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Engineering change management implementation at a South African defence company

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2020
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ENGINEERING CHANGE MANAGEMENT IMPLEMENTATION AT A SOUTH AFRICAN DEFENCE COMPANY

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A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Masters of Science in Engineering.

Johannesburg, 2020

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Declaration

I declare that this research report is my own unaided work. It is being submitted to the Degree of Master of Science to the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree of examination to any other University



Nicola Liesel Johannes
26th day of May, 2020

Abstract

Engineering change management can be defined as controlling a change of a product when it is already released in production or has been previously produced. Engineering change management is a function of configuration management in the complex engineering environment. This research report is a case study on the engineering change process as it happens in a defence company in South Africa. A literature study on engineering changes is done, a theoretical pattern created for the study and then the literature is compared to an observation pattern that was created by collecting data from interviews and reviewing documents. The theoretical pattern is compared to the observation pattern using Trochim's framework for pattern matching. The results are discussed and opportunities for improvement are given to the company.

Dedication

Soli Deo Gloria

Acknowledgements

To Saab Grintek Defence and its employees for inspiring to do a research project and for allowing me to do this research at the company – thank you!

To all the interviewees at Saab Grintek Defence for granting me some of their time to be a part of my research – thank you!

To Teresa Hattingh, my supervisor, for not giving up on me and responding very quickly to my questions and my work – thank you!

To my parents, Manfred and Erika, who have supported me throughout the process of writing the research report and have taught me not to give up on a daunting task – thank you!

To all my friends and family that have helped proofreading and told me not to give up and just do it – thank you!

To my editor and proofreader, Pam Lloyd-Jones, for the valuable advice and quick feedback – thank you!

To my friend and mentor in Germany, Dr Ilse-Maria Bischoff, thanks for pushing me to finish writing the thesis!

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Nomenclature

CA	Criticality Analysis
CCB	Change Control Board
CIB	Change Implementation Board
CM	Configuration Management
CO	Change Order
CR	Change Request
CRQ	Central Research Question
CRB	Change Review Board
D&D	Design and Development
EASA	European Aviation Safety Agency
EC	Engineering Change
ECCB	Engineering Change Control Board
ECM	Engineering Change Management
ECO	Engineering Change Order
ECP	Engineering Change Proposals
ECR	Engineering Change Request
EO	Engineering Order
ERP	Enterprise Resource Planning
FMEA	Failure Mode Effects Analysis
ILS	Integrated Logistics Support
IQ	Informant Question
ISO	International Standards of Organisation
ISS	In-Service Support
IT	Information Technology
MRP	Master Requirements Planning

MTO	Make-to-order
MTOT	Manufacturing Transfer of Technology
MTS	Make-to-stock
PDM	Product Data Management
PE	Production Engineering
PLM	Product Lifecycle Management
PTOT	Production Transfer of Technology
QA	Quality Assurance
RP	Research Purpose
SC	Supply Chain
SE	Systems Engineering
TDA	Technical Design Authority
TQ	Theory Question

1 Introduction

1.1 Purpose of the Study

In today's globalised, highly competitive and customer-focused market, product development is a key function and crucial to the success of industrial organisations (Shapiro et al., 2015). To stay competitive in their marketplace, companies that develop and manufacture complex products are required to improve their products with higher performance and quality at a lower price (Zheng et al., 2015, Pikosz & Malmqvist, 1998). Furthermore, the lifecycle of products steadily decreases and the time it takes to market becomes a competitive factor (Storbjerg et al., 2016). A decrease in lifecycle time does not mean that products do not get changed while they are being produced. Changes are made to a product from product development start until the product's end of life (Honkisch et al., 2018). A product's configuration may be continually updated throughout its lifecycle to improve the design (Kocar & Akgunduz, 2010). Products are changed to make them better, and this is one of the most powerful driving factors of design (Eckert et al., 2004). During this product development cycle, and in new product development, efficient engineering change management is a critical competency (Schuh et al., 2018).

In 1989, Cross found that most companies design new products by adaption from existing products to reduce risk and cost in the design of engineering products. Rouibah & Caskey (2003) say that involvement from functions other than product design, such as manufacturing, other engineering disciplines and marketing, have resulted in a benefit to product development. Hamraz and Clarkson (2015) state that engineering changes (ECs) can be triggered by multiple disciplines including the customer, management or a company's internal departments, the suppliers of partners and by market drivers such as regulations or technology.

ISO 10007 (2017) categorises change control as a configuration management process and states after the initial release of configuration information, all changes to a product should be controlled. Controlling processes has its challenges, especially because design processes are hard to plan and hard to predict (Eckert et al., 2004). In their case study, Fricke et al. (2000) estimated that 30% of the work effort of engineers and managers is due to design changes. The effectiveness of this change control process and the proper application of it in companies can lead to delivering the right products on time, which leads to greater customer satisfaction (Koch et al., 2016).

Applying ECM practices in real-world context can be a challenge (Iakymenko et al., 2018). Therefore there is a need to explore how change management practices can be improved through literature in a specific engineering context. The study to explore this is going to be done at Saab Grintek Defence (SGD), a South African defence company.

1.2 Background

1.2.1 Company Background

SGD is a South African defence company that has a research and development department as well as a production plant. Their offices are located in Centurion, South Africa. The products designed at SGD are manufactured as make-to-order (MTO) and engineer-to-order (ETO). According to Arnold et al. (2014), MTO means that the product will only be produced once a customer order is received. Arnold et al. (2014) further elaborate ETO is a form of MTO, but the product is designed with all the needs of a customer before being produced. At SGD, standard items are used to build the final product, but custom specific components could be

included in the design. Inventory of components is kept in stock as raw material. The products at SGD have a long lead time and are complex with many assemblies, sub-assemblies and software.

At SGD, the time to market when a product is sold is short - sometimes, a concept is sold to a customer, and the final design still needs to be made. Hence change control is an essential aspect of managing design at SGD. Often, the product sold to the customer is an already existing product which has been designed and produced before with customisation for the customer. Even when a prototype is being produced at SGD it can already be under change control. This initial prototype can then be sold to the customer as a production unit. The later the change happens in the lifecycle, the bigger the impact of the change on the product (Reidelbach, 1991 and Subrahmanian et al., 2015). A change that is raised late in the lifecycle could cause expensive re-work and delays in the delivery schedule, which result in loss of customer satisfaction (Shapiro et al., 2015).

In **Figure 1.1** and **Figure 1.2**, Iakymenko et al. (2018) illustrate the difference between ECs that are implemented in an ETO production environment and in a make-to-stock (MTS) production environment. In an MTS environment (**Figure 1.2**), the ECs are collected and implemented in a batch before a new version is built. In an ETO production environment (**Figure 1.1**), ECs are constantly implemented throughout the production duration, with open procurement orders and materials already picked for a production order being affected by the change (Iakymenko et al., 2018). At SGD, the changes are implemented as in the illustration for ETO in **Figure 1.1**. ECs are raised continuously and implemented while the procurement and production processes are already initiated. In this case, version control in production is of supreme importance, and if not managed accurately, the wrong products

could be delivered to the customer, leading to delays in delivery and unsatisfied customers.

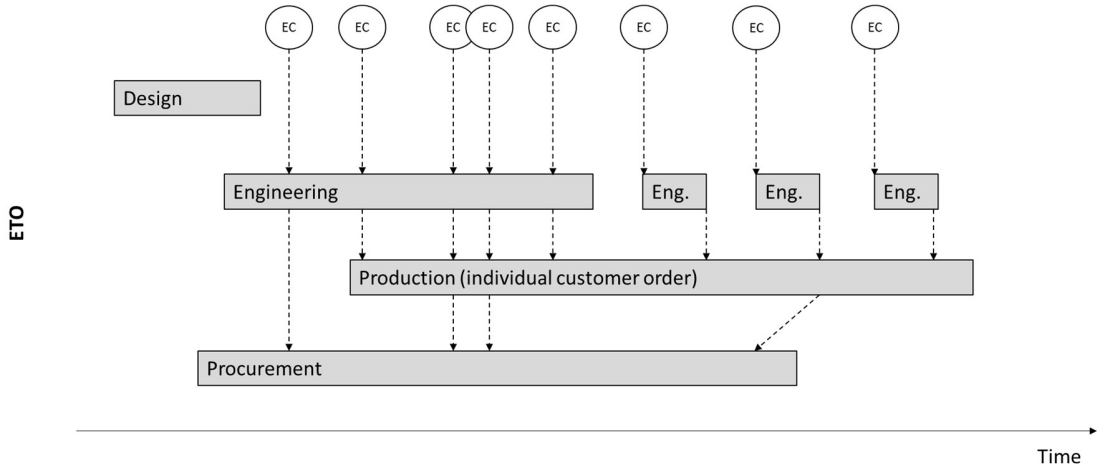

Figure 1.1: Engineering change implementation in ETO production environment (Iakymenko et al., 2018)

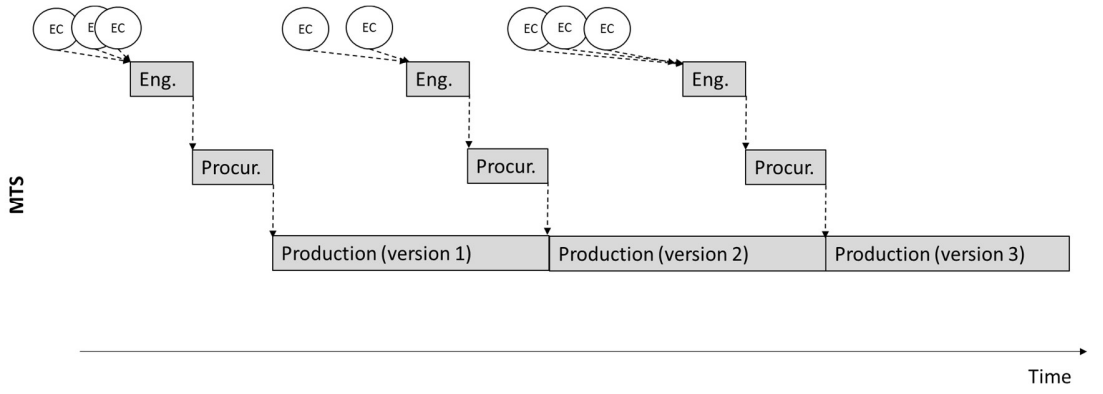

Figure 1.2: Engineering change implementation in MTS production environment (Iakymenko et al., 2018)

1.2.2 The change process and control systems context at SGD

SGD is a defence company and is therefore regulated by many standards. Configuration management at SGD is based on the ISO 10007 standard. ISO 10007 (2017) states that all changes should be controlled after the initial

release of configuration information. The change should be documented and should include the following characteristics (ISO, 2017):

1) The description of the change
2) The reason for the change
3) The documented information of the change
4) A categorisation of the change (according to complexity, resources and scheduling)
5) An evaluation of the impact or consequences of the change
6) How and what material should be disposed of after a change is completed
7) How the change should be implemented and verified that it is implemented

In the early 2000s, an electronic configuration system and a Master Requirements Planning (MRP) system were introduced in SGD. From then on, the Engineering Change Proposals (ECPs) were raised based on the ISO 10007 standard using the configuration system. However, the process of signing off a change was still very manual. Every person needing to sign the ECP for approval had to do so in person and by hand. This process was very paper-intensive and the risk of losing papers while being routed between the signees was great. To mitigate the risk and improve the process by digitalising the process an electronic routing and approval system, to load ECPs and having them signed off by all departments, was implemented at SGD in 2010. Due to the decrease in direct communication between role-players involved in the change process, change requests were signed off without proper investigation. Errors in the change request were then picked up at the final step of the Engineering Change (EC) process – the change control board (CCB). This new process meant that the change needed to be revised before it could be signed off and so created additional effort and time

for the role-players in the process. Due to this, the process change caused possible delays in the delivery schedule.

The need for inter-departmental communication of the change proposal creation became necessary, and in 2015 it was decided that checklists should be implemented as preparation for change. Numerous checklists were created including lists for the Design and Development (D&D), In-Service Support (ISS), Integrated Logistics Support (ILS), Product/Project Manager (PM), Supply Chain (SC), Systems Engineering (SE) and Quality Assurance (QA). The process of numerous departments filling in checklists and then reviewing the checklists during a change review board (CRB) before accepting the ECP during the CCB has since been implemented, but has nevertheless proven to be time-consuming and costly. The CRB is, however, a meeting that is of utmost importance for the change to be controlled and communicated correctly. Thus the different role-players understand all of the implications of the change.

In conclusion, SGD is an excellent example of a company that requires effective and efficient change management practices. The products designed and produced at SGD are ETO and continuously change due to various change triggers. The company follows the change implementation standard ISO 10007. SGD operates in a complex design and production environment, which can make implementing changes a challenge.

1.3 Research Motivation

If managed appropriately and implemented efficiently, ECs can benefit companies in aspects such as cost reduction, on-time delivery, and quality enhancement (Ullah et al., 2018). The goal of ECM is to integrate changes into the product development cycle with as few disruptions as possible

(Iakymenko et al., 2018). Managing ECs ineffíciently can negatively influence the productivity of a company (Ullah et al., 2018). Therefore, there are two benefits to having an efficient and effective ECM process – significant costs caused by ECs can be avoided and additional profit can be generated by satisfying customer needs (Iakymenko et al., 2018, Hamraz et al., 2013, Jarratt et al., 2011).

Subrahmanian et al. (2015) claim that 70% costs of product development are committed in the design stage of a product and the design stage only costs 5% of the overall cost for product development. Furthermore, they state that for capital intensive products an installation may last only 30 years, but the product family may last for 100-200 years (Subrahmanian et al., 2015). Hence the product lifecycle requires rich and stable representations that allow for managing of ECs throughout the product life cycles (Subrahmanian et al., 2015). Companies that make complex products have long-lead-time production and therefore have long product support contracts with their customers (Reidelbach, 1991). SGD is a company where complex products are built. Products are supported for up to 20 years after they have been delivered. Furthermore, at SGD, the production and maintenance of a product can be outsourced using a Production Transfer of Technology (PTOT) and a Maintenance Transfer of Technology (MTOT) process, which makes the management of engineering changes post-production even more complicated.

An engineering change management process should exist in a company to ensure that these changes are controlled and executed efficiently and effectively. The process should be designed in such a way that it minimises customer delivery delays and additional project cost while also maximising the control and proper governance of the process. Moreover, if properly

implemented “an EC process that is fast and reliable can even improve customer relations” (Pikosz & Malmqvist, 1998).

Reidelbach (1991) already states that there is a need for strong organisational communication in a change process. If a process turns out to be too complicated and involves added paperwork, it might adversely affect said communication. Pikosz & Malmqvist (1998) explain that communication in the change process is of utmost importance because the further a product is in the lifecycle, the more functions are involved. They state that this is a reason why cross-functional engineering change committees are created which discuss and decide upon the change.

Hamraz et al. (2013) identified the need for further research on engineering changes to be performed on organisational issues. “There is a lack of research on organisational issues of engineering change management” (Hamraz et al., 2013). They suggest research can be done on the different types of engineering change management organisations that are currently applied in practice. According to Storbjerg et al. (2016), there is very little literature on ECM that gives comprehensive guidance for improvement. Therefore they have designed a maturity grid that is designed to aid companies in improving their ECM maturity.

1.4 Research Question and Problem Statement

Problem Statement

As established in the previous sections, SGD designs and produces complex ETO products that have a long lead time and have long service products. Since these products sold by SGD are not always mature products, changes must be implemented without causing too much disruption with the quickest turnover time possible. The change process at the company has significantly

developed over the past 20 years. Several employees believe that non-value-adding and time-consuming activities such as the checklists, the CRB and CCB were incorporated into the process. Are these necessary for all types of changes, or do the changes need to be categorised and a different process followed for different changes? Is the change process conform to the ISO 10007 standard and other suggested standards from the theory? Hence, this research paper aims at investigating the practical application of the ECP at SGD by comparing it to the change management theory and best practice.

Following the preliminary research that was done, the following question is proposed:

How can the engineering change process at Saab Grintek Defence (SGD) be improved?

1.5 Research Objectives

The research objectives that are to be determined in the research report are as follows:

1. To develop a theoretical framework for the engineering change management process
2. To establish the change process that is currently being used at SGD
3. To perform a gap analysis between the theoretical EC process and the EC process performed at SGD
4. To establish areas where the EC process at SGD can be improved
5. To recommend improvements of the current EC process at SGD

1.6 Research Delimitations

There are some limitations to the research that is known before the study has started. Because the defence industry is confidential, the process is only analysed at one defence company in South Africa. This is a research limitation for the study as a practical framework will only be analysed at one company and it may not be applicable to all defence companies. SGD was established about half a century ago in South Africa and therefore is an excellent example of a defence company in South Africa.

1.7 Outline of Chapters

The chapters following this report are structured as follows:

Chapter 1 introduces the background of the company, identifies the problem and motivates why the report is being done.

Chapter 2 critically reviews the literature on this topic and aims to introduce the reader to the theory on engineering change management, and review frameworks that have been created for the engineering change process. The theoretical framework is established in this chapter using EC models found in the literature. The analytical framework is then created using the theoretical framework and Trochim's framework for pattern matching. The topics in the EC process chosen for the study are then researched further in the literature review to aid in establishing a theoretical pattern.

Chapter 3 contains a description of the methodology and the method for the study. The research methods explored will be qualitative research in the form of a case study with the use of semi-structured interviews and reviewing documents.

Chapter 4 – the change process at SGD is established. The results are collected from the interviews and the documents and the analysis will be done on the results.

Chapter 5 – The recommendations and conclusion that will be given to SGD will be discussed in this chapter.

2 Literature Review

2.1 Introduction

The literature review looks at engineering change management found in theory preliminary for companies that manufacture ETO and MTO products. It starts with the definition and role of the Configuration Management (CM) department in a company. CM is a function that is highly developed in complex engineering environments and is responsible for creating and controlling the physical items, product structure and documents linked to products. CM has the responsibility of running four processes and ECM is one of the four processes (Wasson, 2007). CM is the department that coordinates the ECM process at SGD. Hence, it is vital to have the background of the configuration of a product to understand the function of ECM fully.

The topic of EC management is then introduced, looking at definitions of ECs found in literature, guidelines for EC management that authors have established, how ECs are handled during the lifecycle of a project and what change triggers exist. This section aims to help the reader understand what ECs are, how they should be handled in a company, how they affect products at all stages during their lifecycle and why changes are raised.

Next, different EC models found in theory are explored. First, the ECM processes created by various researchers are explained. The models are reviewed by doing a comparative representation and so topics of the theoretical framework are established. Trochim's framework for pattern matching is explained and the analytical framework is established using Trochim's framework and the topics of the theoretical framework.

The final part of the literature study is a thorough investigation of the chosen topics of the EC process. In this section, the definition of ECM and the characteristics of an EC are explored in theory to aid the research in establishing the theoretical observation for the theoretical framework.

2.2 Configuration Management

According to Burgess et al. (2005), CM is a technique used by companies to support the control of the design, manufacture and support of a product. According to ISO, configuration management is a compliance requirement (Ali & Kidd, 2013). ISO 10007 (2017) is the international standard that provides companies with guidelines for CM. The standard defines CM as a management discipline that applies technical and administrative direction to the development, production and support life cycle of a configuration item. This discipline applies to hardware, software, processed material, services, and related technical documentation (ISO, 2017). Daniels (1985) describes CM simply as a management tool that describes the product, then controls the change. Xu et al. (2013) have a similar definition, saying that CM deals with managing changes across the lifecycle of a product. Lindkvist et al. (2013) write that "the aim [of configuration management] is to check the consequences of a change before it is made, and to provide traceability of product data to understand where problems occur, diagnosing and contributing to recovery."

Lindkvist et at. (2013) describe configuration management as a process of maintaining system integrity while handling changes to both the data-set and the real-world engineering system it represents. Furthermore, they state that "configuration management has become more, rather than less, important in complex engineering in an era of 'big data'" (Lindkvist et al., 2013, p. 173).

Figure 2.1*Figure **2.1***: Evolution of requirements adapted from the International Council on Systems Engineering was adapted from the International Council of Systems Engineering Hand Book as cited in Xu et al. (2013). It illustrates the evolution of requirements that a product goes through during its lifecycle. A product evolves throughout its lifecycle, and as time progresses, change triggers alteration or deletion of specific customer requirements. Some reasons for this could be due to new or deleted requirements by the customer or due to new technology being developed.

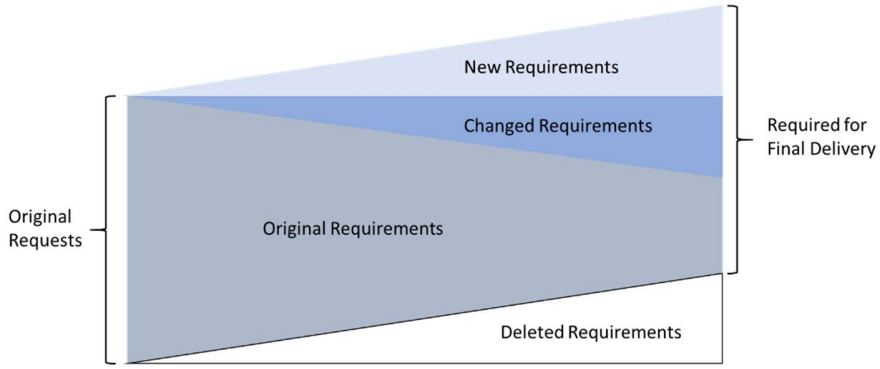

Figure 2.1: Evolution of requirements adapted from the International Council on Systems Engineering (Xu et al., 2013)

It is the responsibility of configuration management to control these changes and to have control over which product is delivered to which customer at what baseline (ISO, 2017). It is important to capture and maintain this information because where products comprise multiple layers of sub-assemblies and components and are quite complicated to build, and customers with long service contracts exist, one must be sure of the build-state of a product that returns for maintenance or repairs.

2.3 Engineering Change Management

Engineering design change management plays a vital role in all successful industrial organisations (Kidd & Thompson, 2000). No matter where the

request for an engineering change may originate and no matter what beneficial effects may result from its incorporation, it will be disruptive to the routine process and the normal flow of production work (Dale, 1982). That is why “engineering change is the focus of concern and is a sensitive area in most companies” (Dale, 1982, p. 202). When changes do occur, a formal way to manage them is required for efficiency (Bhuiyan et al., 2006). “Good change management has always been a crucial process, but in today’s fast-paced market it has elevated in importance – it is now being viewed as a competitive tool to increase product profitability through improved market responsiveness in addition to improving efficiency” (Brown & Boucher, 2007, p. 5).

2.3.1 Engineering Change Definition

“An engineering change (EC) is a modification to a component of a product after that product has entered production” (Wright, 1997, p. 33). Engineering changes are “the changes and modifications in forms, fits, materials, dimensions, functions, etc. of a product or component” (Huang & Mak, 1999, p. 21). Rouibah & Caskey (2003) define “ECM is the process of making ECs in a planned or systematic fashion. […] An engineering change requests (ECR) drives requests and approval. An engineering change order (ECO) drives change realisation. Both ECR and ECO are usual formal documents notifying select persons of proposed, pending, or accomplished changes.” (p.18). “Engineering change orders (ECOs) [are] changes to parts, drawings or software that have already been released” (Terwiesch & Loch, 1999, p. 160). An EC is defined as an alteration made to a part, drawing or software, designed in-house or acquired by a transfer technology, that has already been released during the product design process (Jarratt et al. 2011). According to Xu et al. (2013), change management involves the control of changes to a product and its configuration documentation during its life cycle. Engineering changes are a necessity in the product development cycle,

however, “it should be kept in mind, that each innovation is a change, but that not each change is an innovation” (Fricke et al., 2000, p. 170).

2.3.2 Guidelines for Engineering Changes

For a company to optimise its design process and have a minimal amount of changes, some authors have written guidelines on managing the process of an engineering change.

In their article on managing the process of engineering change, Terwiesch & Loch (1999) describe four principles of engineering change management.

1. Avoid unnecessary changes. If an engineer spends more time on the first release of a design, it could save cost and time due to future changes being minimised.
2. Reduce the negative impacts of an EC. The bigger a change, the higher the cost of implementing a change. The size of the change also is directly related to the impact on the delivery schedule.
3. Detect ECs early. The later an EC is released in a lifecycle of a product, the higher the cost of the change and the more complex the implementation of the change. Using computer simulation, computer-aided design (CAD) tools, rapid prototyping and design-for-manufacture tools can enable a company to detect problems with the design as early as possible.
4. Speed up the EC process. The problem with ECs often is that during the process, there is a lot of non-value-adding wait time. The longer an EC takes to implement, the more production delays there are, which can result in high costs in penalties. Furthermore, if an EC is open for very long, multiple ECs could be opened at the same time on a product or system, possibly resulting in a missed impact in the analysis as the one open change implementation could affect the next change.

Reidelbach (1991, p. 88) writes guidelines for the management of engineering changes:

1. “Anticipate and take steps to plan for engineering changes which may impact current and/or future production.
2. Keep in mind the typical long-lead-time customer demands – conformance to design specifications and on-time delivery.
3. Have excellent relations with critical suppliers.
    - Encourage intimate knowledge of suppliers’ abilities to accommodate change
    - Provide suppliers of critical items advance notice of all engineering changes.
4. Optimise communication and linkages.
5. Stress timely dissemination of vital information about an engineering change to all involved [parties].
6. Develop a priority-establishing system recognised and respected throughout the organisation.
7. Negotiate both supplier and customer contracts to limit and streamline engineering changes.
8. Create an engineering change review board to filter unnecessary changes.
9. Eliminate non-manufacturing steps which interrupt the direct flow of material to the work centre.
10. Use forecasting techniques to remove some uncertainty on the impact of long-lead-time engineering changes.
11. Anticipate reluctance to change.”

Not only is it important to follow these guidelines to have fewer changes, but also to understand what different characteristics an EC has in the different stages of a product’s lifecycle.

2.3.3 Engineering Changes during the Lifecycle of a Product

Documentation related to the product must be updated and maintained during the complete lifecycle of a product. Some customer contracts specify the documents which will need to be maintained. In the aerospace industry, the lifecycles of a product can exceed 50 years (Burgess et al., 2005). The long lifecycle contracts mean that ECs will have to be done during the complete lifecycle of a product.

Furthermore, there is a direct relationship between product complexity and intergenerational lifecycle. When a product is complex the product structure, assembly structure, design objectives, drawing structure, resource management and interface to inventory control and supply chain need to be well defined (Subrahmanian et al., 2015).

“Engineering requests may occur before, during or after production” (Bhuiyan et al., 2006, p. 5). The later in a design process a change is implemented, the more potential for disruption there is (Jarratt et al., 2011). The products changed in the pre-production phase are due to products not working correctly or because they don’t meet specification. During this cycle, prototypes are built to aid in qualifying the design. According to Bhuiyan et al. (2006), this phase accounts for most of the Engineering Change Requests (ECRs) in a lifecycle. During the mid-production phase, there will be fewer changes because the product will have reached stability. The post-production change will have more changes again due to obsolescence management and updating designs to be used in new products (Bhuiyan et al., 2006). This is displayed in **Figure 2.2**.

