Improvement of an Engineering Change Process
A Case Study at Ascom Wireless Solutions

Master of Science Thesis in the Master Degree Program Supply Chain Management

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Gothenburg, Sweden 2013

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Abstract

As a result of the business environment including dynamic customer requirements, access to new technology, changes regarding regulations etc. companies are forced to make changes on products in order to stay competitive. Thus, it is important for companies to perform changes in an efficient manner. The focus in this thesis is on engineering changes and the procedure companies use to execute these changes is called the Engineering Change Process.

The purpose of this thesis is to give recommendations on how the Engineering Change Process can be improved and how the process performance can be measured. To be able to answer this purpose a case study at Ascom Wireless Solutions was performed as well as a literature review. And to gain additional knowledge regarding how other companies work with engineering changes three additional companies have been visited. The Engineering Change Process studied at Ascom Wireless Solutions is called the Physical Change Process.

In the first phase of this thesis the current state was studied in order to identify the main challenges in the Physical Change Process. The main data collection method used in this phase was semi-structured interviews since this is a qualitative study. The challenges identified were based on fundamental problems concerning the Physical Change Process and therefore a choice to focus on generic solutions improving the overall process was made. After the current state was defined, the work to identify potential solutions started through an examination of what factors affect the performance of the Engineering Change Process. Based on findings in literature and at the study visits the following factors are considered to be crucial for the process performance; lead time, communication within the process, process input, responsibilities within the process, understanding the process as well as classification and prioritisation.

The identified challenges at Ascom Wireless Solutions and the important factors were considered when making the decisions of what solutions to propose in order to improve the overall Physical Change Process. The choice of solutions was mainly inspired by literature and study visits. The three most important improvements are to develop a clear process description, to clarify responsibilities within the process and to have clear requirements on the input to the process. These solutions are all closely related to the overall understanding of the process.

Furthermore, a study on how the Engineering Change Process can be measured was conducted. The performance measurements suggested in literature were few, though information regarding performance measurements were also collected during the study visits. When comparing literature and findings from the study visits the performance measurements lead time and the number of open changes was mentioned in both. In addition to these two measurements, the recommendation to Ascom Wireless Solutions is to measure “direct runners”.

Key words: Engineering Change Process, engineering change, process performance, performance measurement

PREFACE

This thesis has been conducted in close cooperation with Ascom Wireless Solutions. The company has provided highly valuable feedback and support during this work. We have gained great knowledge and have always felt welcome at the company.

We would like to show our gratitude to all involved in the thesis, especially the “core” team at Ascom Wireless Solutions and the interviewees providing information regarding the studied process. Without you the report would never have been published. Also, the represents from the study visit companies have contributed with important information and therefore we would like to give them our acknowledgement. Without them, it would have been impossible to gain the knowledge needed to give recommendations on how to improve an Engineering Change Process.

Unfortunately, we could not fulfil everyone’s expectations, wants and needs. But hopefully this thesis will contribute to a clear, quick and more resource efficient Physical Change Process at Ascom Wireless Solutions.

Malin Lundqvist

Anna Månsson

Göteborg
June 2013

Definitions of terms and concepts

This table summarise and defines frequently used terms and concepts. The terms are defined according to how they are used in this thesis, and might have different definitions in other contexts and organisations.

Concept	**Explanation**
Agile	The PLM-system used at Ascom Wireless Solutions.
Change board	A cross-functional team used in order to facilitate communication and ensure that all aspects of the change will be considered. The change board usually has the authority to prioritise, reject and approve change requests/orders.
Change order	The actual decision for implementation of the requested change.
Change request	A written request for a change. Externally or internally initiated.
Coordinator	A person responsible for coordination of change requests and change orders in the PLM-system.
CR-accountable	A person responsible for change requests in the PLM-system.
Engineering change	”An engineering change is an alteration made to parts, drawings or software that have already been released during the product design process. The change can be of any size or type; the change can involve any number of people and take any length of time” (Jarratt, Eckert, & Caldwell, 2010, p. 106).
Engineering Change Process	The process handling engineering changes. Used as a synonym to Physical Change Process.
Function	Refers to a specific role within the company, could be a department or a group of employees responsible for a certain activity.
Lead time (L/T)	Lead time is “the elapsed time associated with completing an activity” (Keyte & Locher, 2004, p. 26).
Originator	The person initiating and writing a change request or a change order.
Physical change	A physical change is an alteration made to mechanical parts, hardware or labels that affects a physical product that is in the lifecycle phases active sustain or passive sustain and of a size that do not require a project.
Physical Change Process	The process handling physical changes at Ascom Wireless Solutions. Used as a synonym to Engineering Change Process.
PLM-system (Product Lifecycle Management System)	Computerised system handling changes in products and related information during the whole product lifecycle.
Process time (P/T)	Active time spent on each change per person
Response time	The time from detection of a problem to final implementation of solution (Terwiesch & Loch, 1999a).
Study visit companies	Three companies were visited to investigate how the Engineering Change Process is handled by other practitioners.

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1 INTRODUCTION

This chapter aims to give the reader an introduction to this Master thesis. Firstly, a background to the Engineering Change Process and the purpose of the thesis is presented. Secondly, a short description of the case study company, Ascom Wireless Solutions, is provided. Thereafter, the problem analysis and the research questions are described. The chapter ends by outlining the scope and limitations.

1.1 Background

In the best of worlds companies would not need to make changes on products. However, the reality is far from the ideal situation. Even when the design is right at the time of development, companies are forced to make changes on products that are already released due to dynamic customer requirements and changes in regulations etc. (Malmqvist & Pikosz, 1998; Fricke et al., 2000; Bhuiyan, Gatard, & Thomson, 2006). Jarratt, Eckert and Caldwell (2010) mention two fundamental reasons for changing products; one is to rectify mistakes and two is to improve, enhance or adapt the product. The change can be initiated by several sources such as new customer requirements or suppliers who are unable to continue to supply certain components (Watts, 2012). Such changes are often called engineering changes and handled through an Engineering Change Process. Ström, Malmqvist and Jokinen (2009, p.1) define engineering changes as "changes to design and manufactured products that are made after the first release of drawings for tool manufacturing or serial production". Other definitions of engineering changes can be found in literature, an example of a general definition combining different aspects is;

"An engineering change is an alteration made to parts, drawings or software that have already been released during the product design process. The change can be of any size or type; the change can involve any number of people and take any length of time" (Jarratt, Eckert, & Caldwell, 2010, p. 106).

