Good Way of Identifying Our Risks**

![Bar Chart](image2.png)  
**FIGURE A24 – MEAN = 4,3**

**A Living Product Throughout the Whole PD-process**

![Bar Chart](image3.png)  
**FIGURE A25 - MEAN = 3,5**

**A Must in Order to Move to the Next Gate**

![Bar Chart](image4.png)  
**FIGURE A26 - MEAN = 3,7**

**“Desktop Product”**

![Bar Chart](image5.png)  
**FIGURE A27 – MEAN = 3,3**

**Only an Update of an Old Analysis**

![Bar Chart](image6.png)  
**FIGURE A28 – MEAN = 2,9**

**Not so Important, We Mainly Use Our Gut Feeling**

![Bar Chart](image7.png)  
**FIGURE A29 - MEAN = 2,1**
15. In which phases of the product development do you work with FMECA? *

*Multiple choices are allowed*

![Figure A30 - Phases of the product development and work with FMECA](image1)

16. Is there a difference between how you work with FMECA and how you should work with FMECA according to OMS? *

![Figure A31 - The EIC's work with the FMECA in more phases than definition employees, except during the detail phase](image2)

![Figure A32 - 8 out of 9 definition employees do not know whether they work in accordance to the instructions in OMS with the FMECA. 36% of the EIC's claim that they work in accordance to OMS, 27% claim that they don't and the remaining don't know if they do.](image3)
16. Another view of product risk management is given within project risk management, which of the following aspects have been considered in your project risk analysis? *
Multiple choices are allowed

![Bar chart showing aspects considered in the project risk analysis](image)

**FIGURE A33 – ASPECTS CONSIDERED IN THE PROJECT RISK ANALYSIS**

17. The Project risk management analysis is an important complement to the FMECA in order to understand how product risks are handled! *

*To which extent do you agree with the statement, on a scale of 1-6; 1 = Do not agree at all 6 = Completely Agree*

![Bar chart showing agreement levels](image)

**FIGURE A34 - THIS SHOWS THAT THE ORGANISATION DOES NOT SEE A STRONG CONNECTION BETWEEN THESE TWO RISK MANGEMENT TOOLS.**
Appendix 2 – AIM-diagram based on Survey Results

AIM fråga: Vad hindrar GKN från att arbeta effektivt med FMECA och Produktriskhantering?

**Omfattande arbete, för lite tid tilldelad för FMECA-arbete**
- För tidsblandande verksamhet (FMECA)
  - Vi är inte resursstarka för arbetet
  - Tar mycket tid och kraft
  - Stort jobb som är svårt att få överblick över
- FMECA är komplicerat och omfattande
  - FMECA kan vara stort och invexerat
- FMECA görs efterhand
  - Risken är stor att det bara blir att konstaterande i efterhand i FMECA-arbetet
  - Kännas som något man gör i efterhand för att tillfredsställa systemet (riskerna har tagits hand om på annat sätt)
  - FMECA används på fel sätt, gör den för att uppfylla systemet snarare än att arbeta proaktivt
- Risker kopplat till producerbarhet är ej tydligt definierat
  - Producentär har inte klarnat om producerbarhet och hur den ska definieras
  - FMECA används på fel sätt, gör den för att uppfylla systemet snarare än att arbeta proaktivt
- Svårigheter med helhetsperspektiv, fånga upp och prioritera riskerna
  - Svårt att fånga upp felmoder/Risker
  - Svårt att fånga upp alla tänkbara felmoder, kan bara åtgärda det man kan komma på.
  - Svårt att fånga risker utanför boxen, dessa risker som vanligtvis missas (vi borde ha systematiskt färdiga av olika risker från andra projekter)
  - Ej omfattande arbete för lite tid tilldelad för FMECA-arbete
  - Övriga riskperspektiv prioriteras ej tillräckligt