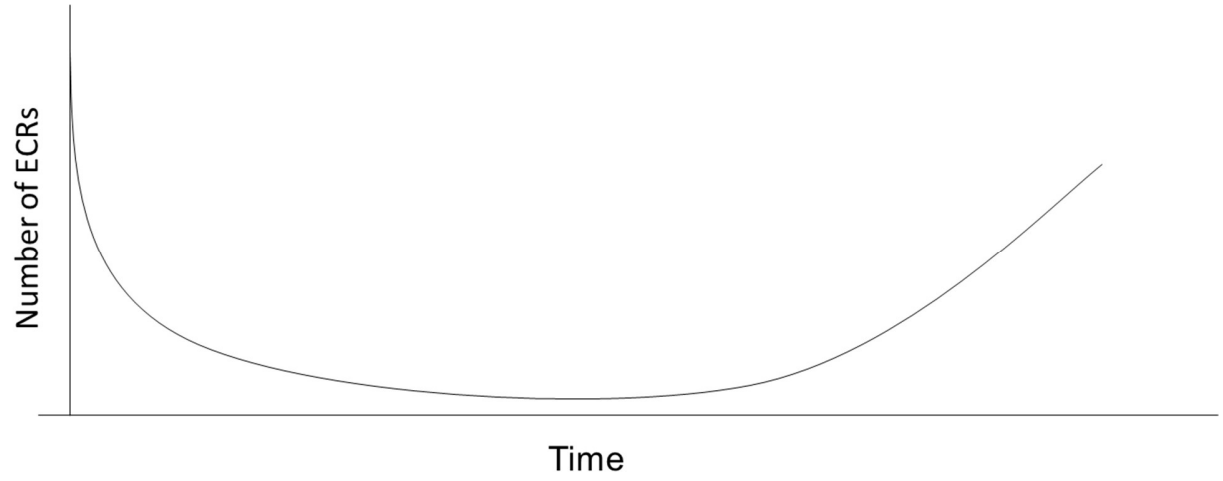

Figure 2.2: The number of ECRs as a function of time for a product in use (Bhuiyan et al., 2006)

However, in their study “Engineering change during a product’s lifecycle” that was carried out for an aero-engine for all phases of its lifecycle, Saeema & Kanike (2007) found that 8% of ECRs happen in the pre-production phase, 76% of ECRs during the mid-production phase and 16% during the post-production phase. Having expected that most changes occur during the pre-production phase, this finding was somewhat surprising (Saeema & Kanike, 2007). At the time of the report, the product was still under a service contract, so the post-production phase was not complete, which means the percentage of the changes in the last phase could increase. A graph to elaborate on this finding can be seen in **Figure 2.3**.

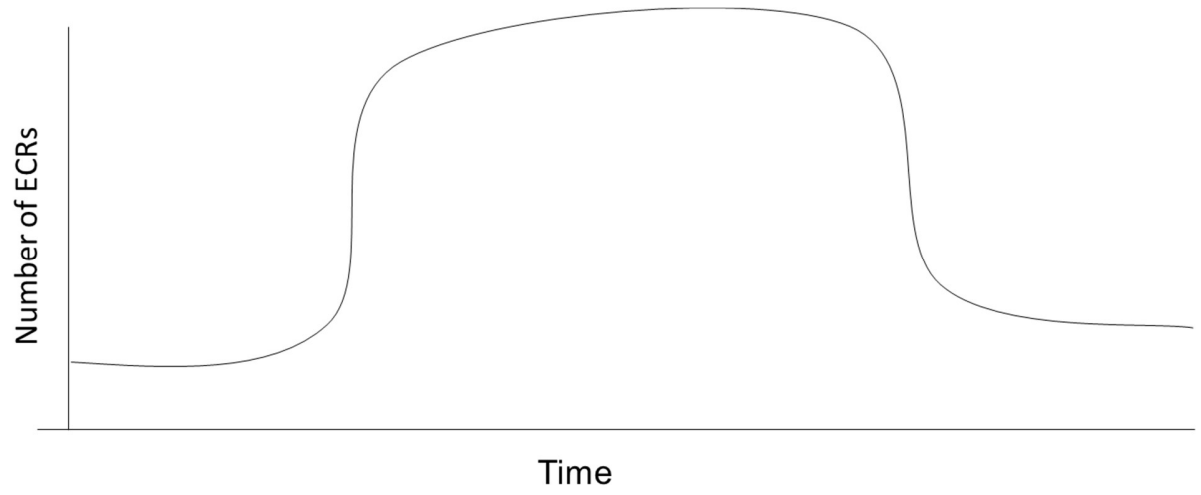

Figure 2.3: The number of ECRs as a function of time as per study (Saeema & Kanike, 2007)

The features of an engineering change will now be described in the three different lifecycle phases.

Pre-production

Before procurement is started or a production plan is frozen, creating a necessary production change will have minimal effect on the impact. The changes at this stage occur because errors were picked up during improvements found during prototype testing or due to a cost analysis (Reidelbach, 1991). Furthermore, ECs could be raised in this phase due to not meeting customer specification, changes in specification, certification-related problems and because of manufacturing or assembly problems detected during prototype building (Saeema & Kanike, 2007). After approval of the change, the necessary drawings will need to be updated, the Bill of Materials (BOM) will need to be updated for procurement and the production plan will be renegotiated. The success of this change depends on how quickly and how well the information regarding the change is communicated to the involved departments within a company (Reidelbach, 1991).

Mid-production

Once procurement has started buying the parts and they have arrived at the company, manufacturing can commence. When a change request is raised during this lifecycle stage, it can have a tremendous impact on long-lead production (Reidelbach, 1991). It is therefore crucial that the impact and the coordination of the change take place very quickly (Reidelbach, 1991). According to Reidelbach (1991), the planner will assess the impact of implementing the change. In their study on a long- lead time manufacturer, Saeema and Kanike (2007) found the reasons for a change in the mid-production and testing phase could be due to manufacturing difficulties picked up, reliability problems, durability problems that are forecast and buildability problems.

Post-production

The later in the lifecycle the changes occur, the more complex the implementation and analysis of a change becomes (Reidelbach, 1991). This partially is since companies re-use specific designs to develop new products (Cross, 1989). If a design is updated to be used in a new product, but the design is part of a current product that is still being manufactured, the design team will need to decide whether to update the current product with the new design as well. If the choice is to update the current product, the change of the current product may affect the delivery schedule and cost. The reasons for a change in the post-production phase as identified by Saeema and Kanike (2007) are due to manufacturing and assembly problems, for cost reduction efforts, problems found during operational experience and buildability problems.

2.4 Engineering Change Models

The engineering change process is a crucial fragment of engineering change management. It can be viewed as a mini design process that directs the steps from initiation to the review, to the implementation of an EC (Veldman & Alblas, 2012). In this part of the research report, the change processes as defined by some researchers since 1982 are examined. The models are presented author by author in chronological order. This is done to understand the processes found in literature and how the models have developed or have not developed over time. Furthermore, in this way, one can analyse what the authors find important in the EC process. The models will be used to create a theoretical framework on which the study will be based and the gap analysis will be done in chapter 4.

The specific models were chosen because the article from Hamraz et al. (2013) named “Holistic Categorisation Framework for Literature on Engineering Change Management” referenced these authors as having studied the EC process. The EC maturity model of Storbjerg et al. (2016) was designed after the article of Hamraz et al. (2013) was written, and this was found due to Hamraz et al. (2013) being cited by Storbjerg et al. (2016).

Dale (1982)

Dale (1982) splits the EC process into two parts – the procedure to approval and the procedure on approval. According to Dale (1982), the procedure to approval starts with product engineering creating an EC package which contains the reason for a change, the related documentation which in 1982 would have been hard copies of all the documents related to and necessary to execute the change. This package is then given to the engineering coordinator who prepares the EC note. To fill in the note correctly, the EC coordinator will need input from stores, purchasing, industrial engineering,

quality control, finance and marketing. A copy of the suggested note can be seen in **Figure 2.4**.

Upon completion, the note is presented to a management committee which is chaired by the manufacturing manager and exists of members or the managers from engineering, marketing, materials, planning and purchasing, production control, quality control, the plant controller and the EC coordinator.

Once the change is approved, Dale (1982) suggests the package be given to the product engineering department who will be responsible for actioning the EC. The coordinator communicates an advanced change notice to all departments stating that the EC is approved and that action will be required by each department once the new configuration package is complete. Once the package is back with the coordinator, a check on the stock is carried out once again, and new purchase orders with the new drawings are given to the procurement department so that orders for new materials can be created (Dale, 1982).

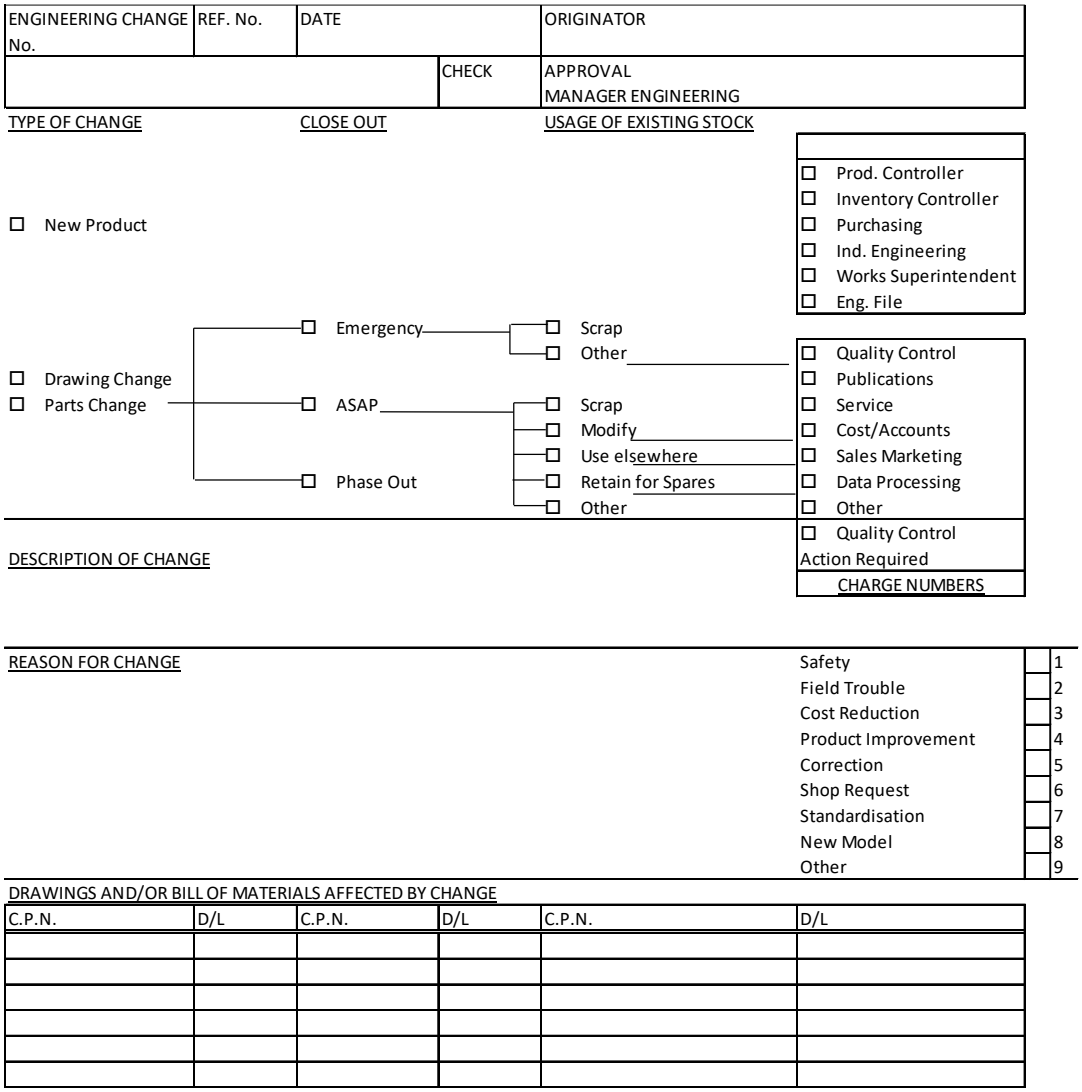

Figure 2.4: Engineering Change Note adapted from Dale (1982)

Dale (1982) was one of the first authors to publish an article on ECs. The process is fundamental, but, as explained in the article, includes a list of role-players. The process contains the reason for and description of the change and furthermore includes an impact analysis. It also gives priority to the change and helps to strengthen the communication of the change to all role-players involved in the change. However, there is some room for error as it is optional which resources to select for the change, which could result in the

change not being passed on to the right person and errors thus happening in the process. The impact analysis is only based on affected documents and numbers and does not include the propagation of changes.

Riviere et al. (2003)

Riviere et al. (2003) state that the configuration manager is responsible for the configuration of a system. Therefore, the configuration manager is also responsible for all engineering changes related to the system. The engineering change process they describe can be seen in **Figure 2.5**. The process is highly sequential, but for a change to happen efficiently, some processes should be done in parallel. This requires concurrent engineering principles to be introduced into the engineering change process. This should aid collaboration and coordination between role-players in the process (Riviere et al., 2003).

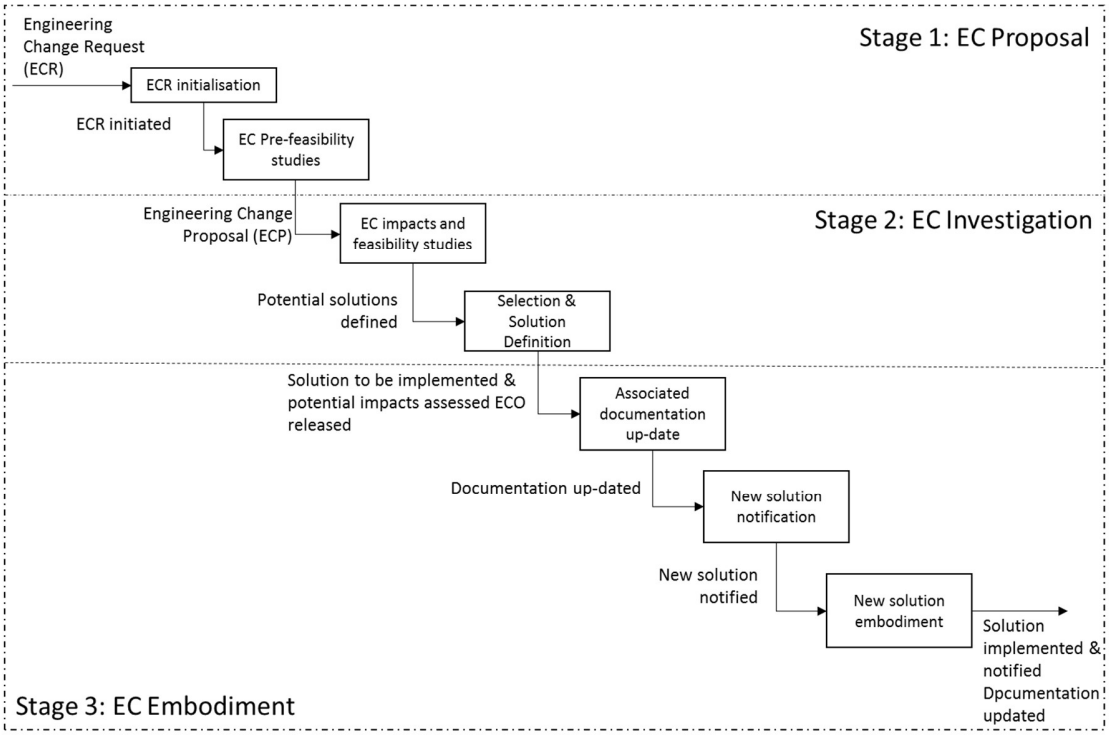

Figure 2.5: The Engineering Change Process (Riviere et al. (2002) cited in Riviere et al. (2003))

Riviere et al. (2003) suggest that the following items be included in the product model to improve the process:

1. The Product Data Management (PDM) system should be programmed to show the role-players involved in the process, including the configuration manager.
2. The information on an item's lifecycle should be included as this could differ from the product's lifecycle. Changes in a system should be limited when they happen close to a decision milestone.
3. The documentation of an item's customer requirements should be linked so that one knows which requirements are frozen and cannot be changed.
4. The information about an item's behaviour to engineering changes. Some items could propagate engineering changes if they are changed and others can absorb them.
5. The history of engineering changes on an item should be included in the system as it could help understand the current state of its design due to previous engineering changes. This can help with the impact analysis of the current engineering change.

The process that Riviere et al. (2003) wrote down 20 years after Dale's 1982 article contains more detail and is more structured. The pre-feasibility study is introduced to filter out changes that will not be cost-effective at an early stage. Feasibility and impact studies are done before a solution is selected. This means that more than one solution is found to solve a problem and the best solution can be selected and implemented. Riviere et al. (2003) state the importance of looking at the impact of a change and the history of engineering changes on items changing to help with the impact of the current change. However, in the process, no forum approves the change and verifies whether the process was followed to come up with the solution. This may

allow changes that have not followed the correct process to be implemented. The suggestion to include the role-players involved in the PDM system will, however, ensure that the change gets communicated to the right people.

The documents are updated after the change is approved and people are only notified once the documents are updated. If the notification of the change is so late in the process, it could be that the product that needs the change is still being built without the change. More items needed to be reworked to the new baseline before the product being shipped to the customer since the production continues on the old baseline. The notification of the change should already be done early in the process so that a decision about whether to keep on building on the current, old baseline or stop production can be made regarding the items that are currently on the production line. Riviere et al. (2013) do state that some processes need to happen in parallel for them to occur efficiently. Documentation updates can have a long waiting time and as a result, if the change to be implemented is urgent in order to meet customer deadlines, an option exists to carry on building with documents that are changed by hand and configured in the system could reduce the waiting time.

Lee et al. (2006)

According to Lee et al. (2006), the engineering change management process consists of four stages. The process begins with initiating an engineering request, evaluating the ECR, issuing engineering change orders (ECOs) to relevant role-players, and storing and analysing the ECOs for management purposes. A figure of this process can be viewed in **Figure 2.6**.

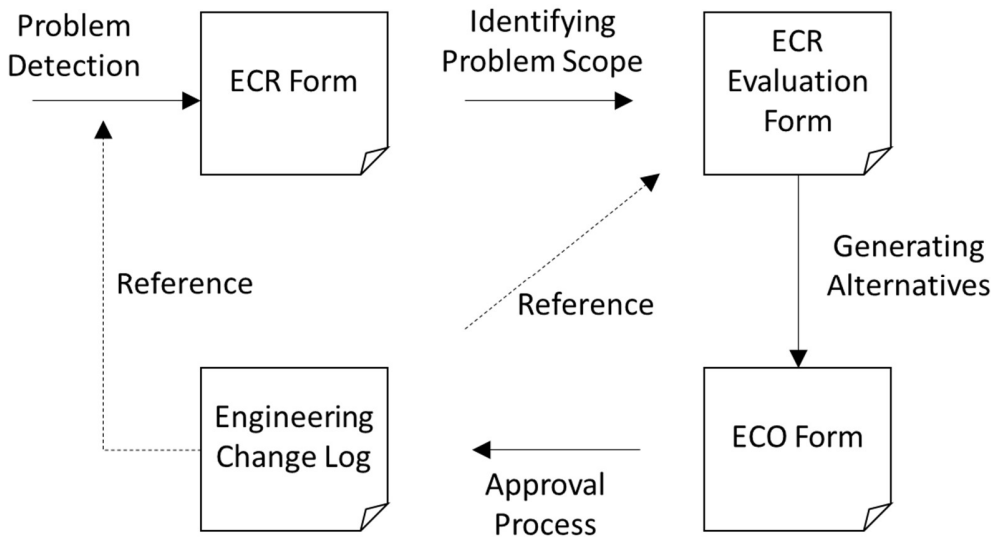

Figure 2.6: The process of engineering change management (Lee et al., 2006)

Lee et al. (2006) conducted a case study at an automobile company. **Figure 2.7** displays the engineering change process that is followed by this company. The process is split into three phases: problem detection which happens at manufacturing and testing, the problem-solving process which is done by the engineering department and the Engineering Change Order (ECO) approval process which is the responsibility of the engineering and administrative team.

When a problem is detected in a process, manufacturing and testing will raise a ticket to discuss the issue with the engineer of the component. It is then decided whether to initiate an ECR. Engineering or an engineering team will review the ECR and decide whether to accept or reject it. Next, the ECR is analysed by communicating with the relevant engineers. They check the system for similar problems which might have occurred before in the same or other products before. They use their experience and knowledge to look for alternative solutions. The engineer in charge will then create an ECO that contains the information from the ECR. The ECO contains information such

as changes in weight, production costs, when the change will become effective and plans to handle obsolescence should this be forecast. If the change affects the product cost, the cost management department will have to do an analysis and approve the change. The change is then sent to the technology management team to validate it for consistency and check for possible errors in the change. Finally, the ECO and product data is released and stored in the intranet of the company.

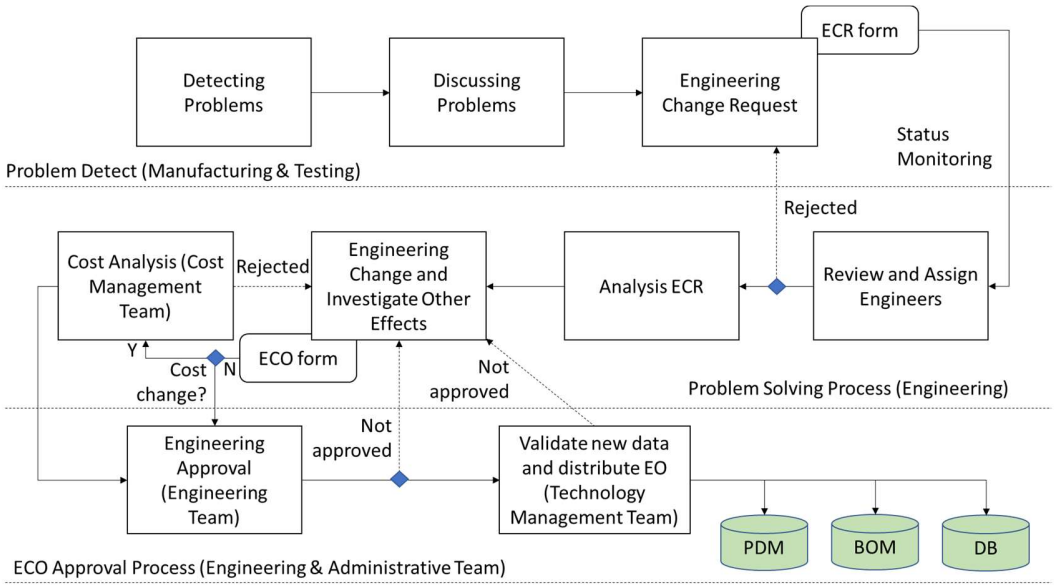

Figure 2.7: The process of engineering change of the company in the case study by Lee et al. (2006)

Similarly to Riviere at al. (2003), Lee et al. (2006) suggest that alternative solutions should be studied before a change is selected. In this process, an approval process is included for the first time. The process that Lee et al. (2006) described from the case study includes a cost analysis quite late in the process. If a cost analysis happens very late, a lot of effort will have already been completed and if the cost is too high, the money it cost for resources to analyse the ECR will have been lost. Therefore, a cost estimation should be done at the beginning of a change being raised. Throughout the process this

cost estimate should be checked to ensure it is still in line with what was predicted.

Jarratt et al. (2011)

Jarratt et al. (2004) cited in Jarratt et al. (2011) have created a model of a generic change process which can be seen in **Figure 2.8**. There are six steps in creating an engineering change:

1. A change trigger will result in an ECR being raised. Jarratt et al. (2011) state that most companies have a generic form for this. The reason for the change, the priority of the change, the type of change, the affected components or systems and other characteristics of a change are documented in this step.
2. Next, there will be an identification of possible solutions to the problem. Sometimes there is more than one way a problem can be solved, but due to time constraints, the engineers will only investigate one solution to the problem.
3. This is followed by a risk/impact assessment of the solution and a decision of which solution will be implemented. During this impact assessment, different issues will be examined, for example, what the impact on the production schedules is, how the change impacts relationships with suppliers if the change will have an impact on the budget and the effect on other designs. The first three steps happen before approval.
4. During approval, there is a selection and approval of a solution by the change board. This consists of middle to senior ranking members of all departments involved in a change.
5. Finally, after approval, the solution is implemented. A change could be implemented immediately or phased in. The documentation for the product must be updated in order for a change to be implemented. Wright (1997) states that a great difficulty in the engineering change

process is ensuring that the documentation that production works with is the current documentation.

6. There will be a review of the particular change process.

There are two points in this process where it is possible to reiterate the steps, namely at the risk assessment where it could be decided that a change is too risky, and a new possible change should be identified. The next point is at the selection and approval of a solution, where the change board might deem it necessary to go back to the risk/impact decision and more risk analysis is to be done. During the breakpoints in **Figure 2.8**, the engineering change process can be stopped. These breakpoints act as a stage-gate.

Jarratt et al. (2011), similarly to Lee et al. (2006), discusses a selection and approval of a change by a change board. However, in the process of Lee et al. (2006), the approval is done by an engineering team. Jarratt et al. (2011) recommend a board that includes all middle to senior management who are in some way involved in the change and also state that sometimes alternatives are not found so there could only be one solution to a change.

Furthermore, in the process by Jarratt et al. (2011), the break-points are unique from all the other processes discussed in this section and act as a gate where a change can be stopped earlier in the process and end without it being implemented. In the process of Lee et al. (2006) iterations were specified – if a change would not pass a gate it would go back to a previous stage. The process of Jarratt et al. (2011), however, specifies the breakpoints as stage gates, meaning that the change can also stop there.

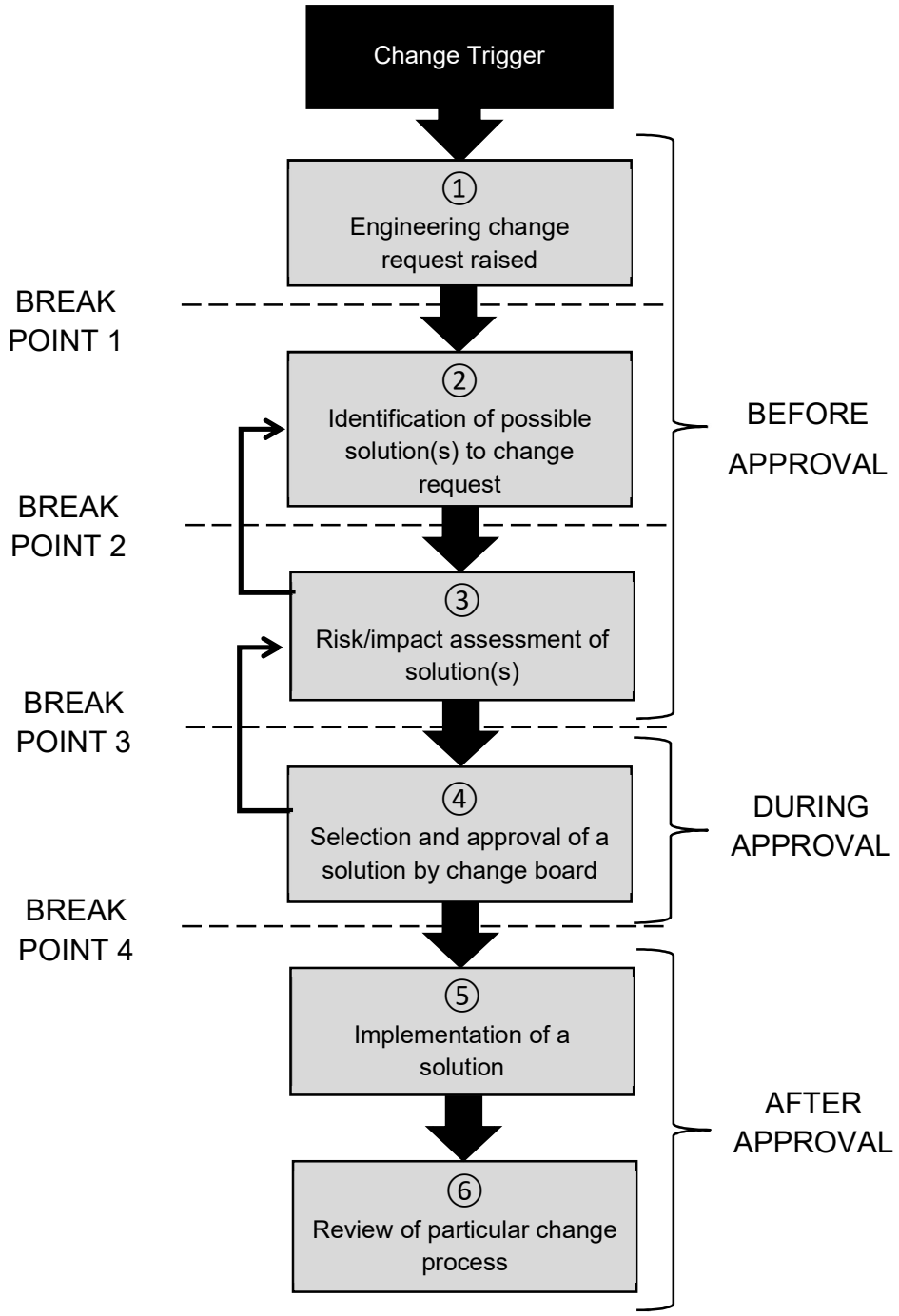

Figure 2.8: A model of the generic change process (Jaratt et al. ,2004, cited in Jarratt et al. (2011))

Storbjerg et al. (2016)

Storbjerg et al. (2016) have developed an engineering change management maturity grid which can be seen in **Figure 2.9**. The maturity model was created to be used in industry. It should be used by companies to find the area of focus when wanting to improve ECM. It was specifically developed to be used in companies that design complex products (Storbjerg et al., 2016).