The Engineering Change Process is complex since it often involves several functions and dependencies within and between products, production sites and organisations (Ström, Malmqvist, & Jokinen, 2009). According to Malmqvist and Pikosz (1998) the complexity of the process leads to long throughput times and difficulties for temporary and new employees to learn the process. Moreover, Watts (2012) states that although engineering changes are done on a regular basis, companies often lack an overview of the change process, resulting in confusion among employees and a slow process. This is in line with Malmqvist and Pikosz (1998) who argue that it can be difficult for the employees to understand the design of the Engineering Change Process and the reasons for why the information has to be processed in a certain way. This lack of understanding and knowledge might lead to uncertainty and unwillingness to use the predefined change process.

Engineering changes can both provide opportunities and be a burden for companies (Jarratt, Eckert, & Caldwell, 2010; Huang & Mak, 1999). A well-functioning Engineering Change Process can for example result in improved customer relations and the product lifetime in the market can be prolonged (Malmqvist & Pikosz, 1998). However, a poor functioning process adds costs and delays the implementation of the requested change (Watts, 2012; Huang & Mak, 1999), and may also result in wasted inventory and disruption in supply and manufacturing.

In literature, engineering changes are described using different terms, such as “product changes”, “design changes” and “product design changes” (Jarratt, Eckert, & Caldwell, 2010). Ascom Wireless Solutions uses the term physical change and the change process is called the Physical Change Process. This process is applied to changes that affect a physical product. Also changes of labels are included in the Physical Change Process. And, in contrast to Jarratt, Eckert and Caldwell (2010) who state that engineering changes can occur at any phase of the product lifecycle, the Physical Change Process at Ascom Wireless Solutions does not include changes in the lifecycle phases pre-production, phasing out and terminated (see Figure 6). Moreover, changes considered to be too large and/or too complex are performed as a project outside the Physical Change Process. In this thesis the term physical change is defined according to the context of Ascom Wireless Solutions;

”A physical change is an alteration made to mechanical parts, hardware or labels that affects a physical product that is in the lifecycle phases active sustain or passive sustain and of a size that do not require a project.”

From here on, the term engineering change will be used interchangeably to the term physical change. And the term Physical Change Process will always refer to the reviewed Engineering Change Process at Ascom Wireless Solutions.

Engineering Change Processes often have potential for improvements (Watts, 2012). Furthermore, Ascom Wireless Solutions claims that the company’s Physical Change Process can be improved and therefore an investigation of the current process has been initiated. Instead of improving the change process, one could advocate a reduction of the number of changes made (Terwiesch & Loch, 1999a). However both aspects are important since one cannot fully eliminate the need for changes during a product’s lifecycle (Malmqvist & Pikosz, 1998; Fricke et al., 2000; Bhuiyan, Gatard, & Thomson, 2006). Hence this thesis will focus on how the Physical Change Process can be improved in the most favourable way and factors affecting the performance of the process.

1.2 Purpose

The purpose of this thesis is to give recommendations on how the Engineering Change Process can be improved and how it can be measured. This purpose will be addressed through a single case study at Ascom Wireless Solutions.

1.3 Company description

Ascom Wireless Solutions is a division within the Swiss company Ascom Group. The division produces and develops wireless communication solutions for mission critical communication. Ascom Wireless Solutions was founded in Gothenburg in 1955 and is of today present in 12 countries; Sweden, Norway, Finland, Germany, Denmark, Belgium, Great Britain, France, Netherlands, Switzerland, Russia and USA (Ascom Group, 2012a). The division employs approximately 1 200 persons worldwide (Ascom Group, 2012b).

As illustrated in Figure 1, R&D (Research and Development) is performed at three different locations; Sweden, the Netherlands and the United States. Also, the production is performed at different locations; in-house at the production site in Herrljunga (Sweden) and outsourced to subcontractors in Mexico, Thailand and China.