**Tillräcklig utbildning i FMECA**
- Ej tillräcklig kunskap
  - Svårt att vara konsekvent i beskrivningen av failure cause och failure effect
  - Få som vet hur man jobbar med FMEA
  - (alla som jobbar med) beroende av färdighet och erfarenhet

**Riskarbetet ska ej kontinuerligt**
- Dålig uppföljning och uppdatering
  - Att regelbundet följa upp och arbeta med actions / riskminimering
  - Svårighet att jobba med FMECA kontinuerligt
  - Svårt att hålla FMECA levande och på ett enkel sätt och uppdatera den med spårlighet och på hur riskerna har "rönt på sig"

**Instruktioner i OMS följes ej, eller enbart till viss grad**
- Verkligheten och OMS skiljer sig
  - Finns krav från kund som ej stämmer med OMS → Dubbelarbet
  - Det finns inbäddade funktioner/bälten som skiljer sig från OMS och är accepterade (som som en av de riskerna)
- Risker som inte är specifika
  - Svanenett
  - Svårigheter med prioritering av Risknivåer

**Svårigheter med helhetsperspektiv, fånga upp och prioritera riskerna**
- Ej omfattande arbete för lite tid tilldelad för FMECA-arbete
  - Övriga riskperspektiv prioriteras ej tillräckligt

**Ofrämliga roller, samt bristfällig gruppansammansättning och kommunikation**
- Svårt att få rätt sammansättning i FMECA-gruppen
  - Svårt att få funktionärer att samarbeta och göra att berördas av arbete (TID)
  - Svårt att få en funktionär att jobba med risken och berördar disciplin (många risker att hantera)
  - Risker ska hela gruppen arbeta med, inte bara EIC

**Svårigheter med helhetsperspektiv, fånga upp och prioritera riskerna**
- Svårt att få participants av risknivåer
  - Svårigheter med prioritering av Risknivåer
  - FMECA ej optimiserad i branschen, på Probability vs. Severity (risker åtas in på annat sätt)

**Risker kopplat till producerbarhet är ej tydligt definierat**
- Många projekt skapa flera risker utanför FMECA
  - Man arbetar inte aktivt med projekt risken, den är mer ett "målet" och uppdateras själv

**FMECA görs efterhand**
- Risken är stor att det bara blir att konstaterande i efterhand i FMECA-arbetet
  - Kännas som något man gör i efterhand för att tillfredsställa systemet (riskerna har tagits hand om på annat sätt)

**Större jobb är svåra att få överblick över**
- Svårt att fånga upp felmoder/Risker
  - Svårt att fånga upp alla tänkbara felmoder, kan bara åtgärda det man kan komma på.
  - Svårt att fånga risker utanför boxen, dessa risker som vanligtvis missas (vi borde ha systematiskt färdiga av olika risker från andra projekter)

**Risker kopplat till producerbarhet är ej tydligt definierat**
- Många projekt skapa flera risker utanför FMECA
  - Man arbetar inte aktivt med projekt risken, den är mer ett "målet" och uppdateras själv

**Svårigheter med helhetsperspektiv, fånga upp och prioritera riskerna**
- Ej omfattande arbete för lite tid tilldelad för FMECA-arbete
  - Övriga riskperspektiv prioriteras ej tillräckligt

**Svårigheter med helhetsperspektiv, fånga upp och prioritera riskerna**
- Ej omfattande arbete för lite tid tilldelad för FMECA-arbete
  - Övriga riskperspektiv prioriteras ej tillräckligt

**Svårigheter med helhetsperspektiv, fånga upp och prioritera riskerna**
- Ej omfattande arbete för lite tid tilldelad för FMECA-arbete
  - Övriga riskperspektiv prioriteras ej tillräckligt

**Risker kopplat till producerbarhet är ej tydligt definierat**
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  - Man arbetar inte aktivt med projekt risken, den är mer ett "målet" och uppdateras själv