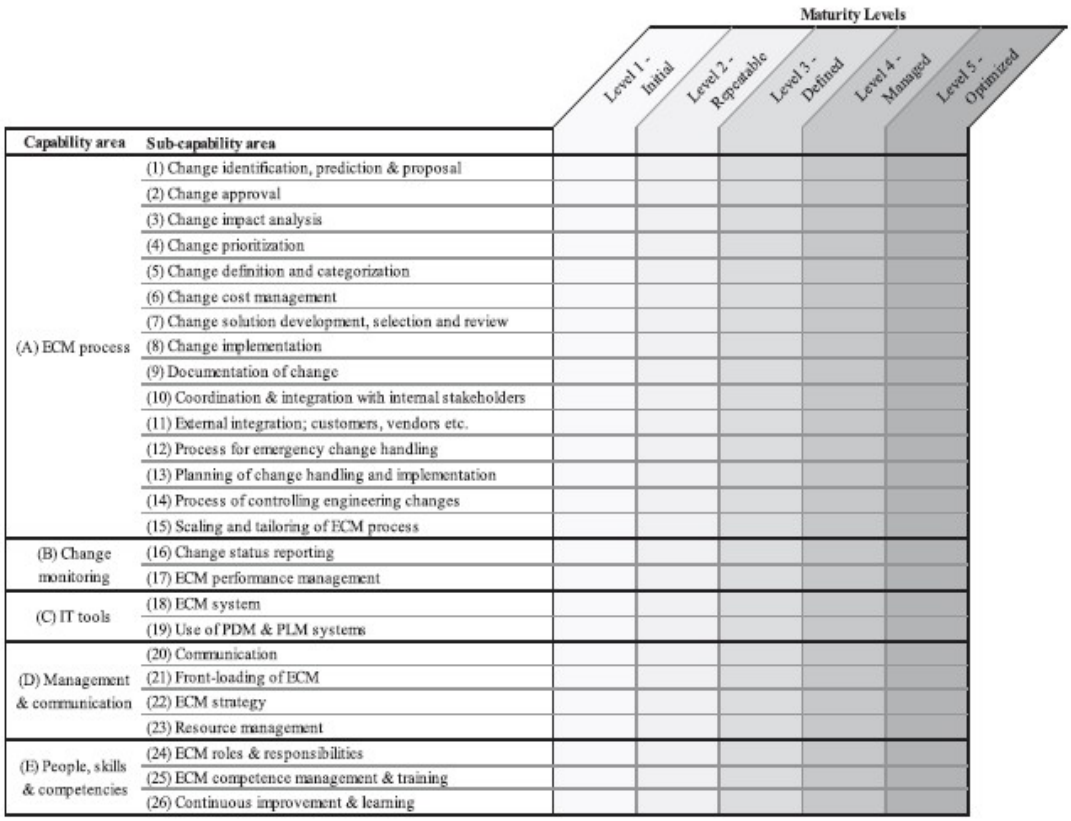

Figure 2.9: Change maturity grid taken from Storbjerg et at. (2016)

This change maturity grid looks at five process areas– the ECM process, change monitoring, IT tools, management & communication and people, skills & competencies. It is then further broken down into 26 sub-process areas. This grid is designed to guide improvement effort within ECM. (Storbjerg et al., 2016).

The maturity model created by Storbjerg et al. (2016) includes a very detailed ECM process (section A) which looks into change identification, approval process, impact analysis, prioritisation, definition and categorisation of the change, cost management, solution development, selection and review, implementation of the change, documentation, coordination and integration with internal stakeholders, external integration with customers and vendors, process for emergency changes, planning of change handling and implementation, process of controlling engineering changes and scaling and tailoring of the engineering process. The maturity model is an in-depth categorisation of a change process and more detailed than any of the models explained in this section. This process does not explain how to improve the maturity nor what are key indicators or topics that need to be addressed to improve maturity. Instead would be used to measure the maturity of all the tasks that should be included in an EC process.

ISO 10007

The international organisation of standards, ISO, describes a change process in their document on configuration management, ISO 10007. A visual representation of the basic change process from this standard can be seen in **Figure 2.10**. According to ISO (2017), the most important steps are to document a change properly, with a change description, justification, responsible for the EC, the items it affects. This step contains similar information to the change process and form described by Dale (1982). Similarly to the very generic model Jarratt et al. (2011) have created, an important step in the change process according to ISO (2017) is the evaluation of the consequences of the change. The third step according to ISO is to identify the details how a change should be dispositioned. The fourth step is the implementation of the change and finally, verification of change.

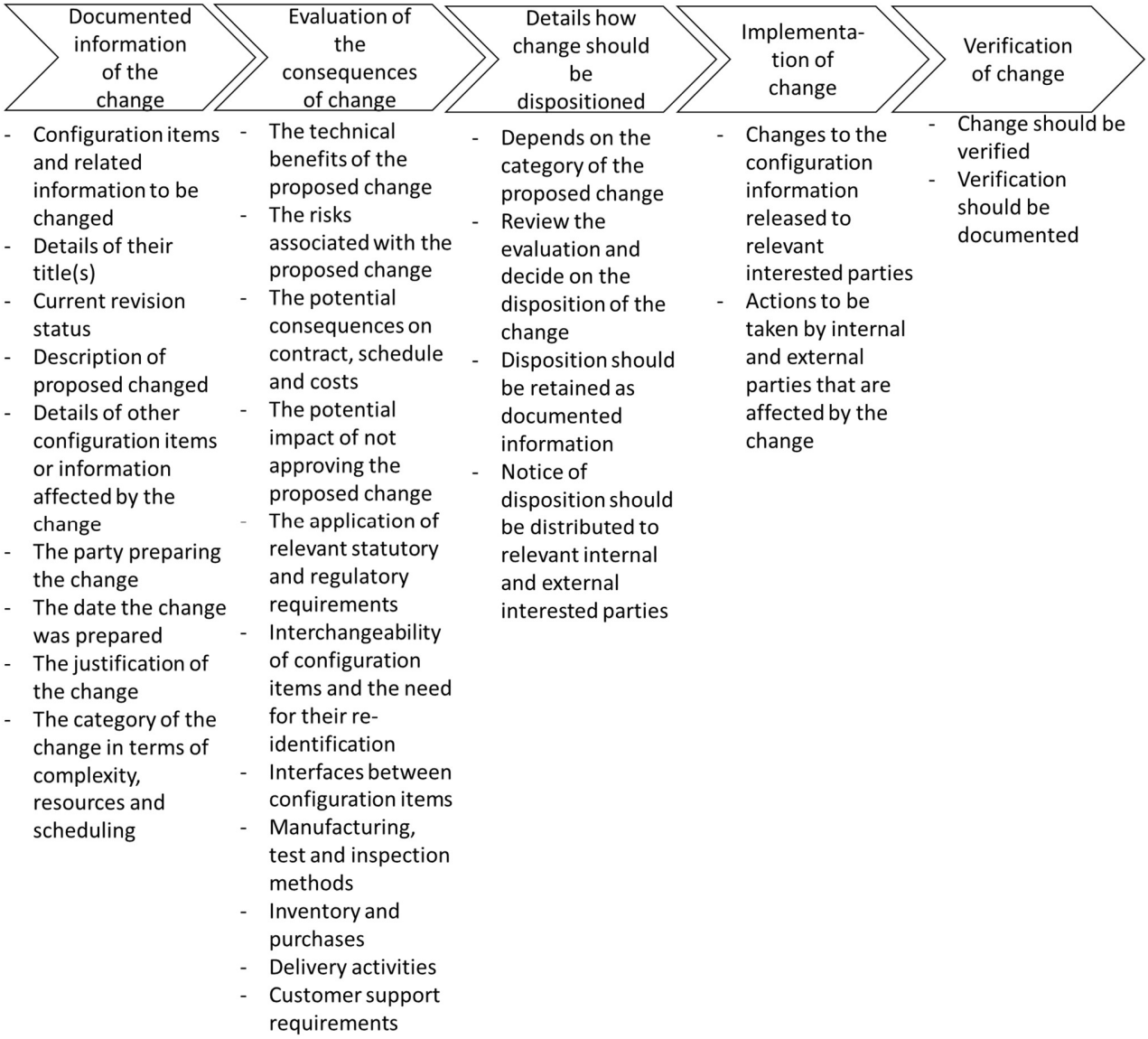

Figure 2.10: Engineering change process adapted from ISO (2017)

2.5 Theoretical Framework Development

According to Merriam & Tisdell (2016), the theoretical framework is the underlying structure of a study. It is derived from the orientation or stance that the researcher has (Merriam & Tisdell, 2016). The theoretical framework for this study is created by finding points from the EC models established in

chapter 2.4 that are relevant to the change process at SGD. To finish, an analytical framework is formed using Trochim's framework for pattern-matching (Trochim, 1989) and the theoretical framework.

2.5.1 Establishing the theoretical framework

The topics that form the theoretical framework of this study is created by writing all the steps down in the EC process of the models found in chapter 2.4 and finding a generic process for the steps how an EC is processed at SGD. The table in which these steps or points that will be more thoroughly studied is established can be seen in **Table 2-1** and **Table 2-2** across two pages.

The fields that are marked in dark grey show duplicates of headings. The fields marked grey with no text in the field, show that the author has not mentioned this topic in their study. The row at the bottom with the heading Saab Grintek Defence indicates the topic chosen for the theoretical framework. The topics "Change Triggers, Raising ECs" and "Change implementation" include some subjects across the different processes because some of these topics from theory overlap each other. Documentation of a change and change categorisation is important when raising the change. Hence they have been put under the topic of "Change Triggers, Raising ECs". As part of the implementation of change it is important to communicate the change internally, externally and verify if the change is done. Hence one category is created for "Change Implementation" including all these topics.

Table 2-1: Theoretical Framework topics for the study at SGD

Author	Date	Article Title	Steps in process				
Dale	1982	The management of engineering change procedure	Product engineering creates and EC package	Product engineering creates and EC package			Product engineering creates and EC package
Riviere et al.	2003	Controlling product related engineering changes in the aircraft industry	ECR initialisation	Selection & solution definition	EC impacts and feasibility studies	EC pre-feasibility studies	EC pre-feasibility studies
Lee et al.	2006	Capturing and reusing knowledge in engineering change management: A case of automobile development	Detecing & discussing problems, engineering change request raised	Engineering approval (Engineering Team)	Engineering change and investigate other effects	Engineering change request	Engineering change request
Jarratt et al.	2011 referenced from 2004	Engineering change: an overview and perspective on the literature	Change trigger/ Engineering change request raised	Selection and approval of a solution by change board	Risk/impact assessment of solution(s)	Engineering change request raised	Engineering change request raised
Storbjerg et al.	2016	Towards an engineering change management maturity grid	Change identification, prediction & proposal	Change approval (CCB)	Change impact analysis	Change prioritisation	Change definition and categorisation
ISO 10007	2017	Configuration Management	Documentation information of the change	Change verification	Evaluation of the consequences of change	Documentation information of the change	Documentation information of the change
Saab Grintek Defence	-	**Theoretical Framework Topic**	Change Triggers, Raising ECs	Change Control Board	Impact analysis	Priorities	Change Triggers, Raising ECs

Table 2-2: Theoretical Framework topics for the study at SGD (continued)

Author	Date	Steps in process						
Dale	1982	Stock Check, Advanced Change Note	Change review management committee	Implementation of change using product engineering				
Riviere et al.	2003	EC impacts and feasibility studies	Selection & solution definition	New solution embodiment	Associated documentation update	New solution notification	New solution notification	
Lee et al.	2006	Cost Analysis (Cost management team)	Engineering Approval (engineering Team)	Validate new data and distribute EO		Validate new data and distribute EO	Validate new data and distribute EO	
Jarratt et al.	2011 referenced from 2004	Risk/impact assessment of solution(s)	Selection and approval of a solution by change board	Implementation of a solution		Implementation of a solution	Implementation of a solution	
Storbjerg et al.	2016	Change cost management	Change solution development, selection and review	Change implementation	Documentation of change	Coordination & integration with internal stakeholders	External integration; Customer vendors etc.	
ISO 10007	2017	Details how change should be dispositioned	Evaluation of the consequences of change	Implementation of change	Documented information of the change	Implementation of change	Implementation of change	Change verification
Saab Grintek Defence	-	Cost of the Change	Change Review	Change implementation	Change Triggers, Raising ECs	Change implementation	Change implementation	Change implementation

2.5.2 Trochim's Framework for Pattern Matching

Trochim (1989) created a general framework, called pattern matching, which can be used to evaluate a theoretical pattern with an observed pattern and match these two. In qualitative research, not all theories are stated in a mathematical form, but all theories provide information which helps the researcher to identify patterns (Trochim, 1989).

The basic pattern can be seen in **Figure 2.11**. There are two realms – the theoretical at the top above the line and the observational realm at the bottom, below the line. The theoretical realm might be obtained from theories or ideas and hunches of the researcher (Trochim, 1989). The conceptualisation task of the researcher is to form these theories and ideas into a theoretical pattern (Trochim, 1989). The topics of the different theoretical fields that will be researched in this study were established in the previous section, section 2.5.1.

The observational realm is formed by techniques such as observations, data and measurements that are collected by the researcher (Trochim, 1989). The data is then organised to create the observed pattern. The task of the researcher is then to match the two patterns, which is shown by the double arrow in the middle of the figure (Trochim, 1989).

Trochim's framework for pattern matching will aid the researcher in systematically forming the theoretical pattern and observed pattern and matching the two to each other. Trochim's framework will be utilised to do the gap analysis where the gaps from the observed pattern are found when being compared to the theoretical pattern.

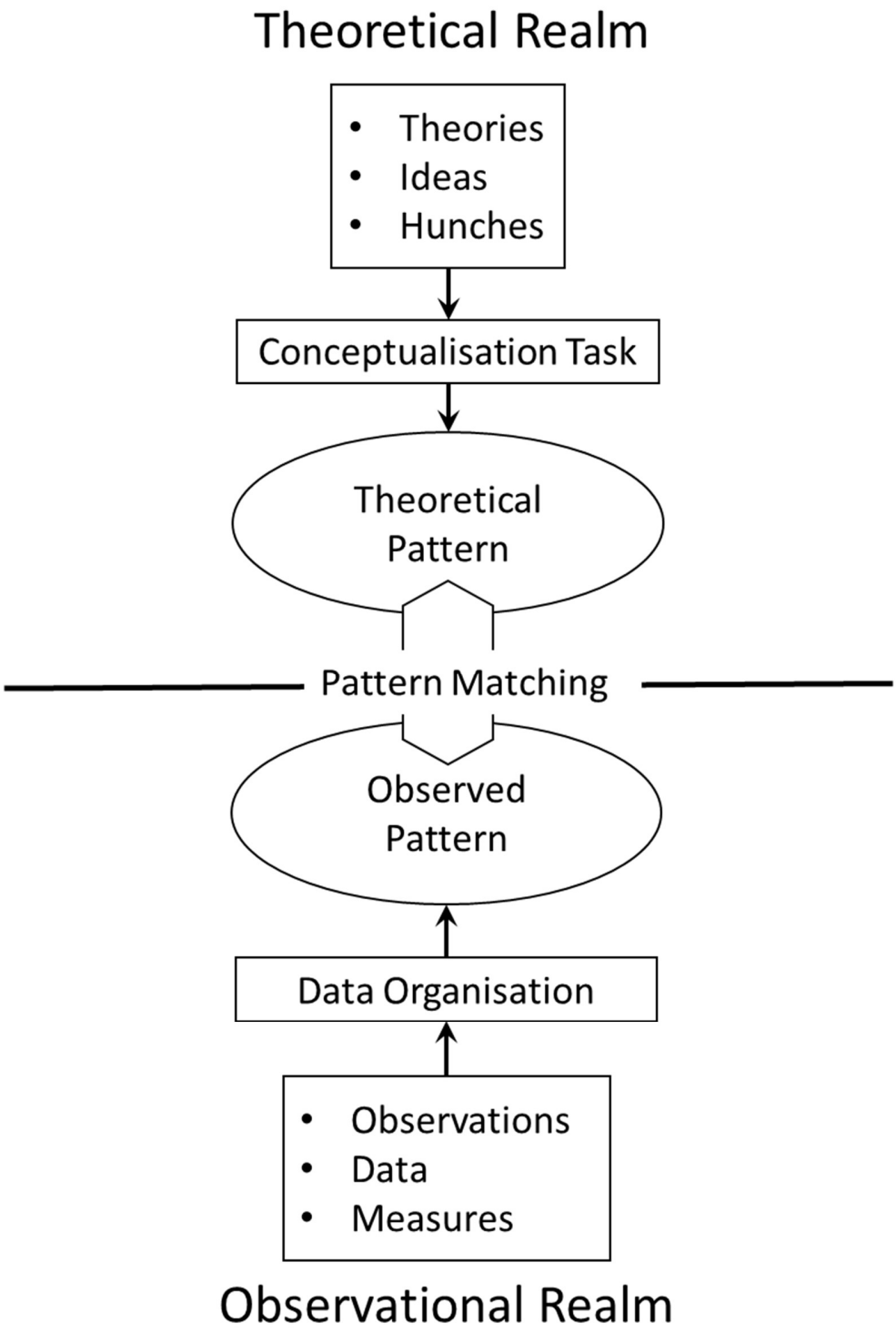

Figure 2.11: Pattern Matching Model (Trochim, 1989)

2.5.3 Analytical Framework of Study

Using the topics chosen from EC models in section 2.5.1 and Trochim's framework for pattern matching from section 2.5.2, the analytical framework is created. A table of this framework can be seen in **Table 2-3**.

Table 2-3: Analytical Framework for the EC process study at SGD

Topic	Theoretical pattern	Pattern Matching	Observed Pattern
Raising ECs			
Impact Analysis			
Priorities			
Cost of the change			
Change Review			
Change Control Board (CCB)			
Change implementation			

2.6 Engineering Change Characteristics

This section explores the literature on the theoretical framework established in section 2.5.1. They aid the researcher in establishing the theoretical pattern to do pattern matching using Trochim's framework.

2.6.1 Raising ECs

An EC is always changed due to a change trigger. The different reasons for triggers found in theory are first analysed, then the way or method of raising

an EC and the information that is important while raising the change are explained.

2.6.1.1 Change Triggers

Pikosz & Malmqvist (1998) describe the causes as coming from changes in the customer specification, faults in the interpretation of customer demands into technical requirements, difficulties in assembly, faults and errors found in the product during prototype testing, quality problems with a subsystem or component and development for updated product generations. Kidd & Thompson (2000) wrote an article on an investigation they did on the change control procedure at British Aerospace (Military Aircraft Division) (Bae(MAD)). The source of the change they identified is the customer, who then will pay for the cost of the change, manufacturing at the company and subcontractors to improve the production quality and from design reviews when difficulties have been encountered during manufacture or assembly of the components. Lee et al. (2006) state the causes of engineering changes are careless mistakes, poor communication, snowballing change, cost savings, ease of manufacturing and product performance improvement.

Fricke et al. (2000) divide the causes and rationales of triggers into eight different categories:

1. Customer needs and requirements that change. These will change throughout the lifecycle of a product and not only in the development phase. Requirements change for two reasons – because the customer changed their mind or because they were incomplete or incorrect, to begin with.
2. Feedback and complaints from the customer. Long-term effects cannot be simulated or extrapolated when developing a product and this will bring on changes.

3. Complexity – the more complex a product is, the more difficult it is to control all relevant characteristics and their impacts on each other. Simulating an entire complex product is difficult.
4. The degree of innovation –one does not have enough knowledge and information about all aspects of new technology. These aspects will only be verified if the physical product using innovative technology is built and tested.
5. Change impacts – changing one thing in a product may cause an avalanche effect, and this can lead to change feedback loops.
6. Communication and coordination – different companies and people perform different parts of a whole product. If a problem is not communicated between all role-players, it can lead to multiple changes.
7. Time – in certain industries, time to market is a competitive factor, and the quicker one gets a product to the customer, the more successful it will be. This statement means that there is minimal time for development or a product will already be sold when it is still in development.
8. Decision discipline – additional changes will be triggered when engineers and managers have a lack of discipline when making decisions.

Saeema & Kanike (2007) categorise the change as being initiated internally or externally. They state that the categorisation of what is considered to be internal or external will differ based on the individual company and the industry business model. External change can be further broken down into initiated by the customer, supplier or a contractual change. Internal changes result from operational experience, manufacture/assembly, production and build.

Eckert et al. (2004) categorise the changes into two different sources: emergent changes and initiated changes. The state of the design causes emergent changes. If problems occur across the design throughout the product life cycle, they bring about emergent changes. Initiated changes arise from an outside source, which could be a new customer requirement, a new requirement by certification bodies or improvement in design.

Emergent Changes

- Problems in design
- Problems in testing
- Problems in prototyping
- Problems in manufacturing
- Problems in use

Initiated Changes

- Customer requirements
- Certification requirements
- Innovations
- Problems with past designs
- New customer requirements
- Recent innovations
- Retrofit

Likewise, Jarratt et al. (2011) categorise the change triggers into emergent changes, as changes from the properties of the product itself and initiated changes which are enhancements or adaptations of a product in various forms and come from the outside.

2.6.1.2 Process of raising ECs and characteristics

According to Ullah et al. (2018), ECs can be raised by suppliers, customers and internal departments. ISO (2017) states that the EC should contain the part changing, a description of the proposed change, the information of the party preparing the change, the date the change was prepared, a reason or justification of the change and a category of the change in terms of complexity, resources and scheduling. Jarratt et al. (2011) write that there should be a category for urgency (immediate, mandatory or convenience) and timing (low impact, mid-production, late/expedited). This information can be used to determine the priority of the change. Kocar & Akgunduz (2010) confirm that the ECR should minimally contain the information which component to change, the attribute to change, the reason for change and a technical drawing representing the change.

In their study on engineering change management, Brown & Boucher (2007) find that best-in-class companies have a pre-approval of the change where the product/program manager approves the change. Not only is it important to only implement changes that the product and program manager determine as necessary, but Jarratt et al. (2011) also state that communication and company coordination have a great influence on the generation of ECs. To promote this culture companies have created matrix structures – an engineer will report to a technical manager for the function he performs as well to a product/program manager who manages the product or portfolio that the company is selling.

2.6.2 Impact Analysis

Once a change is initiated and the ECR is raised, an impact analysis will be done to see if it is worth the effort to implement the change. Terwiesch & Loch (1999, p. 162) describe the impact as “a function of the magnitude of change, its timing and the number of components and tools that are affected by the change”. Change can propagate through an assembly, and it would need to be redesigned until all components can work together to perform the product’s intended function (Ahmad et al., 2013). Ahmad et al. (2013) recommend that to fully understand the impact of the change, the information as to why a specific design is a way it is should be available and understood. ISO 10007 states that it is a requirement to evaluate the consequences of a change (ISO, 2017). Plehn et al. (2016) define the impact as “the cost incurred by a change in terms of money and time due to any activities related to its planning and implementation”.

According to Reidelbach (1991), the planner assesses the impact of the change by: (1) looking at the gross requirement for each new material, part or component; (2) initiating the purchase and manufacturing orders for the new parts; (3) cancelling or changing the existing purchase orders that are no longer required because of the change; (4) procuring the items in the revised drawings/specifications; (5) checking the revised BOM on the computer system; (6) coordinating production control efforts to accommodate the change; (7) following up with accounting to make sure the standard cost for the new items have been entered; (8) determining the disposition of parts that are obsolete due to the engineering change; (9) and ensuring that all non-production contractual requirements are fulfilled. The analysis Reidelbach mentions here is the analysis of effects on the supply chain. Iakymenko et al. (2018) furthermore state the EC impacts on production and supply chain should be analysed. ISO (2017) specifies the analysis for supply chain to include the potential consequences on contract, schedule and cost,

interchangeability of configuration items and the need for their re-identification, manufacturing, test and inspection methods, inventory and purchases and delivery activities. Brown & Boucher (2007) find that best-in-class companies have a formal impact analysis. The supply chain analysis at these top companies include the impact on production requirements, change in manufacturing or tooling equipment, current supply chain or purchase orders, current demand or sales orders, change in manufacturing processes and current inventory.

Not only supply chain impacts need to be analysed, but engineering impacts too. ISO (2017) specifies these as the technical benefits of the proposed change, the risks associated with the change, the potential impact of not approving the proposed change, interchangeability of configuration items and the need for their re-identification and interfaces between configuration items. Alblas & Wortmann (2010) note that the assessment of a change focuses not only on development but on all areas of business. Brown & Boucher (2007) write about the importance of analysing the relevant documents that will change because of the change. Obsolescence of parts, product reliability and product performance are analysed by best-in-class companies (Brown & Boucher, 2007).

Riviere et al. (2003) state that it is important to identify the consequences of a change on other components, which is called change propagation. This impact analysis should be part of the engineering impact analysis. They suggest that a typology should be defined and modelled that can help determine the propagation of changes. This typology link goes beyond the “where-used” information of an item that is under change and also looks at the indirect propagation of changes. The “association link” to where a product is in its lifecycle will help to detect all the physical items impacted. The “interface link” which detects how close two components are within the

system can help predict a collision between components. “Dimensioning links” is a component property and should be used to see if other components should be changed depending on the property change. Finally, “organisational dependency links” should be defined where different partners share the product and work and changes may impact the work that a partner is doing on a product.

Project management impacts such as project revenue, project follow up risks, brand image and project leadership position should be analysed (Honkisch et al., 2018). Customer support requirements, as well as the potential consequences on contract schedule and costs and the application of relevant statutory and regulatory requirements impacts, should be analysed according to ISO (2017). Alblas & Wortmann (2010) specify that the serviceability of products should be analysed when the product undergoes a change. The cost of a product is always monitored in a project and is an important factor in the ability to sell the product. The impact of the cost of the change is discussed in section 2.6.4.

2.6.3 Priorities

In their article on managing large engineering changes, Alblas & Wortmann (2012) write that in a change assessment, prioritisation rules and balancing workload principles should be included. Prioritisation should help to improve the throughput times, and essential changes can be distinguished from changes that are not essential but would make a product better. If a desirable change is not a priority and is postponed to a later time, it will create capacity for the essential changes to be implemented.