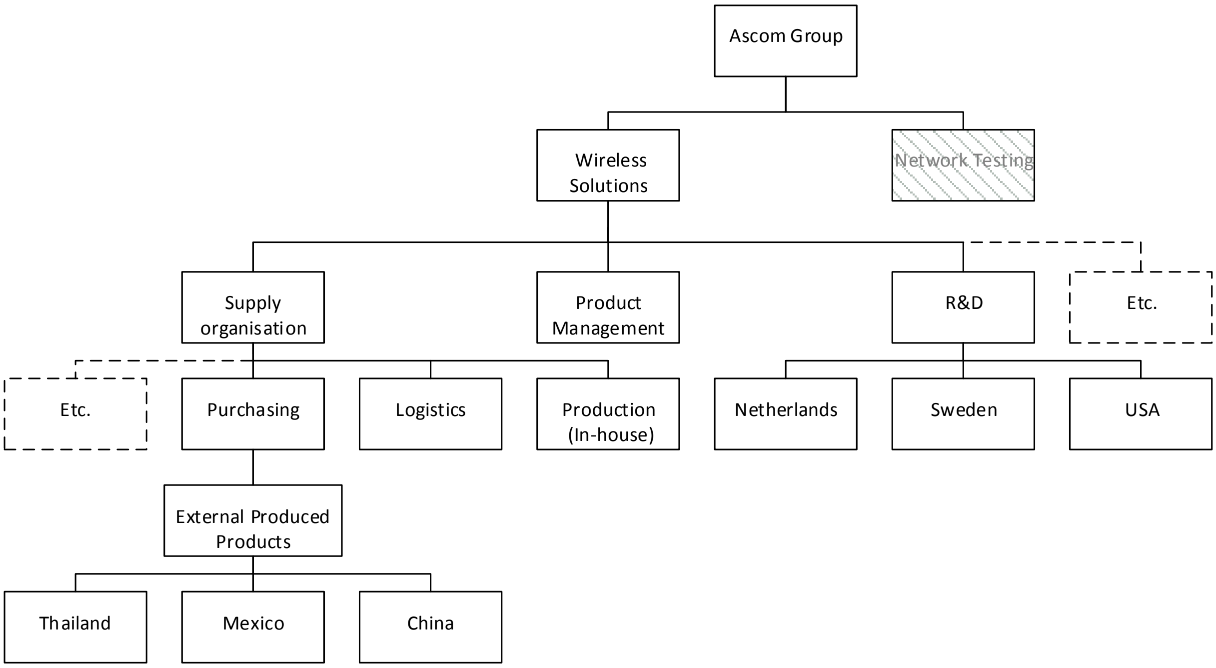

Figure 1. A simplified illustration of Ascom Wireless Solutions' organisation structure.

The company uses three different sales channels; an OEM-channel supplying products to companies within the telecommunication industry, a direct channel through own sales units and an indirect channel via international sales partners (Ascom Group, 2012b). The products are sold Business to Business, mostly within the healthcare sector such as hospitals and elderly care centres and also to industries, secure establishments, hotels and retailers. Common products sold to hospitals are communication systems handling for example critical alarms and patient monitoring. These communication solutions include mobile handsets, personal alarms, paging devices etc. (Ascom Wireless Solutions, 2013).

The products are, in most cases, composed of hardware (PCBA), mechanical parts (Cover) and software. Also packaging and labels as well as documentation are a part of the end product structure. These main components of the product are further broken down; see Figure 2 for a generic example.

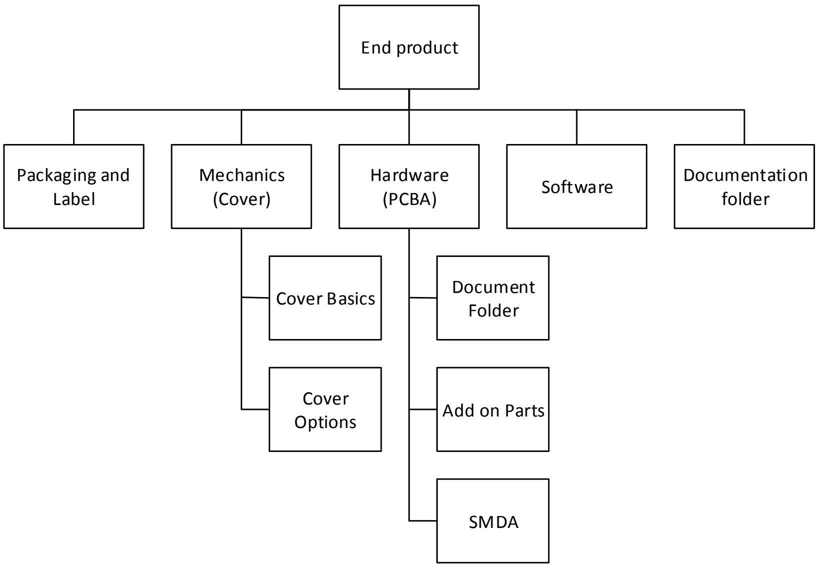

Figure 2. An example of a generic product structure.

1.4 Problem analysis and research questions

Ascom Wireless Solutions has more than 1 000 products in the lifecycle phase called active sustain. In active sustain, the products are approved for the market and sold without financial discount. About 270[1] change requests were initiated during 2012 and approximately 1 600 change orders were released in the PLM (Product Lifecycle Management) system whereof roughly 850 were engineering changes. Of those 850 about 270 change orders were processed in the workflow handling changes on products in the lifecycle phase active sustain. A change can be initiated by different stakeholders such as customers, Sales and Marketing, Production and/or legislation (Jarratt, Eckert, & Caldwell, 2010). The reasons for engineering changes vary from quality problems and safety issues to improvement of products in order to reach a wider market or to rationalise the production. A change may require approval from various parties before it is implemented and the Engineering Change Process can thus be highly bureaucratic (Jarratt, Eckert, & Caldwell, 2010) and requires large investments in time and resources.

As part of Ascom Wireless Solutions' continuous improvement philosophy, a review of the Physical Change Process is conducted in order to identify potential improvements. But, to be able to improve the process, understanding the current situation is crucial. Hence the first step is to answer the following research question;

RQ1: *What are the challenges in the current Physical Change Process at Ascom Wireless Solutions?*

The process complexity, mentioned by Ström, Malmqvist and Jokinen (2009), is the reality for Ascom Wireless Solutions. This is due to involvement of several functions and, dependencies within and between products and production sites (see Figure 1 and Figure 2).

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[1] Request type in the PLM-system: CR & LTB Investigation

Firstly, R&D is performed at three different locations and the production is managed in-house as well as outsourced. Secondly, the use of both in-house and outsourced production capacity results in different flows of information through the organisation. The outsourced production is managed by the purchasing division meanwhile the in-house production has direct contact with the supply organisation. The close interaction between the in-house production and the supply organisation results in a risk of sub-optimisations in favour for the in-house production. Thirdly, the complexity of the process is increased since Ascom Wireless Solutions produces products that are sold under other brand names via the OEM-channel. This results in a need for approval from the OEM-customers before changes can be made to these products, which can take several months.

Since the products are regulated by legislation and certificates, regarding for example what frequencies are allowed to use, the options when making changes are restricted and regulatory issues must be carefully evaluated. Moreover, the end products are often a combination of software, mechanical parts and hardware making the complexity even higher as the process has to be able to handle interdependences and changes within all areas.