**Svårigheter med helhetsperspektiv, fånga upp och prioritera riskerna**
- Ej omfattande arbete för lite tid tilldelad för FMECA-arbete
  - Övriga riskperspektiv prioriteras ej tillräckligt

**Svårigheter med helhetsperspektiv, fånga upp och prioritera riskerna**
- Ej omfattande arbete för lite tid tilldelad för FMECA-arbete
  - Övriga riskperspektiv prioriteras ej tillräckligt
## Appendix 3 – Interview Template

<table>
<thead>
<tr>
<th>#</th>
<th>Risk management in General</th>
<th>Keywords / Additional Questions</th>
<th>Answers</th>
<th>Suggestions for Improvements</th>
<th>Purpose of Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>What is your discipline and role at GKN, what are your daily tasks?</td>
<td>Role within Risk Management?</td>
<td></td>
<td></td>
<td>Provide a background and investigate how the person sees his/her own work in relation to risk management.</td>
</tr>
<tr>
<td>2</td>
<td>What practices are used to handle different types of risks?</td>
<td>What tools are use for what type of risks? In general!</td>
<td></td>
<td></td>
<td>Establish different kinds of risk</td>
</tr>
<tr>
<td>3</td>
<td>When during the product development process do you mainly work with risk management?</td>
<td>Where is the main focus put? In what PDP-phases? When is it started?</td>
<td></td>
<td></td>
<td>Establish when employees work with risk management and if it is proactive. Discuss with the product development process flow as a basis.</td>
</tr>
<tr>
<td>4</td>
<td>What aspects are affecting how you work with risk management?</td>
<td>Internal/External Customer, different programs, OMS, Different requirements, Control, AS9100, ISO 31000</td>
<td></td>
<td></td>
<td>What set the constraints for risk management and affect the work</td>
</tr>
<tr>
<td>5</td>
<td>How does the actual risk management differ from the instructions in OMS?</td>
<td>How? Why? Why don’t you know? User friendly?</td>
<td></td>
<td></td>
<td>Does the instructions in OMS really fill its function?</td>
</tr>
<tr>
<td>6</td>
<td>Besides traditional risk management tools, are there other tools that reduces uncertainties and risks and therefore creates proactivity?</td>
<td>Specific Tools, Proactive measurements</td>
<td></td>
<td></td>
<td>Find out if any additional and complementing tools/practices are used in order to be proactive</td>
</tr>
<tr>
<td>#</td>
<td>FMECA</td>
<td>Keywords / Additional Questions</td>
<td>Answers</td>
<td>Suggestions for Improvements</td>
<td>Purpose of Question</td>
</tr>
<tr>
<td>---</td>
<td>----------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>---------</td>
<td>---------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>7</td>
<td>To which extent are risks, which are not connected to flight safety, included in the FMECA?</td>
<td>Producibility, Robust Design/Variation risks, Project risks, Alternative Practices, Interface Risks</td>
<td></td>
<td></td>
<td>How are different types of risks lifted, different perspectives, and alternative risk practices?</td>
</tr>
<tr>
<td>8</td>
<td>What is the input in the creation of a new FMECA?</td>
<td>Old FMECAs, Is this positive or negative, Customer Requirements, How do you work to get a holistic view?</td>
<td></td>
<td></td>
<td>Establish the input used for the FMECAS</td>
</tr>
<tr>
<td>9</td>
<td>After a new FMECA has been created, how does the work progress?</td>
<td>Continuity and Iterative work? Follow-ups? In what phases of the PDP</td>
<td></td>
<td></td>
<td>Establish the continuity of the tool, follow ups and when risks are closed, investigate extent of proactivity</td>
</tr>
<tr>
<td>10</td>
<td>What is the output from a FMECA?</td>
<td>Mitigation/Control: RPN, KCs ((\rightarrow) Measure/control) Critical Items, Are FMECAs evaluated at the end of the project to create lessons learned?</td>
<td></td>
<td></td>
<td>Value Creating, what do you perceive to gain from the tool, Establishing the process flow for the FMECA</td>
</tr>
<tr>
<td>11</td>
<td>Have support been used from any super users/method specialist in the work with FMECAs? How do you find this type of support?</td>