When a change is raised, the person creating the request must state the priority of the change in the proposal (Jarratt et al., 2011). Honkisch et al. (2918) and Veldman & Alblas (2012) state that prioritisation of the change

should be discussed in the change assessment. ISO (2017) mentions a category of change should be included in the change proposal. This could be interpreted as a category for prioritisation. In his template of an engineering change note, Dale (1982) has three categories that could help to prioritise a change – emergency, ASAP and phase out. Depending on the priority, the usage of the existing stock differs. Ullah et al. (2018) call the categories "immediate, mandatory and convenience" and Wänström & Jonsson (2006) divide the prioritisation into error, mandatory, salesforce inquiry and planned phase-in. Kocar & Akgunduz (2010) say that the priority depends on the cost, the potential savings, the effect on customer satisfaction, the effect on the lead time and the manufacturing complexity.

2.6.4 Cost of the Change

The effects of a change increase the cost of a product and create delays in the schedule. The cost of each change should be analysed in the impact analysis (Honkisch et al., 2018, Subrahmanian et al., 2015, Brown & Boucher, 2007, Eckert et al., 2004). If the cost is higher than the benefit it would bring, the change should not be implemented. (Fricke et al., 2000). Plehn et al. (2016) and Subrahmanian et al. (2015) define the impact of the change as the cost of the change. Huang et al. (2003) state that the man-hours invested in an engineering change range from two to 36 days.

It is complicated to measure the cost of an EC (Subrahmanian et al., 2015). There are first-order and second-order costs related to a change. The first-order costs that are measurable are time and effort for creating and validating engineering changes. The second-order costs are costs due to rework, retrofit, delay in market introduction, project delays and costs related to supply and inventory management. Furthermore, the more complex a product is and the more people are needed to validate an EC, the higher the first-order costs of an EC will be. Jarratt et al. (2011) split the cost of the change

into tangible and intangible elements. Terwiesch & Loch (1999) talk of a cost breakdown between design, changes in prototype and change in production tools.

2.6.5 Change Review

ISO (2017) recommends that the evaluation of a changed should be reviewed. The implementation of change boards can help to find a more specific selection of changes (Fricke et al., 2000). In their study done at BaE (MAD), Kidd & Thompson (2000, p. 75) find that “once a design change is initiated it is reviewed to assess the viability of the proposed change”. Every role-player receives a notification to check for specific areas where they or their department could be affected by the change. The system is programmed so that different departments can access the same information at once, so that time taken does not create any bottlenecks. Once every department has done their review and acknowledged the change proposal, and there are no further problems or implications found with the change, the review process can go on. If there any problems are identified with the change, then the original design needs to be modified, or the change proposal needs to be withdrawn (Kidd & Thompson, 2000).

In their study on engineering change management in companies, Brown & Boucher (2007) found that best-in-class companies take a structured approach to the change processes. They have a separate meeting for change review and the CRB exists of a cross-functional team. Alblas & Wortmann (2010) and Kocar & Akgunduz (2010) also find a review should be done of the EC in an interdisciplinary team to check for quality and completeness of the change. Storbjerg et al. (2016) state in order to allow for decision-making at the lowest level possible, the review should be differentiated according to the class of the change.

2.6.6 Change Control Board

ISO (2017) states that a dispositioning authority should review and decide upon the disposition of a change. Dale (1982) states that a committee chaired by the manufacturing manager and having members of management of various departments involved in the change should meet once a month (or more if emergency changes are required), to act as a gate for accepting, rejecting, or calling for more information about the change. According to Dale (1982), this committee also decides how the change will be implemented – it could specify the date of the change, batches to changes and machine serial numbers. Furthermore, the committee should consider the impact of the change (Dale, 1982). Brown & Boucher (2007) find in their study that best-in-class businesses have a cross-functional review board. Collaboration is important for ECM (Iakymenko et al., 2018). Alblas & Wortmann (2010) explain after the introduction of a change it should be assessed by a CCB. The CCB consists of experts in several fields within the organisation including, service, manufacturing, logistics, supply and development.

Reidelbach (1991) highlights the importance of an EC control committee that assesses, implements and manages EC methods and procedures. Kidd & Thompson (2000) state an Engineering Change Control Board (ECCB) should hold meetings daily to decide if a change is accepted or rejected. The ECCB consists of senior engineering heads who analyse the data collected during the change review and decide whether to accept or reject a change.

Huang et al. (2003) found that two of the four companies in their research have an ECM board. This board consists of delegates from multiple disciplines and is tasked to deal with the main issues caused by ECs. The other two companies had strong reservations about establishing an ECM board based on their previous experience. They rather had a person starting an engineering change and made sure it was routed to relevant participants

of the change. The implementation of an engineering board at these two companies possibly could have failed because of resistance to change, not a relevant structure in the CCB or the lack of discipline of attendants.

Jarratt et al. (2011) state that most companies have an engineering change board or committee. This forum reviews each change makes a cost-benefit analysis for the company with all factors calculated and then approves the change for implementation. This forum exists of middle to senior ranking staff that represent the departments that are connected to the product, which could include product design, marketing, manufacturing, procurement, quality assurance, finance and product support.

2.6.7 Change Implementation

When a decision is made to change, the change should be implemented without delay (Fricke et al., 2000). For a change implementation to happen optimally, every role-player should know what to do and when to do it. Therefore, efficient communication and information tools or methods that display the status of a change implementation should be used. Kocar & Akgunduz (2010) talk about an engineering change note that is used to communicate the change to all departments deemed necessary. Lee et al. (2006) call the documentation an engineering change order and Brown & Boucher (2007) state that best-in-class companies have formal change implementation plans. The formal plans allow the company to determine the optimal way to implement the change. They also emphasise the importance of placing the focus on the execution of the plan (Brown & Boucher, 2007).

Jarratt et al. (2011) state changes can either be implemented immediately or be phased in and that it depends on the nature of the change and where the product that is changing is in its lifecycle. Nadia et al. (2006) state that batch implementation is more efficient, whereas Fricke et al. (2000) say that

implementation should happen directly after a decision has been made. Ullah et al. (2018) created an algorithm which calculates whether to implement a change immediately or in a batch by looking at the urgency of the change and the rework risk.

ISO (2017) states that changes have to be communicated to internal and external parties and that changes should be verified and this verification should be documented. Storbjerg et al. (2016) and Rouibah & Caskey (2003) say the information on the change should be distributed cross-company.

2.7 Conclusion

This chapter started with the introduction of configuration management and background engineering change management. Different engineering change models found in the literature were explored and a theoretical framework for the case study was developed using these models. The analytical framework was created by combining the theoretical framework and Trochim's framework for pattern matching. The chapter ends off with a literature review on the topics that were established in the theoretical framework. The information on these topics sets the theoretical pattern for the pattern matching analysis.

3 Research Methodology

3.1 Introduction

This chapter explains the research methodology that was applied to do the study. The research strategy is explored and motivated. The study done at SGD is a qualitative study and is done in the form of a case study at SGD. Next, the case study process is analysed and it is explained how it was employed in the study. The research will be done by doing semi-structured interviews with role-players involved in the change process and by looking at documents used in practice. The results of the research will be presented and then a gap analysis, using Trochim's framework for pattern matching and the developed theoretical framework from Chapter 2, will be done to determine the differences between the theoretical and practical patterns. The validity and reliability methods are researched and explained how they are included in the study. The section ends off with ethical considerations and the limitations of the study.

3.2 Research Strategy

3.2.1 Qualitative Research Methodologies

Flick (2018) writes about the features of qualitative research methods. He states that this is the type of research that is done in real-world settings and not in a laboratory. Furthermore, he says it aids to analyse the experience of individuals or groups, interactions and communications, and documents of various types (Flick, 2018). Hancock & Algozzine (2017) write that if not much is known about a subject and deeper knowledge is desirable, a qualitative approach might be more useful. Qualitative researchers visit the environment of the field they want to research (Merriam & Tisdell, 2016; Flick, 2018; Hancock & Algozzine, 2018). The purpose of the qualitative data is to understand how participants in the study make sense of their lives, describe

the process, and describe how people interpret what they experience (Merriam & Tisdell, 2016).

In qualitative research, the researcher is the primary instrument for research and is interested in understanding the way that people experience their world (Merriam & Tisdell, 2016; Hancock & Algozzine, 2018). Hancock & Algozzine (2018) add that therefore it is required that the researcher spends a significant amount of time in the environment of those being studies (Hancock & Algozzine, 2017).

Qualitative research is an inductive process (Merriam & Tisdell, 2016). The researcher uses information from interviews, observations and documents or a combination of these and works from particular to general (Merriam & Tisdell, 2016). The product of qualitative research is richly descriptive (Merriam & Tisdell, 2016). The result of the research is presented in text and pictures, and not in numbers (Merriam & Tisdell, 2016).

This study is conducted at SGD, a company in the defence industry. The researcher will obtain information from people who are working with the EC process every day and from documents used in the EC process. The EC process will be analysed as it is as the researcher wants to find out how the people working with the EC process everyday experience and view the process. The information gathered will be used to create an observed pattern. This will need to be very descriptive of the change process at SGD so that it can be used to pattern match against the theoretical framework established in chapter 2.

3.2.2 Case Study Research

Case studies are a form of qualitative research (Hancock & Algozzine, 2017). According to Hancock & Algozzine (2017) “they are intensive analyses and

descriptions of a single unit or system bounded by space and time". Case study research can be used to analyse individuals, events, situations, programs and activities (Hancock & Algozzine, 2017) as long as they only analyse a single entity (Merriam & Tisdell, 2016).

Hancock & Algozzine (2017) define the following characteristics of a case study:

1. Case study research focuses on an individual representative of a group, an organisation, or a phenomenon
2. A case study is performed in its natural environment
3. A case study is richly descriptive because it is grounded in deep and varied sources of information

For this study, the case or entity is the EC process at SGD. It is a single process at a company that is researched. The number of people that can be interviewed about this process is finite and the study is done at the company in its natural environment.

3.3 Case study process

The case study process is used to outline the rules and procedures that govern the conduct of the researcher and the research project (Miles & Huberman, 1994). The case study protocol for this study is designed according to Yin's six-stage process – plan, design, prepare, collect, analyse and share – and is elaborated in the next sections (Yin, 2009).

3.3.1 Plan

The first stage in the case study process exists of identifying the research question or justification for the case study (Yin, 2009). This process was done in chapter 1 of this report by explaining the purpose of the study,

understanding the company background, elaborating the research motivation, setting the research question, objectives and finding delimitations. The literature review is then done to find out what is already written on the topic (Hancock & Algozzine, 2017). This was done in this report in chapter 2.

3.3.2 Design

The design stage focuses on:

1. Defining the unit of analysis and the likely case to be studied
2. Developing theory/propositions and identifying issues underlying the anticipated study
3. Identifying the case study design
4. Developing procedures to maintain case study quality (Yin, 2009)

For this study, the unit of analysis/case that is studied is the EC process at SGD. The researcher wants to find out how this process can be improved. The case study is classified as intrinsic because the researcher wants to find out more about a process in an organisation (Hancock & Algozzine, 2017). The case study research design is a descriptive design because it will be used to illustrate and explain the key features of a phenomenon in its context. When identifying a design, case study researchers must attend to issues of validity and reliability as they establish procedures and select instruments for their studies (Yin, 2009). Procedures to maintain case study quality can be found in section 3.3.7.

3.3.2.1 Sample Selection

There are two types of sampling called probability and nonprobability sampling (Merriam & Tisdell, 2016). Nonprobability sampling is the method of choice for this study. Nonprobability sampling can have two forms – purposive and purposeful. For this study, purposeful sampling is chosen – the

investigator wants to understand and gain insight into the change process at SGD. Therefore a sample must be selected from which they can learn the most (Merriam & Tisdell, 2016). The chosen type of purposeful sampling is maximum variation so that an all-round concept of the change process at SGD is formed. Merriam & Tisdell (2016) describe this as seeking out participants who represent the widest possible range of the characteristics of interest for the study. A list of the interviewees can be seen in **Table 3-2.**Table indicating the interviewees and the departments they belong to

3.3.3 Prepare

The prepare stage focuses on:

1. Developing skills as a case study investigator
2. Training for a specific case study
3. Developing the case study protocol
4. Conducting a pilot case
5. Gaining any relevant approvals (Yin, 2009)

The researcher should be familiar with the study domain to understand the main concepts and theoretical or methodological issues that could come up in the study (Yin, 2009). The researcher should understand why the investigation is being done, which evidence is being pursued, what variations could be expected and what to do if a variation occurs, and what constitutes supportive or contrary evidence (Yin, 2009). For this case study, the researcher has worked in the company for five years prior to doing the study. They had been involved in the change process and with the people doing the change process for more than two years. Hence, the researcher is familiar with the field that the study is being done in.

To prepare for the study, activities include reviewing the case study protocol and reviewing sample reports. The data of the case study is interpreted in

real-time and the data collection activities will be adjusted to suit the case study (Yin, 2009).

A case study protocol is an overview of the case study project including objectives, issues and relevant findings of the topics being investigated (Yin, 2009). It contains field procedures, including procedures governing access to case study sites (Yin, 2009). In this case, only one company has been studied, but the case study protocol could be used to expand the same study in other companies. It includes case study questions, data collection forms and sources of information for answering each question. A guide for the case study report including an outline of the report and references. The case study protocol can be found in Appendix F.

A pilot case study can be done to test the structure. For this study, it was not done due to time constraints and due to the research being investigated only at one company in one process.

Relevant approval should be collected from the site of the study as well as participants taking part in the study. The participation letter inviting participants to take part in the study can be found in Appendix A. An example of the letter of consent the participants signed to give their consensus to take part in the study can be found in Appendix B. A letter of consent to do the study at SGD was signed by the configuration manager and can be found in Appendix D.

3.3.3.1 Developing Interview Questions

A part of the case study protocol is identifying additional research questions and developing the interview questions. The research for this study is done by one-on-one, semi-structured interviews. Explanations as to why these types of interviews are selected can be found in section 3.3.4.

In case study research, the researcher is the main instrument for data collection and in most forms of qualitative research, the data are collected through interviews (Merriam & Tisdell, 2016). Wengraf (2001) has created a framework for developing interviews. The framework can be seen in **Figure 3.1.**

The development of the interviews starts with the research purpose (RP). From the RP the central research question (CRQ) is formulated. The RP and the CRQ need to be formulated clearly to ensure the design of the interview is clear (Wengraf, 2001). The theory questions (TQ) are formed to answer the CRQ. The TQs are broken down into informant questions (IQs). The IQs are broken are the questions that are asked to the interviewee. The questions are broken down to this level to ensure the interviewee understands the IQs easily. The researcher will then use the responses of the IQs to draw up a conclusion about the TQs.

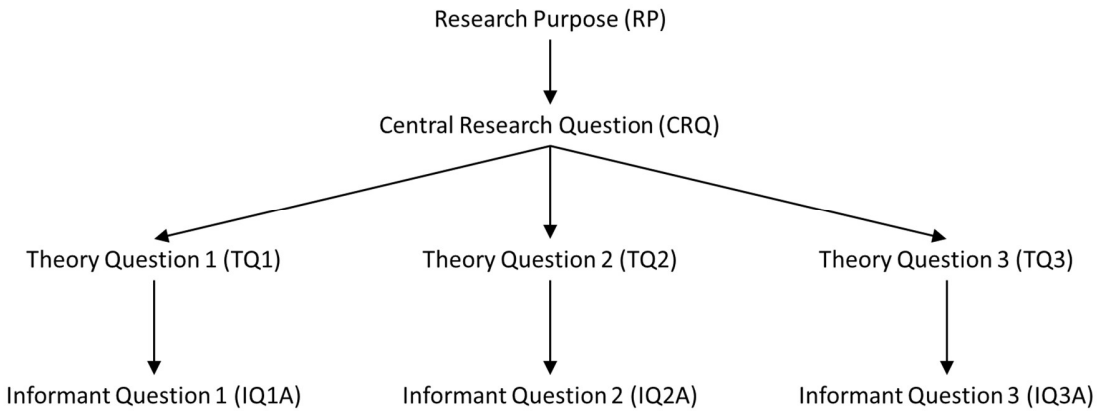

Figure 3.1: The process of obtaining interview question from the research purpose (Wengraf, 2001)

For this study, the TQs have been formed from the theoretical framework which was created in section 2.5. The CRQ was developed into 7 TQs which contain the content of the theoretical framework. Development of the TQs can

be seen in **Figure 3.2**. The TQs were then further broken down into IQs. These can be seen in **Table 3-1.**

The RP will be reached when the study is complete. The study is completed by interviewing participants with the IQs developed. Once the IQs are answered, the researcher can answer the TQs and so the answer to the CRQ can be developed and the RP be reached. For this study, interviewing is not the only research instrument used, but documents will also be analysed. The interview process is explained in section 3.3.4.1 and data collection by documentation is further explained in section 3.3.4.3.

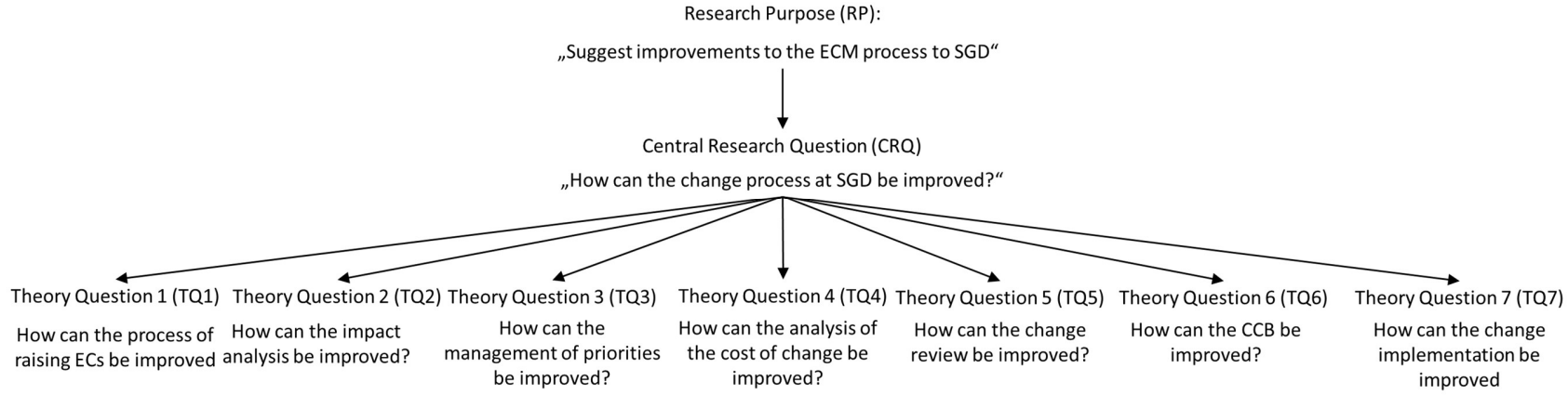

Figure 3.2: Development of the TQs according to Wengraf's model for the development of interview questions

Table 3-1: Development of the IQs according to Wengraf's model for the development of interview questions

TQs	How can the process of raising ECs be improved?	How can the impact analysis be improved?	How can the mangement of priorities be improved?	How can the analysis of the cost of change be improved?	How can the change review be improved?	How can the CCB be improved?	How can the change implementation be improved?
IQXA	What are the change triggers?	When is the impact assessment done on the solution?	Are changes prioritiesed at SGD? Please explain how?	Does SGD assess the cost of an ECP? Please explain when and how this is done	Does the change at SGD get reviewed before sending it to the change control board?	Is there a forum or board that signs off the change?	How do changes get implemented at SGD?
IQXB	Does SGD do a pre-feasibility study?	Please explain the impact assessment at SGD. What is important for you to assess?			In your opinion, is this review useful?	Explain who the CCB consists of and what happends in the CCB?	When do changes get implemented at SGD?
IQXC	When is an engineering request raised?					Does SGD have an ECP coordinator and an ECP committee?	Is the change implementation at SGD planned? How?
IQXD	How is and engineering request raised?						When and how are changes communicated to the customer? Does the customer approve the change?
IQXE							Does SGD review a change after implementation? Please explain when and how this is done?

3.3.4 Collect

According to Yin (2009), the collect stage involves following the case study protocol, using multiple sources of evidence, creating a case study database and maintaining a chain of evidence. The data collection methods for qualitative research include doing individual interviews, focus groups, observations, a review of existing documents, or a combination of these (Hancock & Algozzine, 2017).

The case study will be carried out at one company only and therefore is an intrinsic case study (Hancock & Algozzine, 2017). The types of data collection methods in case studies are collecting data from interviews, collecting data by observation and collection data from documents (Hancock & Algozzine, 2017). For this study, the method that is chosen for doing data collection is by doing semi-structured interviews and by reviewing current processes and documentation. These methods will aid the researcher to understand the process fully. The people involved in the process have knowledge of the process and documents they use during the process will help the researcher to understand the whole concept of the change process.

3.3.4.1 Data Collection by Semi-structured Interviews

Interviews are a common form of data collection in case study research (Hancock & Algozzine, 2017). Interviews can be structured, semi-structured or unstructured. Semi-structured interviews are chosen for this study, which allows the interviewer to ask predetermined questions as well as follow-up questions that seek to gain a profound understanding of the interviewee's opinion. In the semi-structured interview, the sequence of questions can be participant-led (Flick, 2018).

Hancock & Algozzine (2017) give guidelines to conduct successful interviews and comment on how the research was carried out is part of every point:

1. The researcher should identify key participants with knowledge on the research question. The interviews can be done in a group or on an individual basis. The one-on-one interviews result in more information on the perspective and opinion of the interviewee. Group interviews are beneficial when the interviewer would want the interviewees to share and create new ideas. For this study, individual interviews were chosen because it was important to get complete information on ECs from different perspectives of role-players involved in the EC process. A reasoning for sample selection is described in section 3.3.4.2.
2. The researcher should develop an interview protocol with open-ended questions. These questions should be designed in such a way that they allow the researcher to get answers about the study's research question. Research questions primarily based on the findings in the maturity model of Stobjerg et al. (2016) and the EC characteristics found in the literature study were developed to be asked in the interviews. The interview questions for this study have been developed in section 3.3.3.1 using Wengraf's model for developing interview questions.
3. The researcher should choose a setting in which the interview is conducted that promotes getting high-quality information from the interview. Boardrooms and individual offices within SGD were selected for the interviews for this research. These areas are private and undisturbed with the interviewees feeling comfortable in the setting because the locations are part of their everyday work.
4. The interviewer should develop a means for recording the interview data. This could be from handwritten notes to audiotaping the interaction. For audiotaping, the interviewee's permission must be obtained. The interviews are then transcribed by the researcher in an

informal, point form manner. Handwritten notes were taken during the interviews of this study, and the interviews were audiotaped with permission from the interviewees. The researcher transcribed the interviews.

5. Legal and ethical requirements must be adhered to for all research involving people, which will be elaborated more in section 3.4.

The interviews in the study are done in a one-on-one session in a boardroom at the company. The interviews are recorded by the researcher and notes are taken during the interviews. The interviews are then transcribed by the researcher to be used for data analysis. The interview questions can be seen in Appendix C and the transcripts of the interviews can be found in Appendix E.

3.3.4.2 Sample Size of the Interview Process

The sample selection was determined as purposeful and maximum variation in section 3.3.2.1. The number of people selected to be interviewed was determined by the number of departments involved in the EC process at SGD. There are eight departments involved in the EC process at SGD. The semi-structured interviews were completed with a person in each department involved in the EC process. To ensure that participants have knowledge on the subject, every interviewee selected was either the manager of the department or a senior employee that has been with the company for more than ten years.

3.3.4.3 Data Collection by Documentation

Existing documents can be reviewed to gather information related to the research question. There are four categories of documents – the internet, private and public records, physical evidence and instruments created by the

researcher (Hancock & Algozzine, 2017). The internet as a research document should be used with caution because the sources are not always authentic and legitimate (Hancock & Algozzine, 2017). Flick (2018) states that the primary sources for work can be policy documents, organisational documents, newspapers and academic articles and textbooks.

For the case study in this paper, the documents analysed are documents that are used in the process at SGD. The documents that are used are the Change Request (CR) and Change Order (CO) forms in the Product Lifecycle Management (PLM) system, the Engineering Order (EO) document used for the implementation of the change and the checklists that every department fills in when doing an impact analysis before the CRB. These documents will be used to understand how an EC is raised, which characteristics are important at SGD and to get a clearer understanding of what is important to each department involved in the change process during the analysis of an EC.

3.3.4.4 Purpose of data collection

The purpose of the interviews is to build up a database of information on the EC process at SGD. This information will be used to create the observed pattern of the observational realm found in Trochim's framework for pattern matching (1989). While the information is collected, the data collected will be stored under the topic established in the theoretical framework in the observed realm. The information will be stored in a database and will be written in such a way that it can be referenced back to the interviews.

3.3.5 Analyse

In a case study, the data collected needs to be managed and analysed already while the data is collected (Merriam & Tisdell, 2016). Analytic

techniques are used, rival explanations are explored and data and interpretations are displayed (Yin, 2009). This case study does not contain any propositions nor hypotheses. Hence a descriptive framework is used to organise the study. The descriptive framework is the theoretical framework developed in section 2.5. Trochim's framework for pattern matching is used to do the analysis. First, the theoretical patterns will be analysed from the literature review and then the observed pattern will be analysed. The data of the two patterns will be compared and the pattern will be matched.

Flick et al. (2014) say that qualitative content analysis is a systematic way of describing the meaning of qualitative data. This type of analysis is flexible, systematic and it reduces the content of the data. Flick et al. (2014) say the following steps should be done when doing content analysis:

1. Deciding on a research question
2. Selecting material
3. Building a coding frame
4. Segmentation
5. Trial coding
6. Evaluating and modifying the coding frame
7. Main analysis
8. Presenting and interpreting the findings

The interviews and the documents for this study have been analysed using content analysis. The analysis for this study was done in Microsoft Excel with colour coding and creating categories. An example of this analysis can be seen in Appendix H. The analysis is done first to generate the theoretical pattern and later to obtain the observational pattern and then the categories and contents are compared.

3.3.6 Share

The final stage consists of defining an audience, composing textual and visual materials, displaying enough evidence for a reader to reach his/her own conclusion, and reviewing and re-writing until done well (Yin, 2009). The audience for this case study will be the configuration and D&D manager of SGD. They will need to discuss if the improvements found in this study are of value to implement at SGD. The case study protocol could also be shared with other defence companies and they could use it to establish what could be improved in their own change processes. The case study protocol and the theoretical pattern will, therefore, be created to be understandable for all these parties.

3.3.7 Validity and Reliability

Because of the applied nature of qualitative research, it is necessary that researchers have confidence in the way the investigation is conducted and in the results of the study. Validity and reliability are concerns that can be approached when establishing the concept of the study. It should be considered for the way in which the data are collected, analysed and interpreted and the way in which the findings are presented (Merriam & Tisdell, 2016). Internal validity, reliability and external validity will now be explored and it will be explained how they are incorporated into the case study.

3.3.7.1 Internal Validity

Internal validity is done to find out how the research findings match reality (Merriam & Tisdell, 2016). The researcher is the primary instrument of data collection in qualitative research, the reality that is written in the study could be an interpretation of the researcher's perspective (Merriam & Tisdell, 2016). Tools such as triangulation, member checks, adequate engagement in data

collection, researcher's position and peer review are created to check the validity of the research (Merriam & Tisdell, 2016).

For this study, the validity methods chosen are triangulation and member checks. Triangulation in this study is by using multiple sources of data and more than one data collection method. The interviewees of the study are mangers in their department with more than five years of experience in their work. The interviewees chosen all belong to different departments in the company, which ensures the researcher establishes the change process with all perspectives known on the subject. A list of the departments of the interviewees can be seen in **Table 3-2**. To achieve more than one data collection method, interviews with people involved in the process and the documents related to the change process are reviewed.