The next research question seeks the answer to how the Physical Change Process could be improved taking these complexities into account;

RQ2: *How can the Physical Change Process be improved at Ascom Wireless Solutions?*

To be able to suggest improvements of the current Physical Change Process, it is crucial to have knowledge regarding factors affecting the performance of the process. There are several studies conducted in the past within this area (see for example Wänström, Medbo, & Johansson, 2001; Huang, Yee, & Mak, 2003; Ström, Malmqvist, & Jokinen, 2009). The findings of these studies are reviewed in chapter 3, which aims to answer the following research question;

> RQ2a: *What factors are important for the performance of the Engineering Change Process according to theory?*

As for the practical knowledge about the Engineering Change Process, knowledge regarding factors important for the performance and how other companies have designed the change process can be obtained from practitioners within the industry.

> RQ2b: *What factors are important for the performance of the Engineering Change Process according to practitioners?*

There are several methods and approaches to measure process performance and they are described differently depending on the author (Heckl & Moormann, 2010). Further, performances can be measured on both strategic and operational level. The diverse usage of methods and approaches causes confusion concerning what measurements to use at which level. Consequently, there is no straightforward answer to how the performance of the Engineering Change Process should be measured. The following research question aims to present relevant performance measurements for the Engineering Change Process.

RQ3: *What performance measurements are relevant for Ascom Wireless Solutions when measuring the performance of the Physical Change Process?*

To find an answer to RQ3 a literature review is conducted. The aim of this review is to identify possible performance measurements;

> RQ3a: *What performance measurements are used to measure the performance of the Engineering Change Process according to theory?*

Also knowledge and experience from the industry and people working with the Engineering Change Process are valuable when identifying performance measurements that could be used to evaluate the process. Hence, the following research question will be answered;

> RQ3b: *What performance measurements are used to measure the performance of the Engineering Change Process according to practitioners?*

1.5 Scope and Limitations

This thesis was conducted on behalf of Ascom Wireless Solutions and is therefore performed with a particular focus on the company and its context. Nevertheless, the academia is provided with additional knowledge in the field of engineering changes in terms of factors important for the process performance and suggestions on how the process performance can be measured. Other companies might be able to apply the findings in order to improve their change processes.

Due to the complex context some generalisations and simplifications had to be made in order to make the thesis understandable for readers unfamiliar with the Physical Change Process and the change processes studied at the study visit companies. In addition to the Physical Change Process, Ascom Wireless Solutions has processes handling non-conformity issues, changes in software, etc. Occasionally such changes affect the physical products and may then be handled in the Physical Change Process. Hence, our definition of a physical change is not absolute. Even though, the change processes are interrelated this thesis aims to improve the Physical Change Process.

The Physical Change Process applied at Ascom Wireless Solutions differs between the sites in the United States and Europe. The Unites States site has recently been acquired. Hence, only the process used in Sweden and the Netherlands is investigated. Further, the aim of this thesis is to provide Ascom Wireless Solutions with recommendations on how the Physical Change Process can be improved. However, implementation of the suggested improvements is not included. Further, the production is performed both in-house and outsourced to several subcontractors and therefore the processes used for implementation of changes will differ between the production sites. This thesis does not aim to study the implementation of changes at the production sites.

The focus of this thesis is the Physical Change Process that handles physical product changes in the lifecycle phases active sustain and passive sustain. Still, the interface between the Product Creation Process and the Maintenance Process is included (see Figure 6).

Engineering changes are handled in a PLM-system, a IT-system handling information concerning products and related changes. This thesis is not aimed at improving the system as such. The suggested solutions and recommendations will not consider issues related to the implementation of the suggested solutions in the PLM-system.

Ascom Wireless Solutions is working with continuous improvements and has recently carried out an organisational change. This dynamic organisational context could affect the suggestions for improvements and recommendations since the current state, that forms the basis of the analysis, might have been changed during the time frame. Changes that occurred after the current state had been defined are not taken into consideration.

2 METHOD

In this chapter the research strategy of this thesis is presented and it is explained why the chosen strategy is suitable for this study. This is followed by an overview of the research process and an explanation of the data collection process as well as the scientific techniques used for gathering data. Then, the data handling and analysis processes are described. The chapter ends with a discussion on trustworthiness of this thesis.

2.1 Research strategy

A qualitative research strategy has been applied to this thesis since the purpose is to create a deeper insight into a change process in a company specific context. This research strategy has an emphasis on understanding and interpreting information from individuals' or a small group's perspective (Ghauri & Gronhaug, 2005). Since the purpose of this study is to improve an Engineering Change Process it was important to understand the process from the participants' points of view, share their experiences and interpret their problems in a wider perspective. The aim of a qualitative study is not to test theories but rather to create theories (Bryman & Bell, 2003). In this case, this concerned how the process could be improved in the specific context of Ascom Wireless Solutions; hence this thesis has a case study design. The qualitative strategy and the case study design were brought together. And the typical data collection method recommended by Bryman and Bell (2003) is qualitative interviews which were applied in this thesis.

2.2 Research process

An illustration of the research process is presented in Figure 3. The process started with the definition of purpose and ended with the final recommendations to the company. Figure 3 also shows the input to the process; company needs, literature, interviews, a survey and study visits. These data collection methods are presented below and it is through the collection and analysis of data that fulfilment of the milestones was reached. The milestones; Defining the Current State, Improving Ascom's Physical Change Process and Define relevant performance measurements, contributed to answering the research questions. Representatives from Ascom Wireless Solutions have followed the progress of this thesis. And results regarding each RQ have been presented to the company as the milestones were reached. Feedback from the company has been taken into consideration and adjustments have been made accordingly.