<td>Why/Why not? Positive or Negative? Are any functions missing from the FMECA-work? Are there normally a sufficient number of people present? Difficulties of assessing the risks?</td>
<td></td>
<td></td>
<td>Is it available always and for everyone, What effects does it have (make it a less resource demanding task)</td>
</tr>
<tr>
<td>12</td>
<td>Do you have any additional thoughts regarding the FMECA template? Do you find any particular columns harder to work with?</td>
<td>Do you understand the purpose of the different columns? Work in the right way? Failure Cause (\rightarrow) Effect? Current Control?</td>
<td></td>
<td></td>
<td>Evaluate based on the FMECA-template, is it used in the right way? Suggestions of Performance Measurements?</td>
</tr>
<tr>
<td>#</td>
<td>General - Responsibility, Control, Interface Risks and Knowledge Management</td>
<td>Keywords / Additional Questions</td>
<td>Answers</td>
<td>Suggestions for Improvements</td>
<td>Purpose of Question</td>
</tr>
<tr>
<td>----</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>---------</td>
<td>------------------------------</td>
<td>---------------------------------------------------------</td>
</tr>
<tr>
<td>13</td>
<td>Is there a possibility to be proactive and front-load the projects/programs?</td>
<td>Resources, budget, requirements from executive management?</td>
<td></td>
<td></td>
<td>Is there even a possibility to be proactive in the first place?</td>
</tr>
<tr>
<td>14</td>
<td>What is the demand for risk management and how do you perceive the demands of performing risk management?</td>
<td>High/Low Demands? External/Internal customers? Executive Management? Performance Measurements?</td>
<td></td>
<td></td>
<td>Is risk management prioritized? How is it measured?</td>
</tr>
<tr>
<td>15</td>
<td>How is knowledge/experience shared from earlier projects and in between projects?</td>
<td>Obstacles? Attitude to ask for help? Rivalry between programs?</td>
<td></td>
<td></td>
<td>Investigate if there is a need of better knowledge sharing? Obstacles?</td>
</tr>
<tr>
<td>16</td>
<td>Is there anything in the risk management work that could be improved? What do you see as the biggest challenges?</td>
<td>Additional thoughts? Anything specific that is good? Performance Measurements?</td>
<td></td>
<td></td>
<td>Finding areas of improvements and give an opportunity to express additional thoughts</td>
</tr>
<tr>
<td>19</td>
<td>Who has the main responsibility within risk management and how is the responsibility allocated around specific risks?</td>
<td>Responsibility, Ownership of risks? How are interface risks handled</td>
<td></td>
<td></td>
<td>Determine responsibility and ownership of risks</td>
</tr>
</tbody>
</table>
Appendix 4 – Interview Benchmarking Template

1. What practices are used to handle different types of risks?
2. When during the product development process do you mainly work with risk management?
3. What aspects are affecting how you work with risk management?
4. Besides traditional risk management tools, are there other tools that reduces uncertainties and risks and therefore creates proactivity?
5. What kinds of risks are included in you D-FMEA?
6. What is the input in the creation of a new FMECA?
7. After a new FMECA has been created, how does the work progress?
8. What is the output from a FMECA?
9. Have support been used from any super users/method specialist in the work with FMECAs?
10. What is the demand for risk management and how do you perceive the demands of performing risk management?
11. Are you using any Performance Measurements within risk management?
12. How is knowledge/experience shared from earlier projects and in between projects?
13. How do you work in order to in an early phase ensure producibility?
14. How is the connection between your D-FMEA and P-FMEA?
15. How do you work in order to ensure a robust design? Are you using key characteristics?
16. Is there anything in the risk management work that could be improved? What do you see as the biggest challenges?