Table 3-2: Table indicating the interviewees and the departments they belong to

Interviewee	**Department & Role**
Interviewee 1	Design & Development manager
Interviewee 2	Configuration manager
Interviewee 3	Supply Chain specialist
Interviewee 4	In-Service Support manager
Interviewee 5	Systems Engineering manager
Interviewee 6	Integrated Logistics Support manager
Interviewee 7	Programme manager
Interviewee 8	Product manager
Interviewee 9	Design & Development specialist

Member checks were done by getting feedback from the interviewees on the study that was conducted via email. An example of such an email can be found in Appendix G.

Furthermore, Wengraf (2001) states that validity can be built into the interviews during the design phase. He states it is wise to separate the IQs that relate to the same TQ. This will make it harder for the interviewee to find connections between the various questions. This strengthens the validity of the interview. When the interviewee identifies a link between the IQs and the TQs, bias becomes dominant in the interviews (Wengraf, 2001). If the interviewee becomes aware of the TQ and therefore of the CRQ, the responses are then based on their logic and therefore could be manipulated and not be truthful (Wengraf, 2001). This situation is undesirable.

3.3.7.2 Reliability

Reliability is the extent to which research findings can be replicated (Merriam & Tisdell, 2016). This is done with tools such as the creation of case study protocol and the development of a case study database (Yin, 2009). The case study protocol standardises the investigation. The case study protocol for this study can be found in Appendix F. The documents include an overview of the project, field procedures, guiding questions, and a report outline.

Triangulation and peer review, which both are discussed in the previous section 3.3.7.1 also ensure consistency and dependency (Merriam & Tisdell, 2016).

3.3.7.3 External Validity

External validity is necessary to ensure the framework can be used to test other companies (Yin, 2009). The outcome, however, will not necessarily be the same for other companies. Here a very good description, also called a rich or thick description of the study, as well as a detailed presentation of the setting, are necessary (Merriam & Tisdell, 2016). This has been considered

by the researcher when creating the theoretical pattern and the case study protocol for the study.

Maximum variation in the sample is another technique to ensure external validity. For the study, the way the interviewees were chosen was by using maximum variation. They are from different departments and have sufficient experience in the process to be interviewed. All departments involved in the EC process at SGD were included. For the theoretical pattern, as many studies as could be found on EC processes and the relevant standards in the field were analysed to create the theoretical pattern.

3.4 Ethics Consideration

In qualitative research, the researcher is the primary tool for data collection (Flick, 2018). The researcher works closely with the participants, and therefore it is critical, that the researcher is aware of conducting themselves ethically throughout the research. The researcher should be respectful of the participants in the study.

3.4.1 Ethical Considerations of Qualitative Research

Flick (2018) has identified the following criteria for ethical conduct while doing qualitative research. Meeting these criteria increases the quality of research:

1. Credibility: Having confidence in the accuracy of the findings
2. Transferability: Giving sufficient detail in the research which allows readers to judge the applicability of findings to other contexts
3. Dependability: Making provision for access to data which demonstrates the emergence of hypothesis and changes in understanding
4. Confirmability: The ability to provide a chain of evidence between data collected and conclusions that are reached

5. Authenticity: Provision of a balanced and fair view of multiple perspectives.

Following core ethical principles are essential in qualitative research (Orb et al., 2000):

1. Autonomy: The participant shall receive informed consent before the study is started.
2. Beneficence: doing good for others and preventing harm. The participants have the right to remain anonymous and considerable thought was given to inclusion criteria while recruiting participants. Details of participants remain confidential.
3. Justice: Equal share and fairness should be used while doing the study while avoiding abuse and exploitation of participants.
4. Implications for the researcher: the researcher should be able to separate their role as a researcher from the work that they do every day. In the case where the researcher has a job in the field where the research is done, the researcher should stay objective while doing research and not let their role in the business influence the research.

3.4.2 Ethics Clearance

The research done in this study was approved by an ethical board at the University of the Witwatersrand. The ethics clearance number obtained for this research report is MIAEC 001/18. To receive the ethical clearance for this research, the following documents were submitted for approval from the ethics committee:

1. A participant information sheet which was given to each interviewee
2. Letter of consent which was to be signed by each interviewee before commencing with the interviews
3. Interview questions

These documents can be found in Appendix A, Appendix B and Appendix C, respectively.

3.5 Limitations of the Study

The study is subject to some limitations. Due to time constraints, only one person per department was interviewed during the research phase. These people were either the manager of the department or had been working for longer than ten years at SGD, which means that they are specialists in their field. The interviewees all belong to different departments, which should give the interviewer a good understanding of the change process as understood throughout the company.

At the time the study was done, the researcher had worked at SGD for six years. Therefore colleagues and managers that the researcher is familiar with are being interviewed. Moreover, the researcher has been involved in the engineering change process by completing checklists for supply chain management. This could result in some bias during interviews and during the research.

The theory of pattern matching also has limitations and these will be explained:

1. There is no correct way how the theoretical pattern can be best developed (Trochim, 1989). For this study, it will be done by analysing the theory found on engineering changes. The operational pattern will be developed in a similar manner to ensure that the two patterns can be matched.
2. When using pattern matching one needs to be aware of the level of generalisation at which one is working (Trochim, 1989). This has been

considered by the researcher and the analytical framework has been created with this in mind.

3. The pattern matching presentation that Trochim has developed assumes the theoretical pattern is created before the observation pattern is created (Trochim, 1989). For this study, it would have been good to have a researcher that does not know anything about the topic before the time. The researcher is aware of the bias and in a future study, it would be of value for another researcher to build on the theoretical pattern created.

4 Results and Analysis

4.1 Introduction

In this chapter, the results from the study done at SGD are displayed and analysis of the results is done. It starts with explaining the change process as it currently happens at SGD. The process is mapped by reviewing documentation from SGD and by analysing the semi-structured interviews that were held with the role-players in the EC process. Next, using the same sources, the topics of the theoretical framework, as described in section 2.6, will be explained as they happen in practice at SGD. The data has been analysed by doing content analysis and using coding and finding topics. This information creates the observed pattern of Trochim's framework for pattern matching. The framework is used to do by a gap analysis. The framework is shown again in **Table 4-1**. After the finding on each topic, the result is analysed and improvement ideas are discussed.

Table 4-1: The Analytical Framework created for the study

Topic	Theoretical pattern	Pattern Matching	Observed Pattern
Raising ECs			
Impact Analysis			
Priorities			
Cost of the change			
Change Review			
Change Control Board (CCB)			
Change implementation			

4.2 Engineering Changes at SGD

In this section, the EC process at SGD will be described and the change triggers at SGD will be identified and then the EC characteristics as found in practice will be described. The process and characteristics that are explained in this section were constructed making use of data from the interviews and documents analysed for the research.

4.2.1 Engineering Change Process at SGD

The EC process at SGD starts with a change trigger. Then the engineering team find possible solutions to the change and discuss it in their group. Once a solution is chosen the CR and CO are raised by the person responsible for the change in the PLM system. In the CR the person responsible fills in a description and reason for the change. A priority is selected – emergency, urgent or routine. A class for the change is chosen – class I or class II. Class I means that an item's form, fit or function is changed and this change should always be communicated to the customer. At SGD all software changes have to be classified as Class I. Class II changes are to correct documentation or hardware not defined as class I. A rough cost estimate is added in the CR.

Further, in the CR the documents and parts lists linked to the parts that are changing and what version they will be are filled in by the engineer. A design manager and node manager are selected. The design manager and node manager do the pre-feasibility study. They have an informal discussion if the change is feasible and approve it by accepting the change on the system. Only if this gate is passed, the impact assessment is done. The next step is the impact analysis or change review, which is first done per department. Every responsible person in the department is invited to a CRB. In the invite to the CRB is a link to the impact assessments per department that needs to be done before the CRB takes place. For these impact assessments to be

done thoroughly, the change requires a well-defined description and reason for the change in the CR. All the departments involved meet during the CRB to review the checklists. Here all department representatives state that the change is possible and if anything needs to be changed, the engineers need to find a different solution. If the forum agrees with the change and the change is signed off by all role-players, the change passes to the next gate, the CCB. The CCB is the forum where management signs off the change. The forum is chaired by the design and development manager and consists of permanent members from drawing office, systems engineering, production, supply chain, logistics, maintenance and configuration and non-permanent members who have initiated the changes discussed in the weekly CCB meeting. The CCB verifies if the right process was followed and verifies details that were discussed in the CCB. If the CCB does not approve the change, items will have to be updated and be presented in the next CCB. If everything is in order, the design & development manager signs off the change. Now, the drawing office can start updating the drawings that need to be updated, and once that is done, the change can be implemented at SGD. The change is implemented with the help of a Change Implementation Board (CIB) where all members of the departments meet that will be affected by the change and make sure the EO form which describes the implementation, is filled in correctly. The process as described can be seen in **Figure 4.1**.

After the process, the change triggers at SGD are explained. This will give the reader a good idea of why changes are raised at SGD.

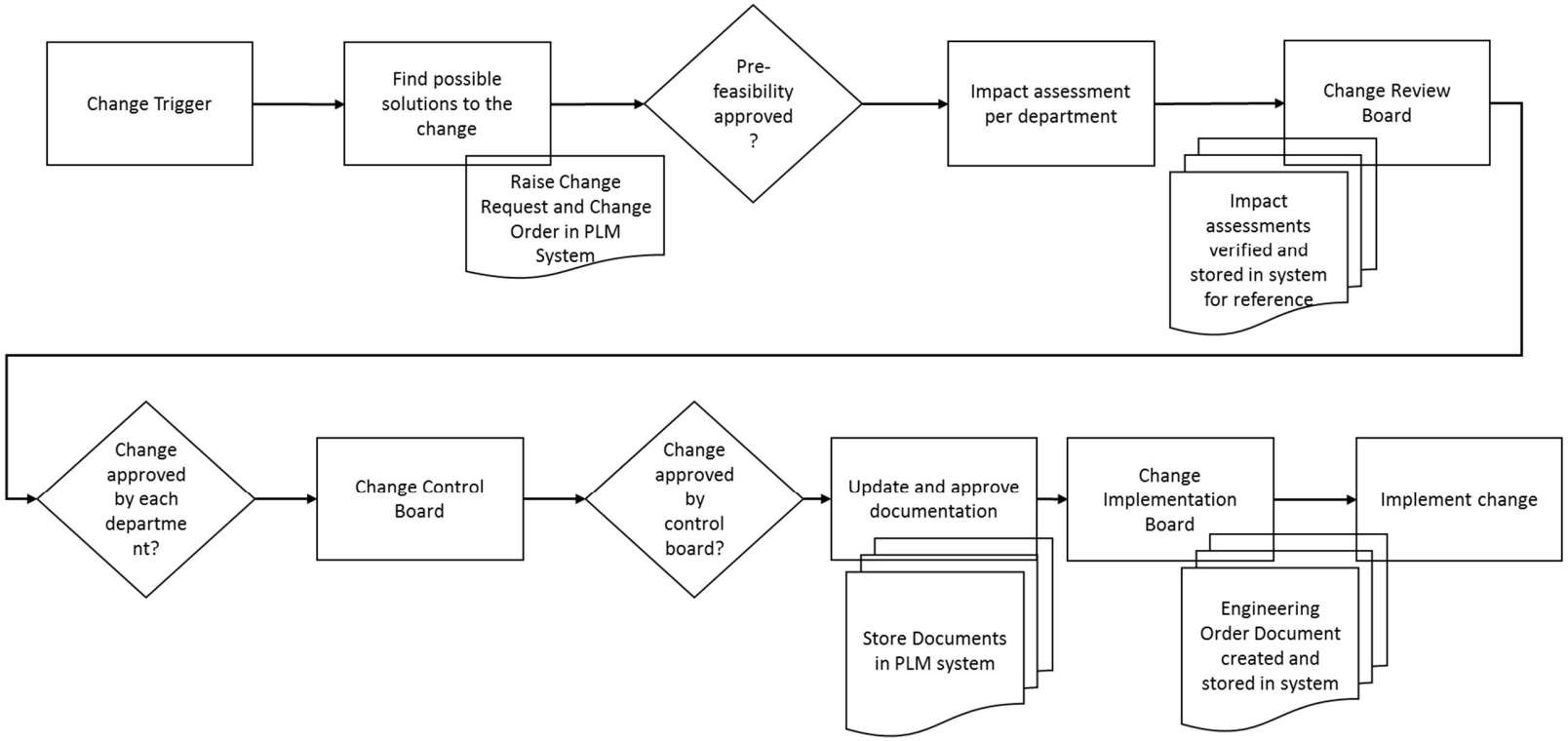

Figure 4.1: Engineering Change Process at SGD

4.2.1.1 Role-players involved in the Change Process

The role-players and their function involved in the engineering change process at SGD can be seen in **Table 4-2**.

Table 4-2: Role-players of the EC process at SGD and their function

Role-player	Function
Configuration Management	The CM controllers at SGD are the coordinators of the change. They create the CO after the design engineer creates the CR. They organise the CRB and CCB meeting and keep the minutes of both the sessions. Together with the Technical Design Authorities (TDAs) of the products they review open changes on products and send tasks to people to action the open changes. Once a change is complete, they update the configuration items and engineering bill of materials in the PLM system.
Design & Development	The D&D manager chairs the CCB to ensure the process was followed and all the departments signed off the change. Once the D&D manager signs off the change, it is complete in the PLM system and the implementation stage can begin. The engineers in the D&D department are responsible for the design, so they often are the initiators of the ECP. They fill in a checklist how the change affects the product and are present in the CRB, CCB and CIB as the initiator of the change.

Initiator of the change	The initiator of the change can be from any department that needs to change the hardware or software of a product or documentation related to a product. The initiator of the EC is present in the CRB, CCB and the CIB. The initiator of a change corresponds with CM on the changes that were raised.
Production Engineering	PE represents the SC department at the CRB. They analyse how the change affects MPS, planning, stores and procurement and should communicate with the departments after the CRB and CCB regarding the actions to be done. A PE representative is a permanent member of the CCB to ensure that the correct process was followed from the PE, planning and procurement point of view. They are present in the CIB as well to sign off the implementation of the change on the EO. Actions from the checklist on the CRB for their own department should be completed by the PE.
Master Production Scheduler	PE informs the MPS of a pending change. Once the change is created, the MPS needs to update the ERP system with delivery dates and renegotiate the dates with an internal customer. The MPS chairs the CIB and ensures all departments understand the description on the EO for the implementation of the change.

In-Service Support	The ISS representative fills in a checklist for the actions for their department resulting from the change and is present in the CRB. A member of ISS is a permanent member of the CCB. An ISS member is part of the CIB and they sign the EO.
Systems Engineering	The SE representative fills in a checklist for the actions for their department resulting from the change and is present in the CRB. The SE manager is a permanent member of the CCB to ensure the correct process was followed from a system's point of view. SE discusses changes with the customer if any technical details need to be negotiated.
Integrated Logistics Support	The ILS representative fills in a checklist for the actions for their department resulting from the change and is present in the CRB. The ILS manager is a permanent member of the CCB to ensure the correct process was followed from an ILS point of view.
Product Management	The product management department is aware of the change but not necessarily present in the CRB nor the CCB. If the change impact was so significant on the product that it is a new product, the product manager would be informed and help to do the pre-feasibility study. Product management attends the CIB and signs the EO for implementation of the change.

Program/Project Management	The program manager is present at the CRB and the CIB and signs the EO for the implementation of the change. The program manager discusses changes with the customer when it is required.
Design Office	The design office is present at the CCB to ensure the correct process was followed and to give their input if something is not possible. Before the change gets implemented, the design office needs to update the designs and drawings that are part of the change.
Customer	In some cases, the customer becomes involved in a change by needing to sign off a change. Certain customers need to be informed of changes in their product and can choose not to have a change implemented on their product. SE and program management are the liaison departments with the customer. In some cases, program management can sign a change in the name of the customer.
Production Manager	The production manager is a permanent member of the CCB to ensure that the correct process was followed and to have the knowledge of which changes are going to be implemented in production.

4.3 Observed pattern

In this section, the observed pattern of the topics chosen for the framework created in section 2.5 is drawn up. The details about each topic are drawn from the semi-structured interviews done and the documents analysed. The characteristics are in the same order as the theoretical characteristics of an EC in Chapter 2.6. The data was analysed using content analysis with categories and colours. An example of the analysis can be seen in Appendix H.

At SGD the products get designed and developed and produced in their facility in Centurion, South Africa. It is a defence company, produces MTO and the products are complex and in high variety. Customer contracts are signed with a maintenance contract of up to 20 years. Therefore the products have a very long lifecycle. In the defence industry, the products are still being designed when the customer has placed an order. To shorten the product's time to market, concurrent engineering should be implemented. To keep track of the baseline that is being built, the bill of materials are configured by CM and formally released as soon as something is scheduled to be built in production.

4.3.1 Raising ECs

How the ECs are raised at SGD is explained in 2 sub-headings. First the change triggers are explored and then the process of raising ECs is explained.

4.3.1.1 Change Triggers

The change triggers and their explanations found at SGD can be seen in **Table 4-3**.

Table 4-3: Change triggers found at SGD

Change Trigger	Explanation
Early release to customer/ Deviation – it was released without meeting specifications	There is a shorter time to market requirement by the customer. SGD will release the product to production with a deviation because it might not meet the requirements to pass all tests yet. When the design is completed, ECs will be raised to update the product baseline.
Obsolescence	Technology is rapidly changing in the 21st century. If a product needs to be maintained for 20 years, or the customer orders a product a few years after their first order, items used in the product will have become obsolete.
Manufacturability/non-conformance in production	The prototype production happens on the production line with the baseline already released. Any errors that were not picked up in the simulated design programme will only be picked up in production
Cost reduction	If a business requirement is created to cut cost or if the price of a component has increased immensely, the product will need to be re-designed to reduce the cost.
Redesign for customisation	When customers require customisation to the standard products that SGD sells the item will need to be changed to include the customer's requirements.
Findings from reliability in the field	The items at SGD are tested in field to see that the design is as reliable in use as it is designed. If

	there is an error from this reliability test, the product will need to change. The reliability test should be done before the production has started, but due to the quick time to market required by the customer, this test can happen when the baseline is already released, meaning that supply chain has started procuring and production has started building sub-assemblies.
Problem identified by a customer	Simulation tests are done on most products at SGD to make sure they will work in a customer environment. However, there is still room for error and a customer might pick up a problem when installing a product into their system because observations are sometimes different on the simulator than on the aircraft.
Process and procedure change	If there are process and/or procedure changes required by law the design will need to be changed. An example of this would be an environmental law changing and a chemical that is used in the design becomes banned.
Improvement	If a product is mature and the market strength would be improved by refining the product, changes will be introduced to the design.
Contract changes from customer	A customer might have a requirement change from one of their customers in the supply chain. This will cause SGD (as the supplier) to have to change their design.
Changes for MTOT and PTOT	If the maintenance or production is transferred to a different plant, this could result in changes

	because of different production technologies being available in the alternative production plant.
New technology	If new technology is developed, a design could be changed to incorporate the new technology. Production technology could also change and result in ECs on the product.

4.3.1.2 Process of Raising ECs

At SGD, An EC is raised on the ERP system. The creator of the change has to fill in the minimum required fields which consist of the reason for the change, the description of the change, the node manager and the design responsible person. Furthermore, they need to state the part number of the item changing and the document numbers that will change. The change is stored in the ERP programme and linked to the part number so that it is always traceable why a part changed.

Sometimes a lot of work happens before a change happen and a pre-feasibility study is done by the engineer and the node manager. The node manager and the design responsible manager have to approve every change before the rest of the process starts. The pre-feasibility study is not captured in the CR form on the ERP system.

Changes at SGD are raised throughout the lifecycle of the product. A customer can request a change or a part that needs to be maintained might be obsolete and trigger a change.

4.3.2 Impact Analysis

The person raising the change does the initial impact analysis. This impact assessment is linked to the CR form on the PLM system and is purely the

impact on the documents and physical items that are affected by the change. Physical items change versions and documents change revision to make the change traceable.

Furthermore, a checklist is used by five departments – D&D, SC, SE, ISS and ILS - involved in the change to analyse how the change affects the company. The checklists are explained by department.

Design & Development

The D&D department is the source for most changes at SGD. This is because they are responsible for the design and if a product changes, the design engineer is the one that raises the change. In this checklist, the questions about how the change will affect the physical, electrical and functional characteristics of the configuration item are asked. Furthermore, it is analysed whether the change affects interchangeability, substitutability and replaceability of the assembly or sub-assembly. Additionally, the engineers answer if the change will affect the environmental qualification that was done when the product was qualified, the maintainability and testability of the product and if the change affects compliance to specifications and regulations and will it negatively affect obsolescence. This explained part of the D&D checklist is to see if the form, fit and function of a configuration item are affected. The second part of the checklist asks “what if” questions. Does the change need to be applied to units in production or delivered units? This knowledge is essential for SC and ISS to be able to fill out their checklists. Finally, it asks if there are any other related open changes this change can be combined with. If there is an open change, it would be better to combine the two to try and minimise the number of open changes on one product at a time. If there are two or more changes happening concurrently on a product, it could be that they will affect each other. Thus it will be better to combine them.

Supply Chain

The SC checklist is filled in by the PE employee responsible for the product in production. At SGD procurement, stores, planning, production and testing are all part of the SC department. The SC checklist starts with asking if the change affects SC. If a change, for example, is done on the software on a rig in systems engineering, the change will not affect production. Next, it is necessary to determine if the product that is changed is still in production. If so, the change will need to be communicated to the Master Production Scheduler (MPS) and needs to be implemented using an EO. The analysis using the checklists goes on asking questions relevant to the departments of SC – first planning, procurement and PE. The planning department is affected by the change if there is an open works order on the line, stock in stores that needs to be scrapped or modified, delivery dates get affected negatively due to the change and cost of the unit goes up due to the change. The planner takes responsibility for the items that need to happen in stores. For the procurement department, it is important to know if the change affects any open purchase orders and if so, how if the open orders need to be cancelled, modified or bought as is. The outcome of this could also affect the cost of the unit and the delivery dates of the final assembly. In the PE section, it is important to find out if the manufacturing bill of material needs to be changed and this needs to be coordinated with the planner. The questions further ask if new tooling or jigs need to be designed, if the test infrastructure will change, how the change affects production documentation and if the delivery schedule will be affected.

Systems Engineering

The SE checklist asks if the change has the right class and if it must be signed off by the customer. It is used to analyse the change impact on the requirements baseline, test baseline, manuals and training material and if the backward compatibility of the unit under change is understood from the

change. The system engineers also double-check that they are content with the part number change or modification strike proposed by the D&D engineer. If the change affects environmental and functional qualification aspects, SE needs to understand if published data of these two qualification types need to be updated. Finally, the question is asked if the system test rig is affected and will need to be modified due to the change.

Integrated Logistics Support

The ILS department analyses with the checklist if the change impacts the safety, any analyses that are done by the department, such as Failure Mode Effects Analysis (FMEA), Criticality Analysis (CA). They check if the change makes repair and maintenance more difficult and if it introduces new maintenance actions. If any documents such as operator manuals, maintenance manuals and other documents created by the ILS department need to be updated, this is noted on the ILS checklist. The final questions in the checklists are regarding customers – are training, facilities impact, support and test equipment, spares provisioning and workforce or personnel of the end-user affected?

In-Service Support

ISS needs to ask themselves at every change how and where the change must be done: will it be in the field, or do we need to recall the units or retrofit them during maintenance. Furthermore, ISS checks if the change will affect the European Aviation Safety Agency (EASA) part 145 regulations regarding the maintenance of the items - will the proposed change ground an aeroplane? Also, they analyse if anything that is completed by production but not yet delivered to the client needs to be changed.

4.3.3 Priorities

ECs are prioritised into three different categories when the change is raised – emergency, urgent and routine. Furthermore, they are categorised as class 1 or class 2 according to a military specification. Class 1 requires customer feedback. If an emergency change is raised, an emergency CCB will be held on the request of the project manager. These changes will not wait for the Friday CCB meeting, but the CCB will mostly be held right after the CRB meeting. Furthermore, SGD gives priority to the changes that hold up production and shipping to the customer. If production cannot produce because there is a pending change, the line is standing still and the fixed cost still needs to be paid by SGD. All the changes happen late at SGD because the products are maturing while already in production; therefore, all changes have a sense of urgency. In ILS the changes are prioritised as *safety* and *not safety* and will impact when the change will be implemented in the ILS documentation.

4.3.4 Cost of the Change

At SGD the cost of the change is not assessed in detail, but cost estimation is done. It is difficult to analyse the cost of the change because there are multiple layers of costing at SGD. Looking from the bottom up there is an impact on product cost, maintenance cost, programme level cost and system-level cost. The costs include physical stock cost and impact on timescales for delivery and cost of updating documentation due to the change. During the impact analysis, supply chain calculates the cost of the stock that needs to be scrapped or modified. The project cost of the change is not assessed during the change process. The project manager should keep track of the project. If a change would be done to improve the product, the return on income should be analysed, but it is not done so. There are few changes for improvement at

SGD because most of the changes are raised to increase the maturity of the product.

4.3.5 Change Review

As can be seen in the previous section, the impact analysis at SGD is quite intense and in-depth. Every change needs to be analysed by every department and the departments gather in a meeting called the CRB to discuss proposed change and how it impacts their department. If there were any questions regarding the change that was unclear from the CR and CO, this is asked in the CRB. The CRB is organised by the CM controller and is chaired by the person that raised the change. The CM controller takes minutes of the meeting. After the CRB the actions in the minutes must be completed before the next CCB and if all the checklists are correct, CM adds these checklists with the minutes of the meeting to the CR on the PLM system. This ensures that one can always refer back to the impact analysis of the change when one needs to.

4.3.6 Change Control Board

The CCB at SGD is a forum that meets every Friday to discuss the changes that have been reviewed in the CRB in the week. The CCB consists of the D&D manager as the chairperson and a CM controller as the secretary taking minutes of the meeting and showing that the changes were signed off by all members. The board further consists of SE manager, PE representative, production manager, ILS manager, ISS manager, design office manager and the CM manager as permanent members. The initiator of the change is a non-permanent member and attends the CCB to present the change they have raised. During the CCB the board looks at the affected configuration items and documents and does spot checks of the CRB to see if all actions are complete from the minutes. Furthermore, they check if the CRB was held,

the minutes and the checklists are attached to the change. Then it is verified if all role-players from the CRB signed off the change. If everything is correct and everyone agrees, the change passes CCB and after the meeting is signed off by the D&D line manager.

4.3.7 Change Implementation

After the change is approved and the drawings are updated, the change is implemented via a CIB. The CIB reviews how the change will be implemented in production or maintenance or both. The initiator of the change writes an EO and sends it to the CM controller. The CM controller notifies the MPS who then calls a CIB meeting where all the signees are present. The signees are the initiator of the change, and representatives from the following departments: program management, planning, production, system engineering, ISS, product management, PE and CM. The EO form explains what needs to be done to implement the change. It states precisely which serial numbers are affected and how the version of the updated parts change and how things need to be marked. It indicates if the change is for production units, support units or both. For units in maintenance that need to be changed, the EO specifies which serial number needs to be changed in what way – in filed, recall or retrofit during maintenance. The EO also has a field where the operator signs off that actions have been done and where QC sign that they have checked the work. This EO becomes part of the build history file of the unit.

4.4 Analysis and Discussion

4.4.1 Introduction

The theoretic pattern has been established in section 2.6 and the observed pattern has been explained in section 4.3 The gap analysis will now be done on each topic with an explanation of the result after each table. The “X” under

the headings “Theoretic Pattern” and “Observed Pattern” indicate that the relevant topic is done in the equivalent realm. Matches will be established and differences discussed.