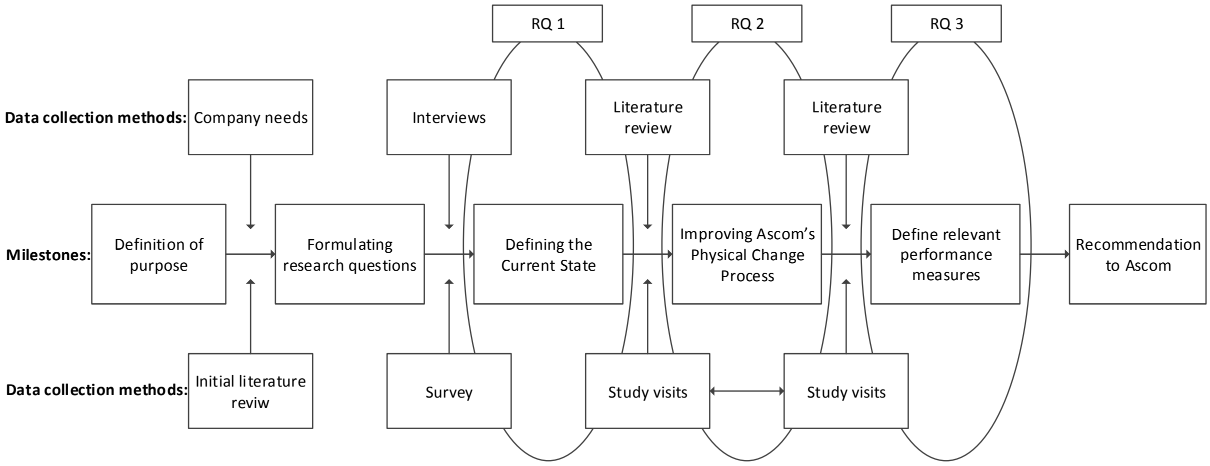

Figure 3. An illustration of the research process showing the milestones, their connections to the RQs and when the different data collection techniques were applied.

2.3 Data collection

The chosen data collection techniques and when they were applied in the research process can be deduced in Figure 3. In this section the techniques of gathering data described are; literature review, interviews, document analysis, survey and Value Stream Mapping. The study visits are considered and described as interviews.

2.3.1 Literature review

A literature review was initiated in the beginning of the thesis work in order to gain knowledge about the Engineering Change Process. The initial literature review formed the knowledge base needed to design interview guides.

The initial literature review was followed by an in-depth review of literature, which was used as a basis for gathering knowledge on potential solutions to improve the Physical Change Process at Ascom Wireless Solutions. The literature search was conducted using databases such as Science Direct and ProQuest, accessed through Chalmers Library. Also Google Scholar was used for finding literature and several articles were found by backtracking references in relevant literature. Key words used to search for literature were for example; Engineering Change Process, Product Change Process, Engineering Change Order, change request, engineering change, Engineering Change Management, performance measurements, key performance indicators, product maintenance process. These key words were used one by one but also in different combinations to narrow down the search. Articles concerning specific company contexts have been studied as well as more general studies on how the Engineering Change Process could be designed and organised.

The KJ-method (see section 2.4) was used to analyse and group the findings from the literature review. Factors affecting the Engineering Change Process discussed in the articles were categorised and summarised. These factors were compared with the factors identified from study visits (see Appendix A). The factors considered being within the scope, that were mentioned in both literature and in the study visits have been further analysed.

2.3.2 Interviews

There are mainly two interview approaches suitable for a qualitative study; unstructured interviews and semi-structured interviews (Bryman & Bell, 2003). The interview approach chosen was semi-structured interviews since the aim was to gather information about the interviewees' experience and opinion regarding the change process. The interview guide supported the participants to stay focused on the topic. Though, the interviewees were given space to express his/her opinions and perspectives and the interviewers were able to ask additional questions. After the interviews some of the interviewees were asked for additional information, to clarify certain opinions and/or statements. When performing semi-structured interviews it is important to use recording equipment to capture the data (Dalen, 2007) and therefore the interviews has been recorded if permitted by the interviewee. Recordings and notes taken during the interviews were used to recall the interviews.

In order to review, understand and learn more about the current Physical Change Process interviews were conducted with employees at the Ascom Wireless Solutions' offices in Sweden. The interviews were supported by a general interview guide (see Appendix B) though the focus in the interviews depended on the interviewee's role in the Physical Change Process.

The identification of interviewees was based on a predefined list of eight people, put together by the supervisor at Ascom Wireless Solutions. Interviews were then booked with these persons who were familiar with the process and had different roles and responsibilities within the change process. During the interviews suggestions of additional interviewees were provided and added to the list of interviewees (see Appendix D). This way of selecting the interview sample, through using one contact to unfold new contacts, is called snowball sampling (Bryman & Bell, 2003). Snowball sampling was suitable for this thesis in order to avoid a subjective choice of interviewees and open up for new interviewees providing information that otherwise might have passed by. All interviewees are working at the Swedish sites, though the same process is used in the Netherlands. Therefore there was a risk of neglecting aspects such as geographical distances and language barriers. Nevertheless, the organisational language is English and the distance between Gothenburg and Herrljunga was taken into consideration.

To reduce the subjective impact the ambition was to interview at least two persons from each function involved in the Physical Change Process and in most cases this ambition was reached. The purpose was to get a wider perspective of how the function was involved and also to be less affected by one person's ideas and opinions. The information provided from the interviewees from the same function was coherent and therefore it was assumed to be sufficient with two interviewees per function.

2.3.3 Documents

As a complement to the interviews internal documents and information from the PLM-system were analysed. These data was mainly used for analysing the current Physical Change Process. It is important, when accessing internal documents, to be aware of that the documents are affected by the author's perspective and position in the company (Bryman &

Bell, 2003). As this was only a complement to interviews, this information was not the only source of data and hence the empirical findings are not based on a single person's perspective.

2.3.4 Study visits

To be able to answer RQ2b and RQ3b, semi-structured interviews were conducted at three other companies. These interviews are presented as "Study visits" in Figure 3 and the interview guide used at the study visits is presented in Appendix C. The purpose of the study visits was to gain input about how other companies work with engineering changes, how they solve problems and handle challenges within the Engineering Change Process. Also, information on how the process performance was evaluated and measured was of interest. In relation to the process at Ascom Wireless Solutions the processes at the study visit companies were briefly investigated due to time restrictions and limited access to information.

Regarding the study visits, the companies were chosen in cooperation with Ascom Wireless Solutions. The selection included companies having formal change processes and in-house R&D. Two of the companies were similar to Ascom Wireless Solutions; one regarding products and one regarding size. However, the third company differs from Ascom Wireless Solutions on both aspects, though this is a large international company that was assumed to have a well-defined change process and to measure process performance.

2.3.5 Survey

As a complement to the interviews a survey was used for data collection. The main purpose with using this method was to collect information about the time spent on each activity in the Physical Change Process and this data were used for the Value Stream Mapping (see section 2.3.6).

A questionnaire was designed with closed questions i.e. fixed-choice alternatives that the respondent could choose from (Bryman & Bell, 2003). In addition, some open questions were asked in connection to the closed questions. Through, these open questions gave the respondents a chance to clarify and/or give other comments concerning the topic of the question.

Before the questionnaire was sent out it was reviewed by four people having knowledge about the Physical Change Process and the questionnaire was adjusted based on the feedback. The questions were sent out by e-mail to 119 persons and the response rate was 58 per cent (see Appendix G). The requirements on the respondents were that they had a user in the PLM-system and also a Swedish e-mail address. Since most participants in the change process are Swedes the questionnaire was written in Swedish and only Swedish-speaking people were selected as respondents. Using native language could avoid misunderstandings and have a positive effect on the response rate. Another reason was that the American site use a different change process than the European sites.

One benefit with using closed questions is that the result is easier to analyse (Bryman & Bell, 2003). The simplicity of analysing the survey data was important since the amount of respondents could be rather high. Also the information wanted was mostly regarding estimated active process time which assumingly was rather easy to answer in closed questions. Disadvantages could be that respondents were forced into one alternative and not able to give the true answers. Another aspect is the personal interpretation of the question. The question itself was rather simple but the process time in each specific case can vary, hence different persons might have referred to different cases resulting in an incoherent result.

2.3.6 Value Stream Mapping

Value Stream Mapping is a tool commonly used in Lean to map processes. The tool is often applied on physical transformation processes in production environments but can also be used for office and administrative processes (Keyte & Locher, 2004). The tool facilitates visualisation of the process (Rother & Shook, 2001), identifies challenges (called waste or non-value adding activities in Lean) and improvement potentials.

Value Stream Mapping is included as a data collection technique and also used to visualise the current Physical Change Process as part of the answer to RQ1.

The data used in the Value Stream Map were collected from the PLM-system and the survey. In collaboration with representatives from the company one end product was chosen for further investigation. This end product was chosen since it has been handled in the current Physical Change Process, which includes both change requests and change orders, during the whole lifecycle. It is also considered to have been in the lifecycle phase active sustain for a reasonable amount of time. The data collection started at the top level of the product structure (see Figure 2) and proceeded downwards in the structure in order to include all the change requests and change orders that were related to the end product or components included in the end product. The collection did not include the entire structure, because of the large amount of data. Though, all change requests are included since they are located in the top level in the structure and the change orders were documented even for some levels under the main structure. The data collected were; start and end dates for each step in the process and number of people involved in each step. This data were manually entered into an Excel sheet, hence there was a risk of entering errors into the data but since there are a relative large number of change requests and change orders, it is assumed that a small number of errors would not affect the result significantly. Moreover, obvious errors were corrected when detected.

The average and median throughput time were calculated from the data. These calculations are not only based on change orders handled in the Physical Change Process but also changes in the lifecycle pre-production. Hence the actual throughput times in the Physical Change Process actual may be longer. Also, one should note that the throughput times are calculated in weekdays not workdays. However, the main purpose of the Value Stream Mapping was to illustrate the approximate correlation between non-value and value adding time in the Physical Change Process rather than give an exact description of the current state. And since the total value adding time is small compared to the throughput time the effect of including weekends etc. could be disregarded. This is supported by Rother and Shook (2001) who state that one should not aim at developing a perfect current state map.

A possible source of error is the possibility of iterations in the process which results in cases were the process is going back and forth between the steps. Often this is done during the same day and hence do not affects the throughput time. However, there are some cases where the throughput time is affected. In those cases only one input date from each step were included. Which input that was used was chosen by an arbitrary decision. But as described earlier, the goal was not to generate an exact description of the current state.

It was not possible to physically follow the process and timing the process step as recommended by Rother and Shook (2001). Instead, the value adding time was derived from a survey where the respondents were asked to estimate the process time for each step in the Physical Change Process. The values used in the Value Steam Map are the times which most respondents answered (see Appendix G). Noteworthy is that the time required may differ between functions and depends on the scope of change.

Also the number of people involved in each step was calculated. Each person was only calculated once per step, even if they performed several tasks within that particular step. However the same person can be counted many times during the process since he/she may be involved in more than one step.

2.4 Data analysis

The KJ-method and the comparable method called affinity diagram, enables categorisation of large amount of data (Courage & Baxter, 2005). According to Courage and Baxter (2005) affinity diagrams is a useful method for analysing interview data. The method is used to group similar findings and concepts in order to identify themes or trends in the data.

We used the method both for categorising the literature findings and data from the interviews at Ascom Wireless Solutions including the data from the open survey questions. The procedure used in this thesis was based on Courage and Baxter (2005) and is described below.

The first step was to write each key point on a post-it note. A post-it note only contained one thought or problem (Scupin, 1997). If necessary other information associated with the data point was noted, like the interviewee's work tasks or department. The next step was to shuffle the note to avoid any predefined groups and then to physically group similar findings or concepts together. One should have an open mind when analysing the data and let the structure and relationship emerge from the data in order to facilitate new ideas (Courage & Baxter, 2005). When analysing interview and survey data it might have been easier for us to keep an open mind since we had few preconceptions regarding the change process. The fourth step was to label each group. A benefit of the grouping into higher-level themes was the possibility to address issues on a higher level instead of on an individual basis (Courage & Baxter, 2005). Hence, a more holistic solution was gained. Large groups were broken down into sub-groups. The groups were then reviewed and regrouped until an agreement was reached. The KJ-analysis of the literature findings resulted in a list of factors affecting the Engineering Change Process (see Appendix A). And the result from the analysis of the interview and survey data is presented in Appendix E.