4.4.2 Raising ECs

Table 4-4: Gap analysis on raising ECs

Theoretic Pattern	Pattern Matching Topic – Raising ECs	Observed Pattern
X	Trigger	X
X	Knowledge management	X
X	Information required to raise the change	X
X	Classification	X
X	Company culture	X
X	Changes should be handled differently	
X	Pre-approval	X
X	Priority of change specified	X

The only difference found between theory and practice is, in practice at SGD there is one way of raising changes while in theory, it is written that changes could be raised differently depending on the size of the change. Alblas & Wortmann (2010) state that engineering change planning should have a different strategy for large, complex changes than for small, low impact changes. However, in a practical environment, this becomes difficult to manage and allows large, complex changes to be handled in an easier way too. If such a policy should be incorporated, just management of the process will need to be defined and employed.

4.4.3 Impact Analysis

Table 4-5: Gap analysis on the impact analysis

Theoretic Pattern	Pattern Matching Topic – Impact Analysis	Observed Pattern
X	Engineering analysis	X
X	Supply chain analysis	X
X	Program management analysis	X
X	Cost analysis	
X	Service impact analysis	
X	Manufacturability	X
X	Formal change impact analysis	X
X	Cross-functional team	X
	Program management analysis	X
	External impact	X
	System engineering impacts	X
	ILS impacts	X
	Project management	X
	Maintenance impacts	X

SGD complete a strong impact analysis as part of the engineering change process. The cross-functional departments involved in the CRB each have their own checklists with multiple questions. These documents were part of the document analysis for this study. More topics are analysed than are discussed in the literature found for this study. Some interviewees, however, argue that the process is not done correctly or not always done. The ISS interviewee stated that it is not always checked what is already delivered to a customer or in the field. Better management and control of serial numbers could help to better. The product management representative said that the impact analysis is not always done because it is very difficult to do an

analysis on history. It is difficult to determine if a historical client orders a package again, will he want the updated product, or whether he will be able to use the updated, changed product. This is because most of the products designed and built at SGD are part of a bigger system and an updated part might not be backwards compatible with the old version of the system.

4.4.4 Priorities

Table 4-6: Gap analysis on priorities

Theoretic Pattern	Pattern Matching Topic – Priorities	Observed Pattern
X	Setting priorities at assessment of the impact	X
X	Priority category	X
X	Setting priorities when raising change	X
X	Dependent on cost	
X	Dependent on customer satisfaction	X
X	Dependent on effect on lead time	X

At SGD the priority of a change is set when the CR is raised. The priority is discussed at the change review board meeting and if it needs to be updated, it will be done in this meeting. The changes are dependent on customer satisfaction because if a change holds back a customer delivery, it will be handled with urgency and fast-tracked through the process. The priority categories at SGD are defined as “emergency, urgent and routine”. The priority of a change at SGD is not dependent on cost. This could be the case when a change is an improvement and the return on income, if the change is implemented, is very good. SGD, however, does not have a policy or procedure for handling such a change, as it is a rare occurrence that a product would change for pure improvement. There either would need to be a business case and customer for the new, improved product or the change would have to happen due to a legal requirement or regulation changes.

4.4.5 Cost of the Change

Table 4-7: Gap analysis on cost of change

Theoretic Pattern	Pattern Matching Topic – Cost of the change	Observed Pattern
X	Consequences cost analysed	X
X	Impact of change defined by cost of change	
X	Cost of change in lifecycle increases	X
X	Different cost categories	
X	Cost analysis	
X	Cost management department approve cost	X
X	Man hours cost	X

The cost of a change is not fully analysed at SGD. As described in the previous section, the priority is not established on the grounds of the cost of the change. Neither is the impact of the change defined by the cost of the change. The only cost that is assessed as part of the change is the cost of the items that need to be reworked or scrapped as a result of the change. Other than that an estimation is done how much the physical product change will cost. By experience, it is known at SGD that a software release to change a system is very expensive. There is a basic cost estimate for such a change. The project manager must keep track of the cost, but it is difficult as there are many layers of costs at SGD.

4.4.6 Change Review

Table 4-8: Gap analysis on change review

Theoretic Pattern	Pattern Matching Topic – Change Review	Observed Pattern
X	Review before disposition	X
X	Differentiate review by class	
X	Interdisciplinary team	X

Each change at SGD is reviewed by a CRB before it gets sent to the CCB. It helps to keep the CCB meeting short because if a change has been reviewed, everything is in place for the CCB to approve a change. The CRB at SGD consists of an interdisciplinary team. Every member of the CRB has to do the impact analysis of their department before going to the CRB. At the CRB the impacts are reviewed and discussed. SGD doesn't do different reviews for changes of different classes. This could be a suggestion for improvement. Sometimes the information in the CR is not written clearly enough or is not explained well enough for an analysis to be done properly. Then the CRB has to be rescheduled because the impact analysis has been completed incorrectly.

4.4.7 Change Control Board

Table 4-9: Gap analysis on change control board

Theoretic Pattern	Pattern Matching Topic – Change Control Board	Observed Pattern
X	Collaboration	X
X	Authority review and decide upon change	X
X	Documentation at Board	X
X	Cross-functional CCB	X
X	Engineering Team to approve	X

The CCB process at SGD is implemented very well and according to the theoretic pattern, includes all the topics that make up a good CCB. The CCB is a forum after the CRB that makes the final decision if the change should be implemented. The CCB, like the CRB, is an indicator of good collaboration between the departments involved in an EC at SGD. It is a cross-functional team made up of managers and the initiators of the change join when their change is being reviewed. In the review, spot checks are done to see if the change process was followed and the CCB chairman approves the change. If anything was missed in the CRB, the permanent members of the CCB could pick this up.

4.4.8 Change Implementation

Table 4-10: Gap analysis on change implementation

Theoretic Pattern	Pattern Matching Topic – Change Implementation	Observed Pattern
X	IT systems different - danger	X
X	Rules for implementation	X
X	Verification of change	
X	Cross-company process for implementation	X
X	According to classification	X
X	Formal plan/document	X
X	Immediate Implementation	X
X	Batch implementation	X
X	External notification	X

Change implementation at SGD is done by holding a CIB and releasing an EO. The CIB consists of cross-company departments affected by the change and the EO is signed off by all the members of the CIB. The EO contains the rules of the implementation. It is a document that, if applied correctly by the planner, gets changed into a formal plan. The classification of the change determines how the change gets implemented. Mostly changes on products get implemented immediately and rarely a batch of ECs will be implemented with one EO.

The systems engineer and the product/program manager are the direct contacts to the customer. They are part of the CIB and should ensure that a customer gets an EO with instructions of change implementation. Mostly the changes get communicated to an external customer when it is raised

because if it is a class 1 change in the military specification, the customer has to approve the change.

SGD has two different PDM system for drawings of products – one for the electronic design of a board and another for the mechanical design of a product. These systems are not linked directly to the ERP system. The missing link between the system could result in products being produced with old, not updated documentation.

The process of the CIB works well, but what happens after the CIB is not always verified. The verification of the change is done when the advanced test procedure of a product is a pass. This verification is a technical verification. An audit of the implementation of the change is however not done and this could be considered an improvement for the change.

4.5 Conclusion

The EC process at SGD is a stable process where good practices are implemented. When raising an EC, all information required by ISO (2017) is taken into consideration. The impact analysis is a robust process, which, when implemented correctly with the change review, can ensure the smooth implementation of an EC. The cost of the change is an area where SGD could improve. SGD could also consider scaling and tailoring the change review process for different types of changes. The CCB is a stable process which happens once a week so that as many changes as possible get processed on a weekly basis. The change implementation has a stable process and when implemented correctly and all roles and responsibilities are clear, ensures that the changes at SGD are implemented efficiently. The improvements to SGD will be explained in the next chapter and the research will be concluded.

5 Discussion and Conclusion

5.1 Introduction

The aim of this chapter is to verify that the research question has been answered, to review if the objectives of the research have been met and to summarise and explain the improvement possibilities to SGD. After the list of improvements has been created, the implication of the study will be analysed. The chapter concludes by examining the limitations that influenced the results and to determine if the recommendations for future research.

5.2 Study conclusions

The research report is conducted to answer the research question:

How can the engineering change process at Saab Grintek Defence (SGD) be improved?

Furthermore, the objectives of the research report are determined as follows:

1. To develop a theoretical framework for engineering change management
2. To establish the change process that is currently being used at SGD.
3. To perform a gap analysis between the theoretical EC process and the EC process performed at SGD.
4. To establish areas where the EC process at SGD can be improved
5. To recommend improvements of the current EC process at SGD

Chapter 2 contains the literature study. In section 2.5 the theoretical and analytical frameworks of the study were created. This analytical framework

is used to do the final analysis of the study and forms part of the case study protocol. The theoretical framework includes the following topics:

1. Raising ECs
2. Impact analysis
3. Priorities
4. Cost of the change
5. Change review
6. Change control board
7. Implementation

In section 2.6 the theoretical realm of these points was explored. The data of the literature review was analysed using content analysis, and from this, the theoretical patterns were created.

In sections 4.2 and 4.3 the change process that is currently being used at SGD was established and explained. This aided the researcher and the reader understand the environment of changes.

In section 4.3 the observation realm of the ECM process at SGD was explored using the information from the semi-structured interviews and the analysis of the documents. This information was analysed using content analysis and

In section 4.4 the gap analysis was done using Trochim's framework for pattern matching. In the analysis and discussion at the end of each topic, areas for improvement were identified. These will be discussed in the following section.

5.3 Improvement Opportunities

The last objective is to recommend improvement of the current EC process to SGD. The areas where the change process at SGD can be improved have been found in section 4.4. Multiple improvement

opportunities were found and stated in the gap analysis. The following improvement opportunities highlight the ones that the researcher believes SGD can work on to better their process:

1) **Raising ECs:** SGD could consider handling different types of changes with a different process. This could help to streamline “easy” changes and use the resources to analyse big changes. A control system would have to be implemented to ensure that changes that need to follow the conventional process are not being pushed through the quick process.

2) **Impact analysis:** A minor improvement would be to send the completed D&D checklist with the information on the CR in the invitation to the CRB. This would ensure that everyone completely understands the change and the impact of design characteristics before filling in their checklist. Sending the D&D checklist earlier should speed up the process because the communication will be improved and there will be fewer checklists that need to be updated with information, that was not known before the CRB, after the meeting.

3) **Priorities:** If found necessary, the EC could be prioritised according to the cost of change. This already indirectly happens when the company would have to pay large amounts of money in fines for delivering products or systems late. In this case, changes get prioritised as urgent.

4) **Cost of the change:** SGD should consider calculating the first-order and second-order cost of a change as described by Subrahmanian et al. (2015). Analysing the complete cost of a product will help project managers to plan for changes in future projects. The cost of calculating the cost of change should also be

taken into consideration. It would be good to have a template create which calculates the complete cost of the change.

5) **Change review:** This improvement idea is linked to the improvement idea of raising the ECs. The change review could be different for different types of changes. Sometimes not all cross-functional teams are needed in a CRB and this results in unnecessary money being spent on resources. Rules should be created for types of changes and the change control board could verify if the rules were followed.

6) **Change control board:** The CCB is implemented according to all the topics found in the study and executed accordingly at SGD. Here no improvement was found.

7) **Change implementation:** The change implementation can be improved immensely at SGD. The EO form should be redesigned to be more user friendly and a mechanism should be installed to ensure the change is implemented and verified in a correct manner. SGD could possibly consider digitalising the implementation of the EO process on the new ERP system and making it a workflow in the system. Verification or audit could also be implemented on the documentation that is affected by the change. Because SGD has a PDM and an ERP system which are not linked to each other, the chance that a product is manufactured with an outdated drawing exists.

5.4 Implications of this Study

This study has been designed to compare the EC process of a company with the theory written on the subject. Even companies that design complex products and systems are required to improve their design (Zheng et al., 2015). This could be done as customer requirements

increase or to have a competitive market portfolio. Furthermore, the lifecycle of products steadily decreases and the time it takes to market becomes a competitive factor (Storbjerg et al., 2016). This means that ECs are inevitable and a good process of implementing changes is needed to ensure that the company stays competitive. In their document on configuration ISO 10007, ISO gives guidance on how a change should be implemented. The defence companies have to comply with this standard, but it does not ensure an effective change process.

Storbjerg et al. (2016) have created a maturity model for ECs. According to them, there is very little literature on ECM that gives comprehensive guidance for improvement. Their model provides the reader with an idea of different categories of engineering changes, but it does not guide how to improve the maturity of each category. This study was designed to find improvement topics for each step in the change process.

Hamraz et al. (2013) identified the need for further research on engineering changes to be performed on organisational issues. The framework created and each framework for the topic can be used by other companies to do a study on their change process. The case study protocol can be found in Appendix F and can be used by companies to do such a study. Further research could be done worldwide and this research could be used to compare the EC processes of companies worldwide.

SGD has an excellent EC process and they can use the list of improvement opportunities to address the shortcomings found in this study. Processes are continually improving and every small improvement implemented could make a difference in ensuring the changes get implemented without causing delays. The goal of ECM is to integrate changes into the product development cycle with as few disruptions as possible (Iakymenko et al., 2018).

5.5 Limitations of Results

The following limitations of the study were realised when assessing the results:

1) The case study was only completed at one company in the defence industry in South Africa. The results are not an indication of how ECM is done in the defence industry in South Africa nor throughout the world. The Swedish company, Saab, owns SGD, so the high-level EC process is the same for all the companies of Saab across the globe. How it is implemented in every plant though could be very different.

2) Most of the interviewees have worked at SGD for more than ten years. Bias of the interviewees could be present because they know each other very well and they could be afraid to state their honest opinion in case someone finds out. To mitigate this thinking, each interviewee signed a confidentiality agreement where the researcher has promised to keep them anonymous.

3) The researcher has worked at SGD for more than five years when doing the study and with the change process for more than two years. Bias could have been part of the design of the study, but appropriate steps were made in the methodology section to minimise this and ensure the validity of the study.

5.6 Recommendations for Future Research

1) The case study protocol found in Appendix F can be used to expand this research to other cases in South Africa but also worldwide. If the study is done in a significant amount of companies, a quantitative study could be done on the maturity of the EC process in companies.

2) This study could be expanded to include all EC characteristics and not only the steps of the EC process.

3) A study to determine the real cost of a change can be done. The costing of a change is a complicated task and it could be beneficial to SGD to have all cost aspects analysed in an academic study.

4) More research is needed in the field of impact analysis. It could be of value to know all the impacts that should be thought of when implementing a change.

5.7 Conclusion

This chapter shows that the research question was answered and the five objectives of the research were achieved. It reminds the reader of the research question and objectives, proves that these were answered and contains the final answer - the list improvement opportunities. It ends off with the implication of the study as well as the limitations to the study and recommendations for future research.

6 References

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Appendix A

09 January 2018

Dear Madam/Sir

Participation in Research on Engineering Change Management Implementation at a South African Defence Company

I am a part-time MSc student in the School of Mechanical, Industrial and Aeronautical Engineering at the University of the Witwatersrand, under the supervision of Mrs Teresa Hattingh. My MSc title is: *Engineering Change Management Implementation at a South African Defence Company.*

Based on research done, the engineering change management process in companies is tailored specifically to suit the type of business. As Saab Grintek Defence is an engineer-to-order and make-to-order company, I would like to analyse how the engineering change management process at this company compares to the engineering change management process in theory. This should help to create an understanding why SGD performs the engineering change process in the manner it does and help identify areas of improvement in the engineering change process.

I would like to formally invite you to participate in this study. As an employee of Saab Grintek Defence and a role player in the engineering change process, your knowledge and experience would contribute significantly.

The study will be conducted between January and March 2018. Involvement in the study would entail one face-to-face interview of approximately an hour and a half with you, at your convenience. During these interviews I would like to understand how your company operates, map the current engineering change management processes, and understand more about the issues faced in the daily operations of your business (specifically within the engineering change process) and how you manage these issues. The interviews would be conducted at your company.

Participation in the study is voluntary, and you may withdraw at any time. Anonymity (regarding company name and any owner/manager/employee names) and confidentiality of information provided will be assured and respected. I would like to record the interviews, so I can later

transcribe them. Your consent at the time of the interview will be requested. If you do not wish the interviews to be recorded this will be respected.

The results of the study will form part of my MSc dissertation report, and may also be reported in academic papers and at conferences. A summary of the results of the research will be made available to you on request.

Please contact me if you have any questions regarding the research and participation in the study.

I look forward to hearing from you.

Yours faithfully

Nicola Johannes
Tel: 0833201679
Email: nicola.johannes@gmail.com

Supervisor: Teresa Hattingh
Teresa.Hattingh@wits.ac.za

Appendix B

Letter of Consent

I, _____, agree to participate in the MSc research entitled *Engineering Change Management Implementation at a South African Defence Company* to be undertaken Nicola Johannes under the supervision of Mrs Teresa Hattingh, and certify that I have received a copy of this letter of consent.

I acknowledge that the research has been explained to me and I understand what it entails, as follows:

1. I agree to allow access to my company and manufacturing facilities for the purpose of this research.
2. There will be one interview, which is expected to take no more than 1.5 hours.
3. The interviews will be audio taped, and transcribed for analysis by the researcher.
4. The processes of the engineering change process in my company will be mapped.
5. I have the right to withdraw my assistance from this project at any time without penalty, even after signing the letter of consent.
6. I have the right to refuse to answer one or more of the questions without penalty and may continue to be a part of the study.
7. I may request a report summary, which will come as a result of this study.
8. I am entirely free to discuss issues and will not be in any way coerced into providing information that is confidential or of a sensitive nature.
9. Pseudonyms will be used to conceal my identity, and that of my company, my employees, my suppliers and my customers. The information disclosed in the interviews will be confidential.
10. Audio-tapes and transcripts will be kept securely stored during the research and after the research has been completed.
11. This project was approved by the Faculty of Engineering and the Built Environment of the University of the Witwatersrand and the School of Mechanical, Industrial and Aeronautical Research Ethics Committee (non-medical) of the University.
12. If I have any questions or concerns about my rights or treatment as a participant, I may contact the Chair of the School of Mechanical, Industrial and Aeronautical Research Ethics Committee.

Signed:

_____

Date:

_____

Questions concerning the study can be directed to:

Nicola Johannes
Tel: 0833201679
Email: nicola.johannes@gmail.com

Supervisor: Teresa Hattingh
Teresa.Hattingh@wits.ac.za

Appendix C

Student: N Johannes

Student number: 992817

Topic: *Engineering Change Management Implementation at a South African Defence Company*

Questions:

1. What are the change triggers experienced at SGD? Please elaborate.
2. Does SGD do an ECP pre-feasibility study on ECPs? Please explain.
3. When is an engineering change request raised?
4. How is an engineering change request raised?
5. When does SGD identify possible solutions to change requests – before or after approval?
6. When is the impact assessment done on the solution?
7. Please explain the impact assessment at SGD. What is important for you to assess?
8. Does the change at SGD get reviewed before sending it to the change control board? In your opinion, is this review useful?
9. Explain what happens in the Change Review Board at SGD?
10. Is there a forum or board at SGD that signs off the change?
11. Explain who the CCB consist of and what happens in the CCB?
12. Does SGD have an ECP coordinator and an ECP committee?
13. How do changes get implemented at SGD?
14. When do changes get implemented at SGD?
15. Does SGD review a change after implementation? Please explain when and how this is done.
16. Does SGD assess the cost of an ECP? Please explain when and how this is done.
17. Does SGD measure the impact of ECPs on quality? (How do ECPs impact product change frequency vs. product performance?)
18. Is the change implementation at SGD planned? How?
19. Which role players are involved in the change process at SGD?
20. Are changes prioritised at SGD? Please explain how.
21. When and how are changes communicated to the customer? Does the customer approve the change?
22. Does SGD have a process for emergency changes? When and how does this happen?
23. Does SGD scale and tailor the ECP process for different changes? Please explain.

24. Does SGD do status reporting (monitoring and controlling) of ongoing ECPs? Please explain.
25. Does SGD use formal metrics to track effectiveness of the change control process and have clear lead time targets? Please explain.
26. Does SGD use an Engineering Change Management System? Please elaborate.
27. Does SGD use a PDM/PLM system to manage the change? Please elaborate.
28. How does SGD communicate the changes to affected persons as soon as possible?
29. Does SGD make use of front-loading of ECPs?
30. What is SGD's ECP strategy?
31. How are SGD's ECP resources managed?
32. Does SGD do ECP competence management and training? Please elaborate.
33. Does SGD do continuous improvement and learning on ECPs? Please elaborate.

Appendix D



Document identity

Classification
COMPANY
RESTRICTED 1

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Human Resources

To Whom It May Concern

MSc (Industrial Engineering) Project: Company Consent and Support

Saab Grintek Defence (SGD) herewith gives permission and confirms that we will support Nicola Johannes with her research report in partial fulfilment of the requirements for a Master of Science in Industrial Engineering at the University of Witwatersrand.

The research topic is: Engineering Change Management Implementation at a South African Defence Company. It will focus on finding the differences between theoretical engineering change management and the actual practical engineering change management at SGD. The study will be beneficial to the organisation in terms of providing knowledge to improve and get complete understanding in engineering change management.

We reserve the right to review the report and any other documentation before publication due to company confidentiality.

For and on behalf of

Saab Grintek Defence (Pty) Ltd

01 03 26.

ELIAS NKONOANE

CONFIGURATION MANAGER

Saab Grintek Defence (Pty) Ltd

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Appendix E

Interview 1 – Design & Development

Questions:

1. What are the change triggers experienced at SGD? Please elaborate.
    a. To make a design more producible
    b. Obsolescence
    c. Findings from reliabilities – failures in field. Design changes needed to make it more reliable
    d. Process and procedures change
    e. To make things quicker and better
    f. Anything that is required (have to change)
    g. Anything that is an improvement
    h. To lower cost
2. Does SGD do an ECP pre-feasibility study on ECPs? Please explain.
    a. ECP is the CR, CO process in ECP. Now ECP is CR in IFS. The CR is the pre-feasibility study. Node manager that approves the CR should do the pre-feasibility study. Not so formal.
3. When is an engineering change request raised?
    a. Sometimes a lot of work happens before it is raised. Sometimes people raise it as a first step. Depends on person to person and situation to situation.
    b. It kick starts the change in theory
4. How is an engineering change request raised?
    a. In IFS. Fill in minimum required fields – reason for change, description of change, add node manager and design responsible person. Which part numbers, document numbers will change. Not always easy to differentiate for description of change and reason of change.
5. When does SGD identify possible solutions to change requests – before or after approval?
    a. If it is relatively simple, it gets done as in theory
    b. When it is complicated and there are lots of different opinions, it depends and lots of discussions are still.
6. When is the impact assessment done on the solution?
    a. During the Change Review Board where all different stakeholders put in their checklists with their assessments
7. Please explain the impact assessment at SGD. What is important for you to assess?
    a. Minor/Major Change
    b. Form Fit Function
    c. Interchangeability

    d. Recall needed
    e. Cost
    f. Schedule for production implementation is important
    g. Requalification needed?
    h. What needs to be updated or impact
    i. Impacts on other products
    j. Different areas are involved D&D, Development, ILS, Maintenance, ISS, Project Management and Supply Chain are all involved
8. Does the change at SGD get reviewed before sending it to the change control board? In your opinion, is this review useful?
    a. Yes, in the CRB and yes it is useful
9. Explain what happens in the Change Review Board at SGD?
    a. See above
10. Is there a forum or board at SGD that signs off the change?
    a. Yes, CCB
11. Explain who the CCB consist of and what happens in the CCB?
    a. Permanent members of the CCB. D&D line manager chairman, Systems eng, supply chain, logistics, maintenance, configuration. Non-permanent – the initiator/owner of the change
    b. What happens: The initiator of the change explains the reason and description of change. We look at affected items and documents and do spot checks of CRB to see if anything was minutes. Check if the CRB was held, minutes and documents all there. Check approvals. Permanent members can interrogate if there are any questions. Verifies if the process of change was followed until CRB.
12. Does SGD have an ECP coordinator and an ECP committee?
    a. Coordinator is CM, they coordinate the change. They do the checks and manage everything until CCB.
    b. Committee is the CRB members per change.
13. How do changes get implemented at SGD?
    a. Change Implementation Board managed by the Master Production Scheduler. Engineering Order is created where you look at if you scrap, rework. From which serial number is the change implemented.
    b. If design office need to implement something, everything needs to be in place for them to implement.
14. When do changes get implemented at SGD?
    a. It depends on the engineering order. Do analysis of serial number. Different serial number will be implemented at different times.
    b. Do we ever implement a change before having a formalised change? The rule is there will be an EO but we cannot ship anything before the change is not formalised and finalised.
15. Does SGD review a change after implementation? Please explain when and how this is done.

    a. Not consistently do this. On events this gets done. When a problem was solved but it surfaces again, then you will go and review the change to see if there was anything done. This does not get done for every change. Potentially we should once or twice a year have a general review of the changes with the big impacts and see if the change helped and see lessons learned.
16. Does SGD assess the cost of an ECP? Please explain when and how this is done.
    a. This has been done in the past on all the different angles of the change. There are cost questions, but they are not very detailed. Physical cost of the product assessed, not the project cost. Should look at all the effort cost going into the change versus the benefit of the change. Should happen at a feasibility change. If it were an improvement change, we should check the ROI but we don't do this yet.
17. Does SGD measure the impact of ECPs on quality? (How do ECPs impact product change frequency vs. product performance?)
    a. No we don't
18. Is the change implementation at SGD planned? How?
    a. Yes, as part of the CIB process
19. Which role players are involved in the change process at SGD?
    a. Already answered
20. Are changes prioritised at SGD? Please explain how.
    a. Yes, the ones that are holding up production get first priority. And the ones that hold up shipping to the customer
21. When and how are changes communicated to the customer? Does the customer approve the change?
    a. Different customers have different contracts and require to see all changes.
22. Does SGD have a process for emergency changes? When and how does this happen?
    a. Yes, we do. We have a change policy/procedure document. There you can request emergency change and emergency CCB and we have done that. Otherwise the CCB only sits once a week on Fridays.
23. Does SGD scale and tailor the ECP process for different changes? Please explain.
    a. No
24. Does SGD do status reporting (monitoring and controlling) of ongoing ECPs? Please explain.
    a. It is done within programmes and projects and the project manager should keep an eye on this.
25. Does SGD use formal metrics to track effectiveness of the change control process and have clear lead time targets? Please explain.
    a. No, but CM has done some work on this.
26. Does SGD use an Engineering Change Management System? Please elaborate.

    a. Yes, IFS
27. Does SGD use a PDM/PLM system to manage the change? Please elaborate.
    a. There are better tools that we can use but it cannot be done easier. I don't think the change is connected on the PDM/PLM system. So no automatic interface. Would love to have a system where everything happens complete.
28. How does SGD communicate the changes to affected persons as soon as possible?
    a. Inside the company – the formal way CRB, CCB, CIB
    b. Outside the company – clients and suppliers, communicated by supply chain manager and system engineers and programme managers communicate to the clients according to the clients progress.
29. Does SGD make use of front-loading of ECPs?
    a. To improve up-front? Then yes, we do that instead of changing and then checking
30. What is SGD's ECP strategy?
    a. Policy of strategy on changes that Elias is the owner of
31. How are SGD's ECP resources managed?
    a. By the project and line managers
32. Does SGD do ECP competence management and training? Please elaborate.
    a. More informal within Design and Development.
33. Does SGD do continuous improvement and learning on ECPs? Please elaborate.
    a. Yes, we do. We do change things and update checklists etc. But no formal meeting once a year to look at improvement. More a meeting when we realise there is room for improvement. Meeting with D

Interview 2 – Configuration Management

Questions:

1. What are the change triggers experienced at SGD? Please elaborate.
    a. Need for improvement
    b. Non conformance
    c. Problem identified by a customer
    d. Problem identified in the production line
    e. Deviation – didn't meet spec previously
2. Does SGD do an ECP pre-feasibility study on ECPs? Please explain.
    a. CC1 change process, design responsible and node manager make the decision if there is a need for the change and that opens the door. They make the pre-study to see if there is a need to take it further.
    b. How? It is a discussion between the person that raises the change and the design responsible and node manager.