All data from the interviews and the survey were categorised as explained above, still it was unfeasible to include all issues in the report. Therefore a selection was made according to Appendix F. The chosen categories have a focus on aspects concerning the overall process and the steps within the change process. Some aspects were excluded from further work in this thesis due to lack of relationship to the process itself. The following aspects were excluded; external aspects, the PLM-system as such, handling of product revisions and implementation.

2.5 Methodology discussion

There are different opinions concerning how the validation of qualitative studies should be performed and what aspects and criteria that should be applied (Mandle, Whittemore, & Chase, 2001; Sinkovics, Penz, & Ghauri, 2008). Hence, there is no universal or generally accepted way of enhancing the quality of a qualitative study (Rolfe, 2006). Bryman and Bell (2003) refer to authors claiming that validity and reliability can be applied directly to qualitative studies while Golafshani and Nahid (2003) recommend the concept of trustworthiness to assess qualitative studies. The concept of trustworthiness was chosen for this thesis as it seems to be better adapted to qualitative strategy.

2.5.1 Trustworthiness

The concept of trustworthiness is composed of the following four criteria; credibility, transferability, dependability and confirmability (Bryman & Bell, 2003). These criteria are described and discussed below.

The credibility of the study relates to the match between the reality and theoretical models developed in the study. The theoretical model used was applicable to the reviewed processes at the studied companies. In general, the way the Engineering Change Process is described in literature is also the way it was described by the companies, though they use different words describing the process. Of course the reality is more complex than literature, but the fit was higher than expected from the beginning.

Data was collected from several sources and different methods were used. This was a way to strengthen the conclusions of this thesis called triangulation (Wilson, 2006; Bryman & Bell, 2003). Data was collected through interviewees at the company in scope but also at other companies, hence different perspectives were provided. These perspectives were regarded as pointing towards the same conclusions. The data was collected at four companies and also several data collection methods were used within one company. At Ascom Wireless Solutions a survey, interviews and Value Stream Mapping were used, hence both qualitative data and quantitative data were collected in order to give better input to the conclusions and increase the credibility.

The question of transferability can be phrased; Can the findings of this study be applied to other contexts? Qualitative findings are often a result of a small group's or individual's opinions hence they are often related to a specific context (Bryman & Bell, 2003). Though, the general impression is that the findings actually could be applied in other company contexts since factors affecting the Engineering Change Process according to theory, study visits and the studied context seem to coincide. The challenges identified at Ascom Wireless Solutions also seem to be similar to the challenges at the study visit companies and the companies studied in literature.

Dependability is a question regarding the replicability of the study. If the study should be remade it is important to document all the steps in the process (Bryman & Bell, 2003). Though, even if all steps are well documented there are some difficulties to take into consideration regarding this specific study. Firstly, the dynamic context caused by for example competitiveness and new technology may change the preconditions of the Engineering Change Process. So even if the same steps are performed, the result might differ due to external factors like access to new technology. Secondly, since this is a qualitative study based on interviews, there is an uncertainty of whether the interviewees would give the same answer a second time or not. Probably their knowledge is continuously developing, for example they may have learnt something from this study. Thirdly, the findings from the study visits are dependent on few people’s perspectives since maximum two interviewees were interviewed at each study visit company. These findings can therefore have suffered from subjective interpretations since no additional data were collected.

Confirmability concerns how personal opinions and values have affected the results of a study (Bryman & Bell, 2003). It is impossible to be totally objective in business research but in this case it might not be desirable since our previous knowledge and reflections concerning the case study helped us to make relevant decisions. To prevent the findings from being too biased by an individual’s view the aim was to interview two persons from each department. It is difficult to evaluate whether our own thoughts have had a significant impact on the results or not. Though, in order to keep focused on the goal of improving the situation at Ascom Wireless Solutions meetings have been held with representatives from the company guiding us through the process, discussing and giving advice on how to proceed, still giving us space to think freely.

3 LITERATURE REVIEW

In this chapter the findings from the literature review are presented. First, a description of a generic Engineering Change Process model and literature findings concerning each step in the model are presented. Second, factors affecting the overall performance of the process are discussed. Third, literature findings regarding performance measurement in general and evaluation of the Engineering Change Process in particular are provided. The chapter ends with a summary of factors affecting the Engineering Change Process and a table summarising the performance measurements found in literature.

As mentioned in the introduction, the term Physical Change Process is used as a synonym to Engineering Change Process in this thesis. Also other terminology might differ between authors. When the terminology differs the most common term is used in order to ease the reading. Some authors describe a process that is initiated by a change request and ends with a change order, while others describe a process only consisting of change orders. However, in the last case the change order process is often more comprehensive.

3.1 Generic change process model

Some kind of Engineering Change Process is present in most companies and occupies a large part of companies' resources (Jarratt, Eckert, & Clarkson, 2006). According to Jarratt, Eckert and Caldwell (2010) there are two types of Engineering Change Processes; official and unofficial processes. An official Engineering Change Process is a formal process with high requirements on documentation. This is the most common process and the fundamentals of the process are similar irrespective of company and product. The unofficial Engineering Change Process is less formal and often used when changes must be done in a quicker manner. Hence, the documentation is often postponed to get the change implemented as soon as possible.

Since a formal Engineering Change Process is the most common type, a generic model for this process is presented and described in this thesis. However, there are not so many generic models, suggested for the Engineering Change Process in literature. Of the models reviewed Figure 4 is a good representation of a generic Engineering Change Process.

The breakpoints shown in Figure 4 are symbolising four points in the process where the change process can be terminated. The two most important iterations according to Jarratt, Eckert and Clarkson (2006) are marked with arrows in the figure. However, the authors also add that there can be alternative iterations throughout the process. Each step of the process is described in detail below.