3. When is an engineering change request raised?
    a. In product lifecycle – when you start building your qualification unit. Need to know the build state of the product when building the qualification units so that is why it starts then.
4. How is an engineering change request raised?
    a. It is raised by anybody in the company, raised on the configuration system which is currently IFS
5. When does SGD identify possible solutions to change requests – before or after approval?
    a. Before approval, after approval the cost would skyrocket
6. When is the impact assessment done on the solution?
    a. Before the approval of the change
7. Please explain the impact assessment at SGD. What is important for you to assess?
    a. Assess impact on production.
    b. What are the units that were delivered – also MRO
    c. Issue of procurement, what are the orders that were raised
    d. Technical solution of problem – technical impact
    e. Maintenance
    f. Training
8. Does the change at SGD get reviewed before sending it to the change control board? In your opinion, is this review useful?
    a. Yes, Change Review Board before Change Control Board. Multi-disciplinary forum to assess the impact of the change. I think it has improved our changes a lot so it is useful. Everybody assesses its impact before it goes to the CCB
9. Explain what happens in the Change Review Board at SGD?
    a. Different checklists for different disciplines. Reviewed for how the different departments check the impact of the change on their department/field. Everything is recorded. Minutes held and the documents are kept in the configuration system linked to the change.
10. Is there a forum or board at SGD that signs off the change?
    a. CCB
11. Explain who the CCB consist of and what happens in the CCB?
    a. The design and development line manager is the chairman
    b. Configuration is the secretary
    c. System integration
    d. Production
    e. Supply Chain (Production Engineering)
    f. ILS
    g. MRO
    h. Drawing Office

    i. The CCB reviews the directive that is coming from the CRB and after reviewing they review if the process was followed during CRB and if there are any open actions and then they approve the change
12. Does SGD have an ECP coordinator and an ECP committee?
    a. Coordinator is the CM person
    b. The committee is the people that sit in the CRB and CCB
13. How do changes get implemented at SGD?
    a. After the baseline has been updated, there is a change order that is created, then the CIB reviews how the change will be implemented in production
14. When do changes get implemented at SGD?
    a. At different stages, depending on the change and the engineering order giving the instruction
15. Does SGD review a change after implementation? Please explain when and how this is done.
    a. There are test results that are done. Document reviews get done. Review of the implementation is the test result and first article inspection if it was a big change. Re-qualification could be a directive from the change review board.
16. Does SGD assess the cost of an ECP? Please explain when and how this is done.
    a. No, we do an estimation.
    b. How? How much the physical product change costs thumbsuck
17. Does SGD measure the impact of ECPs on quality? (How do ECPs impact product change frequency vs. product performance?)
    a. I think yes, because we are maturing the product with the change process. We do measure how many changes were raised per product but not directly how it influences quality
18. Is the change implementation at SGD planned? How?
    a. Yes, because of the CIB and it is written in the EO
19. Which role players are involved in the change process at SGD?
    a. Previously answered
20. Are changes prioritised at SGD? Please explain how.
    a. Emergency change, but all our changes are late because we are maturing the product in production. We don't have the luxury of changing products to improve the product, but mostly for maturing the products.
21. When and how are changes communicated to the customer? Does the customer approve the change?
    a. If it class 1 and if it affects external form, fit and function of the product, i.e. the interface with the customer is affected so then we will send it to the customer.
22. Does SGD have a process for emergency changes? When and how does this happen?

    a. We haven't had emergency changes w.r.t the military standards in SGD. Emergency changes (according to military standards) are changes that ground the aircraft. Our type of products don't ground the airplane. Our emergency changes are about speed and not about averting a crisis.
23. Does SGD scale and tailor the ECP process for different changes? Please explain.
    a. No, one change for everything. We don't have a fasttrack process because everyone would chose that way.
24. Does SGD do status reporting (monitoring and controlling) of ongoing ECPs? Please explain.
    a. In IFS Lobby we have charts that show us the status.
    b. Monthly meetings with the CM and the TDA are
    c. CM have their own change pulse meeting every Wednesday.
25. Does SGD use formal metrics to track effectiveness of the change control process and have clear lead time targets? Please explain.
    a. Part of the performance appraisal of the CM people. How long does a change take from generation to approval (Gate 1), approval to gate 2 and gate 2 to closure. We used to have this in eB. Has been lost in IFS.
    b. KPIs of the CM from generation of change to CCB should be 7 days.
    c. How long it takes to implement is not measured in CM
    d. We should measure from CCB to closure but difficult to measure in IFS.
26. Does SGD use an Engineering Change Management System? Please elaborate.
    a. IFS, we had to panel beat it a lot to make it similar to old process
27. Does SGD use a PDM/PLM system to manage the change? Please elaborate.
    a. IFS
28. How does SGD communicate the changes to affected persons as soon as possible?
    a. First they become part of the CM
    b. Then the engineering order is used to communicate it officially.
    c. MRB triggers
29. Does SGD make use of front-loading of ECPs?
    a. ?
30. What is SGD's ECP strategy?
    a. For CM we must be able to accommodate change.
    b. We must be able to control change, but controlling does not mean stopping change
31. How are SGD's ECP resources managed?
    a. Too wide
32. Does SGD do ECP competence management and training? Please elaborate.
    a. When a new person arrives we have some presentation slides. Done by configuration manager.
    b. Competency matrix of CM department
33. Does SGD do continuous improvement and learning on ECPs? Please elaborate.

a. Yes, definitely we are doing that. Looking at new methods that are being used outside. Search on the internet. Attend CC conferences and meetings. Process Methods and Tools that we have with our Swedish CM and consulting different standards. Using ISO 10007.

Interview 3 – Supply Chain

Questions:

1. What are the change triggers experienced at SGD? Please elaborate.
    a. Obsolescence
    b. Design Change due to inefficiencies
    c. Redesign for customization
    d. Manufacturability
2. Does SGD do an ECP pre-feasibility study on ECPs? Please explain.
    a. We do raise non-conformances and the NC triggers an ECP or Use as Is depending on the details taken into consideration what has been said in the NC. It is not a formal board but it gets taken into consideration in the engineering domain
3. When is an engineering change request raised?
    a. MRB can trigger it
    b. Raised before we implement. After there was a forum of an informal review whether it is feasible.
    c. Is it always before implementation? No, sometimes in field changes (eg software) will be done before the change is formalised.
4. How is an engineering change request raised?
    a. ERP system is used to create and track the change request
5. When does SGD identify possible solutions to change requests – before or after approval?
    a. Usually done after the ECP is raise. But mostly they know what they want to do.
    b. It also depends on the scenario
6. When is the impact assessment done on the solution?
    a. During the change review board. The change request is generated. The involved parties are informed and then the different fields go into their speciality and assess the impact
7. Please explain the impact assessment at SGD. What is important for you to assess?
    a. From a supply chain perspective:
    b. Operational requirements: stock, WIP, open orders, impact on subcontractors, impact on direct production, impact on product costing, production delays, test infrastructure impacts.

8. Does the change at SGD get reviewed before sending it to the change control board? In your opinion, is this review useful?
    a. It is done at CRB. Depends on EC coordinator to coordinator whether it is done properly. It is mostly useful – in some cases, we don't have the relevant information at the right time. You do (as supply chain) need the info from engineering before you do the impact assessment. Should be a staggered delivery of impact and not a parallel process. Could be improved by enforcing a better use of description and reason for change. Could also have a method of sharing information during the process of filling in the form before the meeting and the meeting would be quicker. So the current way leaves a lot of room for still having to change checklists after CRB.
9. Explain what happens in the Change Review Board at SGD?
    a. We go through all the change review checklists per department and discuss the interconnection between the change and the department. A number of CRBs already had to be cancelled because information was misunderstood and we only realise it at CRB.
10. Is there a forum or board at SGD that signs off the change?
    a. CCB
11. Explain who the CCB consist of and what happens in the CCB?
    a. CCB Chairman, Config controller Secretary, all the relevant departments are present and they review the change that will be implemented and make sure that the right process was followed and everything was signed off.
12. Does SGD have an ECP coordinator and an ECP committee?
    a. ECP coordinator is Config Controller, Committee is the people involved in the CRB.
13. How do changes get implemented at SGD?
    a. With difficulty. Paper Engineering Order is written. A release note, Change implementation board. Doesn't work for me, because we sign off that the EO can be implemented but we don't follow through if it was implemented because there is no physical mechanism enforcing it.
14. When do changes get implemented at SGD?
    a. Ad hoc 😊. Changes get implemented after the ECP has been signed off at the CCB. Then the implementation process begins. Depends on the complexity of the change and the people involved (schedule and resources of people available). In field related engineering orders can take multiple years to implement because you could wait for a unit to come back and be updated during repair only.
15. Does SGD review a change after implementation? Please explain when and how this is done.
    a. I haven't seen it happen. Just design reviews happen and then release notes get signed by the review committee before approving the update in the system.

16. Does SGD assess the cost of an ECP? Please explain when and how this is done.
    a. Previously looked at how many people are involved and how many man hours are used, but not necessarily the hardware cost. They estimated drawing office and ILS times but not the cost of real implementation.
17. Does SGD measure the impact of ECPs on quality? (How do ECPs impact product change frequency vs. product performance?)
    a. I haven't seen anything like that before. QA is part of the forum but they don't perform an analysis like that.
18. Is the change implementation at SGD planned? How?
    a. Do you have WIP, is it in field, what needs to happen. The engineering order needs to specify what needs to happen, when. Sometimes it happens that the engineering orders don't get released.
19. Which role players are involved in the change process at SGD?
20. Are changes prioritised at SGD? Please explain how.
    a. Based on customer related issues and whether the customer will allow the change and hopefully on production urgencies. There is no set change review period.
21. When and how are changes communicated to the customer? Does the customer approve the change?
    a. If it is a change where the customer is directly impacted, the customer has to approve the change. This is managed by the programme manager – form/email sent to customer
22. Does SGD have a process for emergency changes? When and how does this happen?
    a. Still follow ECP process but fast track it. Happens when there is a dire situation and have special CRBs, CCBs and CIBs
23. Does SGD scale and tailor the ECP process for different changes? Please explain.
    a. No difference in method
24. Does SGD do status reporting (monitoring and controlling) of ongoing ECPs? Please explain.
    a. We have a dashboard in IFS which config manages and reports back on to a higher authority.
25. Does SGD use formal metrics to track effectiveness of the change control process and have clear lead time targets? Please explain.
    a. You mentioned that they have. Effectiveness measurement not properly adressed
26. Does SGD use an Engineering Change Management System? Please elaborate.
    a. IFS. CR and CO with linked documents and items that need to be change
27. Does SGD use a PDM/PLM system to manage the change? Please elaborate.
    a. Partially. IFS does this partially. It is not as effective on IFS as it was in eB. No direct link yet to structure

28. How does SGD communicate the changes to affected persons as soon as possible?
    a. Via email (the EO gets sent via email). MRB meeting and hopefully the meeting in that MRB meeting would relate it to the other relevant personnel
29. Does SGD make use of front-loading of ECPs?
    a. No (concurrent engineering definition?)
30. What is SGD's ECP strategy?
    a. Don't know. In order to reduce the number of changes we should look at a 3 month bucket window.
31. How are SGD's ECP resources managed?
    a. There is no cross functional matrix here. Still by their own management
32. Does SGD do ECP competence management and training? Please elaborate.
    a. Mostly experiential training. Only training how to fill in form, but to understand the impact on your department there is no formal training.
33. Does SGD do continuous improvement and learning on ECPs? Please elaborate.
    a. Probably have changed the format twice in 10 years so very little. But we changed the entire system 3 times in the 10 years.

Interview 4 – In-Service Support

Questions:

1. What are the change triggers experienced at SGD? Please elaborate.
    a. Cannot repair because of not being available to get the part or the subpart
    b. Obsolescence
    c. Cannot replace
2. Does SGD do an ECP pre-feasibility study on ECPs? Please explain.
    a. Effects analysis is done, reporting analysis is not done. Helps us to see where the part is used
3. When is an engineering change request raised?
    a. When the baseline was changed
4. How is an engineering change request raised?
    a. IFS. Maintenance raises a complaint or an issue, not a change request
5. When does SGD identify possible solutions to change requests – before or after approval?
    a. After the change request. Change would be raised and then possible solutions would be looked at.
6. When is the impact assessment done on the solution?
    a. We don't do that properly. We don't always check the impact of the items that are in field. It is on the checklist for change review. The company does not know what they delivered (the engineers).
7. Please explain the impact assessment at SGD. What is important for you to assess?

    a. How, when and where must the change be done. In field? Do we need to recall?
    b. Customer notification – EASA or Part 154? Is this going to ground planes?
    c. Do we retrofit anything in limbo at the moment? Between production and delivery?
    d. What must be done to delivered units? Must it be done in field, maintenance or recall? We are missing the stock being available when we retrofit during maintenance.
8. Does the change at SGD get reviewed before sending it to the change control board? In your opinion, is this review useful?
    a. It does happen. Change Review Board. Yes, useful
9. Explain what happens in the Change Review Board at SGD?
    a. Review the process and the different areas
10. Is there a forum or board at SGD that signs off the change?
    a. Ja, the CCB
11. Explain who the CCB consist of and what happens in the CCB?
12. Does SGD have an ECP coordinator and an ECP committee?
    a. Coordinator is project manager – he needs to make sure this change is implemented
    b. Committee is the people working on the project
13. How do changes get implemented at SGD?
    a. Engineering order or updated documents. As maintained data is a big thing for EASA Part 145. If this as-maintained doc pack changes, we need to send out a notification. But we don't send out internal service bulletins. Currently the as-maintained document does not exist in IFS (MRI doc pack).
    b. 2 shortcomings for SGD – maintenance checklist with ECPs and engineering order. Maintenance route sheet does not exist.
14. When do changes get implemented at SGD?
    a. Too late.
15. Does SGD review a change after implementation? Please explain when and how this is done.
    a. No, if there is not a follow on change then it does not get done.
16. Does SGD assess the cost of an ECP? Please explain when and how this is done.
    a. Partial yes
17. Does SGD measure the impact of ECPs on quality? (How do ECPs impact product change frequency vs. product performance?)
    a. No, we don't do that
18. Is the change implementation at SGD planned? How?
    a. We used to have ACNs. Advanced change notes. That is where you plan the implementation.
    b. Release and forget – Maintenance does not believe Eos get done properly.
19. Which role players are involved in the change process at SGD?

    a. Everybody. We don't have all the supply chain members necessary (like stores and procurement) in the change, depending on the change. Should be categorised so that people automatically get notified.
20. Are changes prioritised at SGD? Please explain how.
    a. No
21. When and how are changes communicated to the customer? Does the customer approve the change?
    a. Generally they do.
22. Does SGD have a process for emergency changes? When and how does this happen?
    a. No, not FAA, EASA, Part 145
23. Does SGD scale and tailor the ECP process for different changes? Please explain.
    a. No
24. Does SGD do status reporting (monitoring and controlling) of ongoing ECPs? Please explain.
    a. Yes we do, we have some of 207 days open because the customer rejected it
25. Does SGD use formal metrics to track effectiveness of the change control process and have clear lead time targets? Please explain.
    a. No
26. Does SGD use an Engineering Change Management System? Please elaborate.
    a. IFS
27. Does SGD use a PDM/PLM system to manage the change? Please elaborate.
    a. I think we do.
28. How does SGD communicate the changes to affected persons as soon as possible?
    a. Service bulletins should go to effected persons as soon as possible (this is for external changes)
29. Does SGD make use of front-loading of ECPs?
    a. ACNs. EW no, ACS does it. Avionics reviews everything before qualification is complete. EW built products to own specs and then sells. ACS sells products to customer's
30. What is SGD's ECP strategy?
    a. No idea, not available?
31. How are SGD's ECP resources managed?
    a. Line manager
32. Does SGD do ECP competence management and training? Please elaborate.
    a. Presuming CM has a document
33. Does SGD do continuous improvement and learning on ECPs? Please elaborate.
    a. We do it all the time. The learning we can do better.

Interview 5 – Systems Engineering

Questions:

1. What are the change triggers experienced at SGD? Please elaborate.
    a. First of lets distinguish between 2 categories of changes – product and baseline of customer object
    b. Product:
        i. Early release out to customer – development done to a certain level only when we already deliver to customer. So qualification is done but maturation still needs to happen
        ii. Improvement
        iii. Problems
        iv. Environmental issues (should not be but depends on market pressures)
        v. Obsolescence the older the product is, the more exponential changes
        vi. Production process related things
        vii. Change for MTOT or PTOT to change documents and minor things to product
    c. Customer Project:
        i. If project execution requires an early baseline, requirement changes, but they were planned because you were aware of early release.
        ii. Unplanned project changes: When there are difficulties in the contractual module and something does not work for the customer. This is risk because this is an insufficient model or bad management
        iii. Integration on a rig, don't need an ECP but still need change management for traceability. The moment you released anything you need formal change management
        iv. Observations are sometimes different on the simulator than on the aircraft and changes might then be triggered.
2. Does SGD do an ECP pre-feasibility study on ECPs? Please explain.
    a. Yes, it is not captured in our system though where the CR and CO get raised. It is done before
3. When is an engineering change request raised?
4. How is an engineering change request raised?
5. When does SGD identify possible solutions to change requests – before or after approval?
    a. Before the change approval. We cannot go to CCB and say I want to change something. By the time we are at CCB a solution needs to be in place.
6. When is the impact assessment done on the solution?
    a. It is done through the change review checklists. It is quite good now.

7. Please explain the impact assessment at SGD. What is important for you to assess?
    a. Form fit function
    b. Interchangeability
    c. Topic is listed in systems engineering checklist.
    d. With Maintenance TOT and Production TOT getting into place, we need to expand the checklist
8. Does the change at SGD get reviewed before sending it to the change control board? In your opinion, is this review useful?
9. Explain what happens in the Change Review Board at SGD?
10. Is there a forum or board at SGD that signs off the change?
11. Explain who the CCB consist of and what happens in the CCB?
12. Does SGD have an ECP coordinator and an ECP committee?
    a. Process owner is config manager
    b. Coordinator is assigned to the different CM controller. They make sure everything is in place. ECP committee is CRB and CCB board.
13. How do changes get implemented at SGD?
    a. Engineering order is important. For customer execution the hardware needs to be implemented correctly
    b. Software implementation is done through the normal release process. Ready with an integration baseline – what retesting needs to be done. Test readiness review captures the formal communication. This leads to documents that need to be updated.
14. When do changes get implemented at SGD?
15. Does SGD review a change after implementation? Please explain when and how this is done.
    a. No and I don't think it is necessary. The way we implement it has the checks and balance in phase. ATP pass is sufficient, no need to relook at it again.
16. Does SGD assess the cost of an ECP? Please explain when and how this is done.
    a. No, we are not very good with that. The project manager keeps track of the cost. By experience we know that software releases are very expensive. We have basic cost estimate for it.
17. Does SGD measure the impact of ECPs on quality? (How do ECPs impact product change frequency vs. product performance?)
    a. No, at SGD it is not as easy as this. If a product is released to early or baselined too early there will be a lot of changes and this will increase the cost of the product because formal changes are expensive. But does not say much about the quality of the item.
18. Is the change implementation at SGD planned? How?
19. Which role players are involved in the change process at SGD?
20. Are changes prioritised at SGD? Please explain how.
    a. Everything we do is prioritised. Automatic prioritisation from the trigger.

21. When and how are changes communicated to the customer? Does the customer approve the change?
    a. There is a config management plan that is agreed with the customer that stipulates when a customer need to be informed about and approve an ECP. It is related directly to the class of the ECP. Class 1 should always mean that the customer needs to approve it. So communication depends on the type of the customer. Some require to be informed about changes even when they don't need approve it. It also depends on the release of the baseline. When the baseline is not released, they don't know about the changes.
    b. It is basically stipulated in the customer contract when a customer needs to be performed.
    c. With OEMs the contractual stipulations are more stringent.
    d. Then there is good customer practice to always notify the customer
    e. Equivalent parts does not to be formally changed so is not done.
    f. Obsolescence management, where there is a form fit function change, you would indicate that as a minor revision or mod strike, so you will communicate it with the customer because the mod strike changed.
    g. System engineers are the ones that communicate the technical side of the ECP
22. Does SGD have a process for emergency changes? When and how does this happen?
    a. Same process but it is scaled because you can say it is n/a in the Production checklist
23. Does SGD scale and tailor the ECP process for different changes? Please explain.
24. Does SGD do status reporting (monitoring and controlling) of ongoing ECPs? Please explain.
25. Does SGD use formal metrics to track effectiveness of the change control process and have clear lead time targets? Please explain.
    a. If you look at the customer delivery, you will plan it in, but not real measures and keep not track of how long it took. Delivery milestones will enforce a timeframe. Also capability to classify the change as routine, urgent or emergency and that specifies how long it may take for the change to be implemented.
    b. We do have aircraft on ground states and then it needs to be done quickly
26. Does SGD use an Engineering Change Management System? Please elaborate.
27. Does SGD use a PDM/PLM system to manage the change? Please elaborate.
28. How does SGD communicate the changes to affected persons as soon as possible?
    a. At the right time, not as soon as possible. Meetings with customer, inform them verbally and then formally.
29. Does SGD make use of front-loading of ECPs?
    a. No, it won't really work like that. Maybe with software.

30. What is SGD's ECP strategy?
31. How are SGD's ECP resources managed?
32. Does SGD do ECP competence management and training? Please elaborate.
33. Does SGD do continuous improvement and learning on ECPs? Please elaborate.
    a. I believe so, yes. We moved from one process to an automated process, to a process implemented with the change review boards and checklists. So we constantly improve the process and change.

Interview 6 – Integrated Logistics Support

Questions:

1. What are the change triggers experienced at SGD? Please elaborate.
    a. When we hear about a change
    b. ILS knows about the change well in advance to the change being raised due to good relations with systems engineering
    c. When doing system testing, this could trigger change for a manual
    d. Obsolescence triggers manuals to be changed because it might affect reliability
    e. New procedures, new ways of working
2. Does SGD do an ECP pre-feasibility study on ECPs? Please explain.
    a. Ja, it is part of the CRB
3. When is an engineering change request raised?
4. How is an engineering change request raised?
5. When does SGD identify possible solutions to change requests – before or after approval?
    a. Before approval. At the CRB we already know what the solution is.
6. When is the impact assessment done on the solution?
    a. At the CRB. We complete the list beforehand and at the review something might change. Then you have to update it afterwards.
7. Please explain the impact assessment at SGD. What is important for you to assess?
    a. ILS checklist is based on the internal ILS process
    b. Is the safety of the product affected? All safety documents?
    c. Reliability affected? FMECA?
    d. Are technical manuals affected?
    e. Is training material affected
    f. ILS elements get evaluated in the checklist
8. Does the change at SGD get reviewed before sending it to the change control board? In your opinion, is this review useful?
    a. See 7.
    b. It is definitely useful.
9. Explain what happens in the Change Review Board at SGD?

10. Is there a forum or board at SGD that signs off the change?
    a. CCB – formal process with a core team
11. Explain who the CCB consist of and what happens in the CCB?
12. Does SGD have an ECP coordinator and an ECP committee?
    a. It is kind of the CCB/CRB
13. How do changes get implemented at SGD?
    a. In the past it was a grey area. In corporation with the programme managers we decided we will not update documents after the approval of the minor changes immediately. If there is a change that affects the safety of documents, we do analysis and update it immediately. Any other change gets saved in the ILS folder and then analysis and the documents of certain products get updated once a year.
14. When do changes get implemented at SGD?
    a. Safety immediately, others once a year.
15. Does SGD review a change after implementation? Please explain when and how this is done.
    a. Not formally done. After we did a change we will do a LRU ATP or system ATP. Testing proves that it works.
16. Does SGD assess the cost of an ECP? Please explain when and how this is done.
    a. As part of the registering process of the CR we do that. We do provide a small SOW and costing to the programme managers for the updating of analyses and documents. Need for node/activity number helps in having to calculate the cost in ILS
17. Does SGD measure the impact of ECPs on quality? (How do ECPs impact product change frequency vs. product performance?)
    a. No
18. Is the change implementation at SGD planned? How?
    a. It is planned – once a year, or safety immediately
19. Which role players are involved in the change process at SGD?
    a. Core teams and TDAs, TPMs
20. Are changes prioritised at SGD? Please explain how.
    a. Safety and not safety. Class 1 and 2 on the Change
21. When and how are changes communicated to the customer? Does the customer approve the change?
    a. We always work through programmes and the programme manager does communicate it. Class 1 is always communicated (software). Manual updates are always communicated through the programme manager – print out and electronic copy
22. Does SGD have a process for emergency changes? When and how does this happen?
    a. Yes, emergency CCBs get held. Emergency change review as well.
23. Does SGD scale and tailor the ECP process for different changes? Please explain.

    a. One process
24. Does SGD do status reporting (monitoring and controlling) of ongoing ECPs? Please explain.
    a. Programme managers sometimes monitor and provide feedback.
25. Does SGD use formal metrics to track effectiveness of the change control process and have clear lead time targets? Please explain.
    a. ?
26. Does SGD use an Engineering Change Management System? Please elaborate.
    a. IFS
27. Does SGD use a PDM/PLM system to manage the change? Please elaborate.
    a. I am not aware of it.
28. How does SGD communicate the changes to affected persons as soon as possible?
    a. Communication from Programme Office. Obsolescence (IHS) alerts get sent. Change Review Board
29. Does SGD make use of front-loading of ECPs?
    a. Used to do this on LWS310
30. What is SGD's ECP strategy?
    a. Not relevant
31. How are SGD's ECP resources managed?
    a.
32. Does SGD do ECP competence management and training? Please elaborate.
    a. Training on the config system and change management system was received by ILS.
33. Does SGD do continuous improvement and learning on ECPs? Please elaborate.
    a. We do provide inputs to the config manager if we see a gap in the process in order to continually improve.

Interview 7 – Program Management

Questions:

1. What are the change triggers experienced at SGD? Please elaborate.
    a. Customer Requirements or Requests
    b. Not meeting customer specification
    c. Obsolescence or technology changes
    d. Bad engineering design
    e. Improvements/Enhacements
    f. Environmental Legalities – can plan for it but companies are lagging and waiting for the last minute to implement. Commercial departments should work on this compliance
2. Does SGD do an ECP pre-feasibility study on ECPs? Please explain.

    a. Yes and no. In the case where we have to do it. Sometimes we have meetings when it starts affecting different programmes then call them together to get common ground.
3. When is an engineering change request raised?
4. How is an engineering change request raised?
5. When does SGD identify possible solutions to change requests – before or after approval?
6. When is the impact assessment done on the solution?
    a. How was the ECP raised? Multiple programmes involved the system engineers will sit with the programme managers and designers. Or sometimes they implement without the impact assessment to the programmes but then the programme has an option whether to accept the change or not. Case by case
7. Please explain the impact assessment at SGD. What is important for you to assess?
    a. How does it impact the contract, delivery time scales, can you deliver the same baseline? What do you need to explain to the customer regarding form, fit, function. What are the legalities regarding retrofits later, turn around times to customers, is in field support or is return for retrofit, the risk of impacting programmes additional orders, annoying customers by constant change.
    b. No formal way of doing but project manager will start looking at certain thing and from the bottom up start analysing the change.
8. Does the change at SGD get reviewed before sending it to the change control board? In your opinion, is this review useful?
    a. Yes, there are pre-meetings.
    b. It does help to be properly prepared
9. Explain what happens in the Change Review Board at SGD?
10. Is there a forum or board at SGD that signs off the change?
11. Explain who the CCB consist of and what happens in the CCB?
12. Does SGD have an ECP coordinator and an ECP committee?
13. How do changes get implemented at SGD?
14. When do changes get implemented at SGD?
15. Does SGD review a change after implementation? Please explain when and how this is done.
16. Does SGD assess the cost of an ECP? Please explain when and how this is done.
    a. Yes, it is very difficult because you have multiple layers of costing. Looking from bottom up you have impact on product cost, maintenance cost, programme level and system level you look at time scales for delivery, impact on documentation. Many levels of cost impact. No formal way of doing it. Normally do this in firefighting mode, then you miss all this code. Risk of penalties and cancellation of orders is much higher cost then they forget about the lower cost.

    b. Not planned in project cost. But it is part of the technical risk in the planning
17. Does SGD measure the impact of ECPs on quality? (How do ECPs impact product change frequency vs. product performance?)
    a. No from the start. Think about it but no formal assessment. Trying to lump together multiple changes if we can foresee that many changes are going to happen.
18. Is the change implementation at SGD planned? How?
    a. It is planned. Depends on the type of change. What risk it carries to the project. Time scales. Quality of change – is it temporary or permanent.
19. Which role players are involved in the change process at SGD?
20. Are changes prioritised at SGD? Please explain how.
    a. Depends on who shouts the loudest. Depends on the priority of the programme and on the on the importance of the customer.
21. When and how are changes communicated to the customer? Does the customer approve the change?
    a. Depends on how we communicate. Sometimes the ECP is approved and then we tell them, but some customers want to approve the change and run it past their environmental departments etc. So what we are doing now, we start informing the customer earlier and ask them if they agree with the approach. Technical level systems engineer and then the project manager talks to the programmes that side.
22. Does SGD have a process for emergency changes? When and how does this happen?
    a. Not that I am aware of. Red flag meeting? Emergency CCB can be held but no formal process.
    b. We do have AOG scenarios (aircraft on ground) but it seldomly happens. But these changes have to happen within a very quick turnaround time. More in repair phase than in design change.
23. Does SGD scale and tailor the ECP process for different changes? Please explain.
24. Does SGD do status reporting (monitoring and controlling) of ongoing ECPs? Please explain.
    a. At product management level we keep track of all ECPs on excel or some kind of spreadsheet. Customers can ask for this list as well so we keep track of it in project management. Some customers have online systems where you submit the change to them then you don’t do this.
25. Does SGD use formal metrics to track effectiveness of the change control process and have clear lead time targets? Please explain.
    a. Depends on the level of change and the urgency of the change.
26. Does SGD use an Engineering Change Management System? Please elaborate.
27. Does SGD use a PDM/PLM system to manage the change? Please elaborate.
28. How does SGD communicate the changes to affected persons as soon as possible?

29. Does SGD make use of front-loading of ECPs?
    a. Batching it together before we release the change. May be beneficial for us internally but not for the customer
30. What is SGD's ECP strategy?
31. How are SGD's ECP resources managed?
32. Does SGD do ECP competence management and training? Please elaborate.
33. Does SGD do continuous improvement and learning on ECPs? Please elaborate.
    a. I think we start thinking about it an plan how we change. We are maturing, it has not always been like this before. We should the change the culture from pulling information out from the previous person to pushing it out.

Interview 8 – Product Management

Questions:

1. What are the change triggers experienced at SGD? Please elaborate.
    a. Customer driven – requirement change or scope creep or client not understanding
    b. Technology changes
    c. Obsolescence
2. Does SGD do an ECP pre-feasibility study on ECPs? Please explain.
    a. The product management process is the pre-feasibility study. Because if the process is driven from the product management side then it is typically a feature that the customer wants in the product or it is an obsolescence thing that we need to change for the product to survive or stay viable
    b. Process works with analysing RFPs from customers. And try to pick up on trends or requirements. It works on providing demonstrations to customers at shows. Market analysis – looking at what the opposition is doing. Trying to pick up things from their sides. Looking at the web, their brochures etc. Feedback from marketing and sales. Feedback from them what the market is expecting and what the market trends are.
3. When is an engineering change request raised?
4. How is an engineering change request raised?
5. When does SGD identify possible solutions to change requests – before or after approval?
    a. Before approval
6. When is the impact assessment done on the solution?
    a. Not always done. It is done on projects because the project will be in a better position to check all the links to the projects. On a product side it is very difficult to do an analysis on history – does the historical client want the change when he orders again.
7. Please explain the impact assessment at SGD. What is important for you to assess?

    a. Impact on production. Impact on time schedules. Impact on cost of goods sold. Impact on current projects that are currently happening. To a lesser extent, impact on previous programmes in terms of does it prevent us to provide a solution to the customer. Not necessarily the exact solution they had, but a solution. Because the customer always has a choice to not accept a change. So the difficulty comes in when production says they cannot build the previous baseline because the customer in essence owns the baseline. So obsolescence driven changes should dictate that you need a maintenance contract with the customer but we haven't gotten to that point yet.
8. Does the change at SGD get reviewed before sending it to the change control board? In your opinion, is this review useful?
9. Explain what happens in the Change Review Board at SGD?
10. Is there a forum or board at SGD that signs off the change?
11. Explain who the CCB consist of and what happens in the CCB?
12. Does SGD have an ECP coordinator and an ECP committee?
13. How do changes get implemented at SGD?
14. When do changes get implemented at SGD?
15. Does SGD review a change after implementation? Please explain when and how this is done.
    a. It depends on the change but it is reviewed. So if it is a document change, typically the QA person would go through the document and approve it. If it is a change more related to a software or hardware change then for eg. Software there will be a specific test that would have failed or a condition that did fail that will be rerun to check if the software is now implemented correctly. Then the previous test that was done on the software will also be done, like a regression test. In terms of the hardware. For obsolescence I am not sure if they do another PCA (physical configuration audit). But they do the ATP to make sure what was changed performs like it did before
16. Does SGD assess the cost of an ECP? Please explain when and how this is done.
    a. What is supposed to happen is on all the different checklists, the departments have to give their cost estimate for their work on the ECP. That normally goes hand in hand with impact analysis.
17. Does SGD measure the impact of ECPs on quality? (How do ECPs impact product change frequency vs. product performance?)
18. Is the change implementation at SGD planned? How?
    a. I don't know if it is planned. The scope of work is identified or almost known before the ECP is raised from a project point of view. From our point of view, if something isn't in production and it is not that dramatic it is implemented through an R&D process. But the complicated ones are where there is a current project, that wants to make a change that the product wants to accept. Then those are driven from the project side but

incorporated into the product. Then the planning becomes more project planning. So the planning becomes the project schedule.

19. Which role players are involved in the change process at SGD?
20. Are changes prioritised at SGD? Please explain how.
    a. Yes, they are. Classified Class 1 and Class 2 according to mil spec
21. When and how are changes communicated to the customer? Does the customer approve the change?
    a. It is linked to the class. Class 1 you need to inform the customer about, class 2 you don't need to tell the customer about. There are on a project to project basis a team, which consists of the project manager and the system engineer. And they decide how and when they are going to inform the customer. They need to inform the customer in a timeously manner – monthly meeting or special design reviews with customers where they will use that time in the product. So from a product management side what we do have to inform the customer about is changes to the state of the product. When we change it to end of life or when we stop support or those type of things. We then need to inform the customer. If there is major obsolescence we need to inform the customer about the change. Like MAW 200 to MAW 300
22. Does SGD have a process for emergency changes? When and how does this happen?
23. Does SGD scale and tailor the ECP process for different changes? Please explain.
    a. We don't. But we should. We do differentiate whether the product is only part of a project or on a product. If it is only a project only the project system engineer has to sign for it and not the TPM. But review sheets get sent out to everyone and if there is no involvement for product management we just fill in N/A. But we don't scale it by saying before the time, this product only requires lists by these departments beforehand.
24. Does SGD do status reporting (monitoring and controlling) of ongoing ECPs? Please explain.
25. Does SGD use formal metrics to track effectiveness of the change control process and have clear lead time targets? Please explain.
26. Does SGD use an Engineering Change Management System? Please elaborate.
27. Does SGD use a PDM/PLM system to manage the change? Please elaborate.
28. How does SGD communicate the changes to affected persons as soon as possible?
    a. Externally, we send them the ECP for approval on project level. From Product management side when the product status changes like end of production/end of support we typically write a letter to them, explaining that we sold the items to them previously and for whatever reasons it is going out of production. We highlight potential replacement options like MAW300 and MAW200, we reaffirm our commitment to the maintenance of their existing product for the duration of the contract. And then invite them to

contact us if they require more information about their current products or want information about new products.

29. Does SGD make use of front-loading of ECPs?
30. What is SGD's ECP strategy?
31. How are SGD's ECP resources managed?
32. Does SGD do ECP competence management and training? Please elaborate.
    a. No, I haven't been in any training.
33. Does SGD do continuous improvement and learning on ECPs? Please elaborate.
    a. No. Continuous improvement and learning on ECPs happens as a by-product due to the lack of training on the ECPs and as a byproduct of the general frustration that people have with the process and not understanding the process. Then the frustration levels reach a certain point and someone will look into the process to make it more streamlined, more cost effective, more something and that way the people that were always involved in the ECPs get invited to see if this makes sense. It is a very reactive process.

Interview 9 – 2nd interview design & development

Questions:

1. What are the change triggers experienced at SGD? Please elaborate.
    a. Obsolescence
    b. Contract changes from customers
    c. No performance or functionality on product
    d. New business requirements eg cost cutting
    e. It is dynamic
2. Does SGD do an ECP pre-feasibility study on ECPs? Please explain.
    a. No, because currently we are forced to do the changes. We don't do ECPs for processes so nice to haves. For this we have to use ACNs, advanced change notes, that parks the idea of a change (parking zone for future application). Currently we are only doing reactive changes.
3. When is an engineering change request raised?
    a. Customer related – so very late in the life cycle
    b. During development
    c. For internal purposes it is the first public step in the process
4. How is an engineering change request raised?
    a. IFS tool. No informal meeting, so we use a formal process
5. When does SGD identify possible solutions to change requests – before or after approval?
    a. Before approval. We use the checklist to check the impact of every discipline. If one of the disciplines does not attend the meeting, the person takes the responsibility of not being there

6. When is the impact assessment done on the solution?
    a. During the checklist. It can be internal as well external. That is why system engineering and product management is included.
7. Please explain the impact assessment at SGD. What is important for you to assess?
    a. If you look at the checklist. It asks the project impact. The impact on client. Scrapping impact. Impact on documents being changed. Impact on Revision. Impact on client approval. Impact on the system. The impact is quite well analysed with the different checklists.
8. Does the change at SGD get reviewed before sending it to the change control board? In your opinion, is this review useful?
    a. It is useful but the execution is maybe questionable. You see in the review minutes that some discussions did not take place. The CCB does a lot of spot checks.
9. Explain what happens in the Change Review Board at SGD?
10. Is there a forum or board at SGD that signs off the change?
    a. CCB. Sometimes the change happens before CCB (Software)
11. Explain who the CCB consist of and what happens in the CCB?
    a. There we change a bit from theory. Theory (acquisition management) says that the chairman takes responsibility of all the design authorities. That is like the chief engineer that signs off for all Das. Here we don't do that. Here we check that basic logic applies, that it still meets requirements. It is a place where the people that normally get overpowered (like maintenance and ILS) also have a chance to talk. Then we also do spot checks to see if process was followed and that all disciplines were involved in the changed
12. Does SGD have an ECP coordinator and an ECP committee?
    a. ECP coordinator is the config department/manager or the CCB chair.
    b. Committee is Elias or Alan John – they check the
13. How do changes get implemented at SGD?
    a. Engineering Orders. CIB.
14. When do changes get implemented at SGD?
    a. It depends. Some are in field. Some reactive that we already built with the change before.
15. Does SGD review a change after implementation? Please explain when and how this is done.
    a. Recorded in the baseline. The functional test is done before it is implemented to make sure it works already pre-approval of CRB/CCB
16. Does SGD assess the cost of an ECP? Please explain when and how this is done.
    a. Time sheets of everybody contributing to it. Scrap costs are calculated. Indirect cost (ripple effect of lifecycle cost) are not measured.
17. Does SGD measure the impact of ECPs on quality? (How do ECPs impact product change frequency vs. product performance?)

    a. It is not a driver. We don't do changes that are nice to haves so this won't really help us.
18. Is the change implementation at SGD planned? How?
    a. More reactive, where we have to change. The planned changes are used with the ACN. Sometimes they are grouped as well, so that is nice where it is a lot of small things that need to happen they will be grouped with a big thing.
    b. Misalignment with production planning and the products that are still in the production line.
19. Which role players are involved in the change process at SGD?
    a. Even the customer is involved. It is all the lifecycle guys
20. Are changes prioritised at SGD? Please explain how.
    a. They have a setting in the change where they can say urgent, emergency or routine. Normally prioritised by importance of customer
21. When and how are changes communicated to the customer? Does the customer approve the change?
    a. Yes, definitely. It depends on class 1 or class 2. All software changes are class 1. All form fit function are class 1. The customer can ask to only see class 1 or see both class 1 and 2.
    b. In the ECP form we have a space where the customer signs the change. Sometimes the authority is giving to an internal customer. This form is automated from the system.
22. Does SGD have a process for emergency changes? When and how does this happen?
    a. Set in our priorities. Might have an emergency CCB meeting. Some clients want software release within a few hours and we will have to check if that is possible.
23. Does SGD scale and tailor the ECP process for different changes? Please explain.
    a. We used to do that but that set the precedent for shortcuts. We now have the norm to do the thorough process and have all the disciplines involved. It was previously different between SW and physical items. But there we are not really in a governance point. Because if you do change impact analyses, remember some guys are not working on the product so it is not known to them. So it is very difficult for an outside person to say you can take a shortcut or not. So we rely on the process for impacts.
24. Does SGD do status reporting (monitoring and controlling) of ongoing ECPs? Please explain.
    a. Yes. We have a register of how many ECPs there are. Status accounting is a normal configuration task.
25. Does SGD use formal metrics to track effectiveness of the change control process and have clear lead time targets? Please explain.
    a. Lead time targets – I think we rely on the guy that is originating the impact. Usually that sits with the client so there is high pressure. We definitely do

not have a KPI and should not have the KPI to count the amount of ECPs. That is the incorrect behaviour you would foster if you would count the amount of ECPs. We are trying to see how long an ECP is taking. We should possibly check how long the implementation takes in the production side (idea from myself).

26. Does SGD use an Engineering Change Management System? Please elaborate.
    a. So our tool is IFS. It is very much aligned on the product lifecycle management tool.
27. Does SGD use a PDM/PLM system to manage the change? Please elaborate.
    a. IFS has the documentation so that is why there is a PLM tool.
28. How does SGD communicate the changes to affected persons as soon as possible?
    a. Actually config is doing a good job because they know who is involved. It is semi-automated with all the signees on a form. Config knows who the TDAs are and who all the individuals who are represented. We have selected a few of the common building blocks that is used in the Capricorn site and incorporated it into the D&D checklist to make sure we don't forget about our colleagues in Cape Town.
29. Does SGD make use of front-loading of ECPs?
    a. ECPs batching – a few items together, said early
    b. We actually have good discipline here. Front-loading means that we do changes even if it is in development. Like the AAU project. So you can pick it up where you start or where you stop. It is not only about the physical but also about the system functionality as well. And we are very good with that.
30. What is SGD's ECP strategy?
    a. We accommodate the necessary changes in a controlled manner with multidisciplinary departments involved.
    b. If you look at audits it is one of the services that we need to have
31. How are SGD's ECP resources managed?
    a. Tool is IFS
    b. People involved – we manage them by timesheets. We allocated a % per product that is sustainable.
32. Does SGD do ECP competence management and training? Please elaborate.
    a. Ja, luckily IFS was a vehicle that made us look at the process again. We had to train everybody again with the new tool when it came into play. Also the configuration controllers help people a lot.
    b. Elias has a few courses that he presents. We also have training manuals that were created with IFS implementation.
33. Does SGD do continuous improvement and learning on ECPs? Please elaborate.
    a. Learning, yes. We are constantly looking at the checklists. CCB is also used as a training grounds. We invite all the disciplines to come there. We always learn something in the CCB. You learn about the products, etc.
    b. We definitely do continuous improvement – we see that on the checklist and the ECP form that is changing now.

Appendix F

1. Background
    a. The main research question is “How can the engineering change process at “Company X” be improved?”
    b. A lot of theory exists on engineering change processes that will be reviewed in the literature review
    c. Additional research questions:
        i. How can the process of raising ECs be improved
        ii. How can the impact analysis be improved?
        iii. How can the management of priorities be improved?
        iv. How can the analysis of the cost of change be improved?
        v. How can the change review be improved?
        vi. How can the CCB be improved?
        vii. How can the change implementation be improved
2. Design
    a. This is a single-case study. The study is only done at one company and only for the change process at the company.
    b. The objective of the study is to find areas where the change process at a company can be improved
    c. Identify any propositions or sub-questions derived from each research question and the measures to be used to investigate the propositions
        i. What are the change triggers?
        ii. Is a pre-feasibility study done before raising a change?
        iii. When is an engineering request raised?
        iv. How is and engineering request raised?
        v. What information is captured in an engineering change request?
        vi. When is the impact assessment done on the solution?
        vii. Please explain the impact assessment at your company. What is important for you to assess?

viii. Are changes prioritised at your company? Please explain how this is categorised?
ix. Does your company assess the cost of an ECP? Please explain when and how this is done
x. Does the change at your company get reviewed before sending it to the change control board? In your opinion, is this review useful?
xi. Is there a forum or board that signs off the change?
xii. Explain who the CCB consists of and what happens in the CCB?
xiii. Does your company have an ECP coordinator and an ECP committee?
xiv. How do changes get implemented at your company?
xv. When do changes get implemented at your company?

3. Case selection
    a. A company in the defence sector or engineer-to-order/make-to-order industry can be selected
4. Case study procedures and roles
    a. Interviewer
    b. Interviewees: all people involved in the engineering change process at the company – use maximum variation in sample selection for interviewees
    c. All documents regarding the change process can also be analysed
5. Data collection
    a. Data collection is done by one-on-one interviews, are recorded and should be transcribed
6. Analysis
    a. Data analysis is done by content analysis on the interviews and documents
    b. Pattern matching is used to do the gap analysis and find improvements
7. Plan Validity
    a. Triangulation by using multiple sources of data
    b. Member checks of the interviews
    c. External validity can be done by checking the data against the
    d. Use maximum variation for selecting interviewees
8. Study limitations

a. Beware of generalisation in pattern matching
b. Be careful of bias at interviews – read up on interview techniques before doing interviews

9. Reporting

Following tables can be used for reporting

Theoretic Pattern	Pattern Matching Topic – Raising ECs	Observed Pattern
X	Trigger	
X	Knowledge management	
X	Information required to raise the change	
X	Classification	
X	Company culture	

Theoretic Pattern	Pattern Matching Topic – Raising ECs	Observed Pattern
X	Trigger	
X	Knowledge management	
X	Information required to raise the change	
X	Classification	
X	Company culture	
X	Changes should be handled differently	
X	Pre-approval	
X	Priority of change specified	

Theoretic Pattern	Pattern Matching Topic – Impact Analysis	Observed Pattern
X	Engineering analysis	
X	Supply chain analysis	
X	Program management analysis	
X	Cost analysis	
X	Service impact analysis	

X	Manufacturability	
X	Formal change impact analysis	
X	Cross functional team	
	Program management analysis	
	External impact	
	System engineering impacts	
	ILS impacts	
	Project management	
	Maintenance impacts	

Theoretic Pattern	**Pattern Matching Topic – Priorities**	**Observed Pattern**
X	Setting priorities at assessment of the impact	
X	Priority category	
X	Setting priorities when raising change	
X	Dependent on cost	
X	Dependent on customer satisfaction	
X	Dependent on effect on lead time	

Theoretic Pattern	**Pattern Matching Topic – Cost of the change**	**Observed Pattern**
X	Consequences cost analysed	
X	Impact of change defined by cost of change	
X	Cost of change in lifecycle increases	
X	Different cost categories	
X	Cost analysis	
X	Cost management department approve cost	
X	Man hours cost	

Theoretic Pattern	Pattern Matching Topic – Change Review	Observed Pattern
X	Review before disposition	
X	Differentiate review by class	
X	Interdisciplinary team	

Theoretic Pattern	Pattern Matching Topic – Change Control Board	Observed Pattern
X	Collaboration	
X	Authority review and decide upon change	
X	Documentation at Board	
X	Cross-functional CCB	
X	Engineering Team to approve	

Theoretic Pattern	Pattern Matching Topic – Change Implementation	Observed Pattern
X	IT systems different - danger	
X	Rules for implementation	
X	Verification of change	
X	Cross-company process for implementation	
X	According to classification	
X	Formal plan/document	
X	Immediate Implementation	
X	Batch implementation	
X	External notification	

10. Schedule
    a. Interviews will take about a month of part time work (2 a week)
    b. Transcribe the interviews as they are done so they are done within 2 weeks after interviews are complete

c. Analysis of data should take a month of part time work

11. Appendices

a. The literature review for the original study is available on request

Appendix G

Hi Nicola

I did read through your thesis (not every word). Very interesting.

How is it going with the finalization? Are you planning any kind of paper submission?

Regards,

[redacted]
Executive Manager: Product Design
Saab Grintek Defence

Mobile: [redacted]
[redacted]



Appendix H

Impact Analysis

Categories Theory	Category Observation
Cost impact	When the change is done
Supply chain	Cost impact
Engineering analysis	Supply chain
Cross functional team	Engineering analysis
Service impact	Cross functional team
Formal impact analysis	Program management analysis
Root cause analysis	Service impact
Project management	Formal impact analysis
Program management analysis	Improvement idea
	Root cause analysis
	External impact
	System engineering impacts
	ILS impacts
	Delays
	Project management
	Maintenance impacts

Theory Impact Analysis	Observation Impact Analysis 6,7
Impact on project cost, project revenue, project follow up risks, brand image, project leadership position, customer safety/defect, project undefined, priority convenience, product improvement	6. When is the impact assessment done on the solution? a. During the Change Review Board where all different stakeholders put in their checklists with their assessments

EC impacts on production and supply chain EC impact gets better with having a proper knowledge management system	7. Please explain the impact assessment at SGD. What is important for you to assess? a. Minor/Major Change b. Form Fit Function c. Interchangeability d. Recall needed e. Cost f. Schedule for production implementation is important g. Requalification needed? h. What needs to be updated or impact i. Impacts on other products j. Different areas are involved D&D, Development, ILS, Maintenance, ISS, Project Management and Supply Chain are all involved
The connectivity between product's components via rework probability and impacts allows the flow of information between components.	6. When is the impact assessment done on the solution? a. Before the approval of the change
The technical benefits of the proposed change; The risks associated with the proposed change The potential consequences on contract, schedule and costs The potential impact of not approving the proposed change. The application of relevant statutory and regulatory requirements Interchangeability of configuration items and the need for their re-identification Interfaces between configuration items Manufacturing, test and inspection methods Inventory and purchases Delivery activities Customer support requirements	7. Please explain the impact assessment at SGD. What is important for you to assess? a. Assess impact on production. b. What are the units that were delivered – also MRO c. Issue of procurement, what are the orders that were raised d. Technical solution of problem – technical impact e. Maintenance f. Training
The primary effect and impact of change is influenced by the efficiency of the change management process, engineering change volumes, iteration time for changes, and cost of engineering change process	6. When is the impact assessment done on the solution? a. During the change review board. The change request is generated. The involved parties are informed and then the different fields go into their speciality and assess the impact
Understanding the effects of change propagation	7. Please explain the impact assessment at SGD. What is important for you to assess? a. From a supply chain perspective: b. Operational requirements: stock, WIP, open orders, impact on subcontractors, impact on direct production, impact on product costing, production delays, test infrastructure impacts.

Include prioritisation rules and principles in change assessment	6. When is the impact assessment done on the solution? a. We don't do that properly. We don't always check the impact of the items that are in field. It is on the checklist for change review. The company does not know what they delivered (the engineers).
Assessment focuses not only on development but on all areas of business Ecs are mainly assessed on their impacts on the functioning of the product and on the manufacturability and serviceability of a product.	7. Please explain the impact assessment at SGD. What is important for you to assess? a. How, when and where must the change be done. In field? Do we need to recall? b. Customer notification – EASA or Part 154? Is this going to ground planes? c. Do we retrofit anything in limbo at the moment? Between production and delivery? d. What must be done to delivered units? Must it be done in field, maintenance or recall? We are missing the stock being available when we retrofit during maintenance.
Components which are affected by a change, resolving propagated changes	6. When is the impact assessment done on the solution? a. It is done through the change review checklists. It is quite good now.
Formal change impact analysis Root cause analysis to identify corrective action Best in class companies have following criteria in change impact analysis: Impact on product requirements, change in manufacturing/tooling equipment, Current supply chain/purchase orders, current demand/sales orders, change in manufacturing processes, related documentation, impact on change on related components or assemblies, part obsolescence, change in product cost, product reliability, product performance, current inventory, packaging or labelling impact.	7. Please explain the impact assessment at SGD. What is important for you to assess? a. Form fit function b. Interchangeability c. Topic is listed in systems engineering checklist. d. With Maintenance TOT and Production TOT getting into place, we need to expand the checklist
Changes in weights and production costs, the time when the change becomes effective, the plans to handle obsolete parts.	6. When is the impact assessment done on the solution? a. At the CRB. We complete the list beforehand and at the review something might change. Then you have to update it afterwards.
EC dependency - the level of dependency between items, products, due dates and sequences of parallel ECs	7. Please explain the impact assessment at SGD. What is important for you to assess? a. ILS checklist is based on the internal ILS process b. Is the safety of the product affected? All safety documents? c. Reliability affected? FMECA? d. Are technical manuals affected? e. Is training material affected f. ILS elements get evaluated in the checklist

Knowing consequences of change on quality, cost and time to market	6. When is the impact assessment done on the solution? a. How was the ECP raised? Multiple programmes involved the system engineers will sit with the programme managers and designers. Or sometimes they implement without the impact assessment to the programmes but then the programme has an option whether to accept the change or not. Case by case
	7. Please explain the impact assessment at SGD. What is important for you to assess? a. How does it impact the contract, delivery time scales, can you deliver the same baseline? What do you need to explain to the customer regarding form, fit, function. What are the legalities regarding retrofits later, turn around times to customers, is in field support or is return for retrofit, the risk of impacting programmes additional orders, annoying customers by constant change. b. No formal way of doing but project manager will start looking at certain thing and from the bottom up start analysing the change.
	6. When is the impact assessment done on the solution? a. Not always done. It is done on projects because the project will be in a better position to check all the links to the projects. On a product side it is very difficult to do an analysis on history – does the historical client want the change when he orders again.
	7. Please explain the impact assessment at SGD. What is important for you to assess? a. Impact on production. Impact on time schedules. Impact on cost of goods sold. Impact on current projects that are currently happening. To a lesser extent, impact on previous programmes in terms of does it prevent us to provide a solution to the customer. Not necessarily the exact solution they had, but a solution. Because the customer always has a choice to not accept a change. So the difficulty comes in when production says they cannot build the previous baseline because the customer in essence owns the baseline. So obsolescence driven changes should dictate that you need a maintenance contract with the customer but we haven't gotten to that point yet.
	6. When is the impact assessment done on the solution? a. During the checklist. It can be internal as well external. That is why system engineering and product management is included.
	7. Please explain the impact assessment at SGD. What is important for you to assess? a. If you look at the checklist. It asks the project impact. The impact on client. Scrapping impact. Impact on documents being changed. Impact on Revision. Impact on client approval. Impact on the system. The impact is quite well analysed with the different checklists.