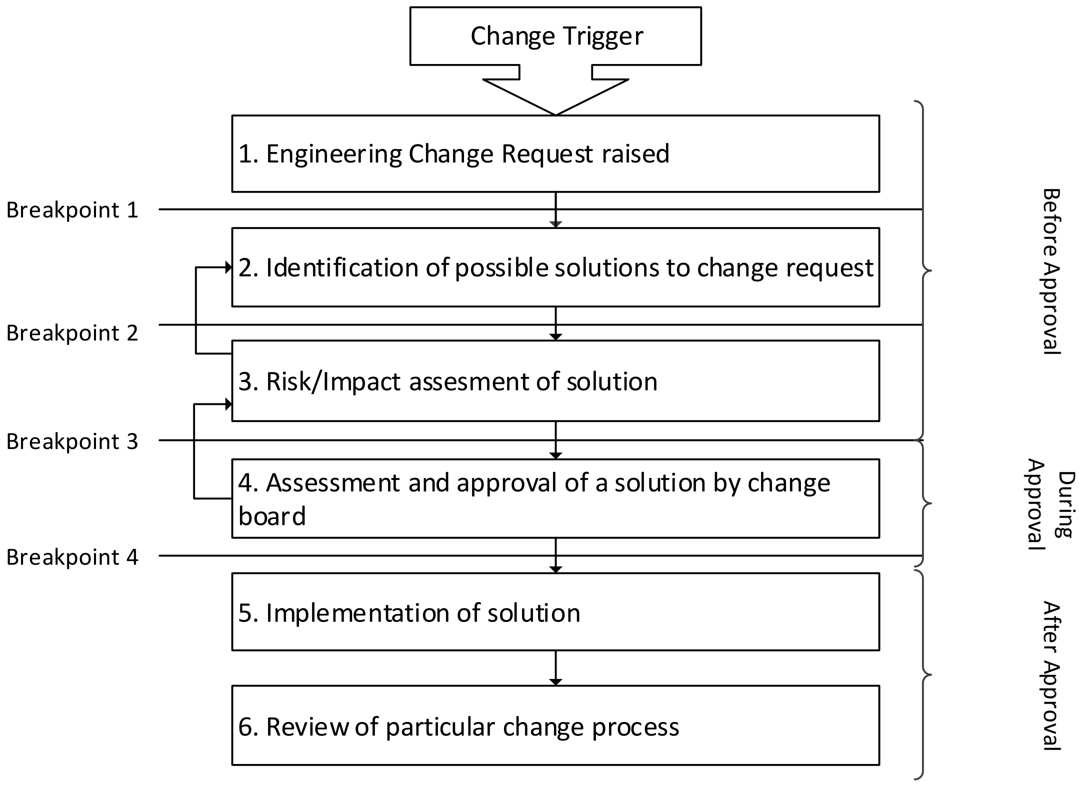

Figure 4. Representation of the Engineering Change Process (Jarratt, Eckert, & Caldwell, 2010; Jarratt, Eckert, & Clarkson, 2006)

3.1.1 Engineering change request raised (Step 1)

The responsibilities within the Engineering Change Process start with a change trigger initiated by for example customers, suppliers or internal sources in order to correct mistakes or improve the product in various ways (Watts, 2012; Jarratt, Eckert, & Clarkson, 2006; Jarratt, Eckert, & Caldwell, 2010). To initiate a change, a change request shall be created. The change request is often a standard form (Ström, Malmqvist, & Jokinen, 2009), in electronic or paper format. This form asks for information regarding type of change, reason for change, priority of change, if the change affects other components or systems etc. Instead of asking for the reason for change Watts (2012) suggests that question such as; ”Why is the change needed?”, ”What is the benefit from the change?” and ”What is the justification of changing?” should be answered in the form. The reason for asking straight forward is to help the originator to answering the requested information.

When a need for change is to be communicated, one way is to let all change initiatives from customers as well as from internal sources go through one appointed person. Depending on the change type and the context, different input data might be needed, but in general one need to have information regarding why the change is needed, what end products that will be affected by the change etc. Balcerak and Dale (1992) state that the change board should be responsible for justifying the change and decide when it should be implemented. However, the authors do not state who should be responsible for collecting the information needed to make the decision. Other authors claim that it is necessary to collect the proposals centrally and make sure that they are well documented (Tavcar & Duhovnik, 2005). It is common that engineers write the change orders, thus it is unlikely that they have knowledge about how the change affects the business from others' perspectives (Watts, 2012), for example the purchasing situation. Since it is difficult for the engineer to provide all necessary input data, and make the correct assumptions, the input should be cross-checked by all concerned departments and corrections should be made if necessary (Watts, 2012).

3.1.1.1 Classification and prioritisation of changes

There is a large variety of how to classify changes (Jarratt, Eckert, & Caldwell, 2010; Scholz-Reiter et al., 2007). One purpose of classifying change requests is to enable prioritisation of changes early in the process. The suggested classification schemes in literature vary in complexity, with the suggested number of possible classifications varies from three to nine (Balcerak & Dale, 1992). Jarratt, Eckert and Caldwell (2010) mention four ways of classifying changes; by origin, purpose, urgency of the change and/or its timing in the product lifecycle. Also Watts (2012) describes different types of classifications used by companies. Balcerak and Dale (1992) have identified two main kinds of classifications; one that describes the nature of the engineering change in terms of the documentation affected and another type that classifies the urgency level. Below classification schemes regarding type of change and urgency level will be described.

Watts (2012) recommends four pre-defined change types; document change only; meet the product specification including reliability, maintainability and safety standards; reducing manufacturing or maintenance cost including Last Time Buys; and exceed product specification. The last category regards improvements and should, according to Watts (2012), only be applied to products that need to be improved beyond the product specifications. The change type gives indications on what functions to involve, actions to take and if the change needs to be processed on the change board (Watts, 2012; Balcerak & Dale, 1992).

Balcerak and Dale (1992) state that one purpose with classification of engineering changes is to determine the urgency of the change request. Watts (2012) suggests two types of change orders depending on the urgency; one fast and one hand carried i.e. "someone walks to/telephones the person who needs to take the next action and expedites the change" (Watts, 2012, p. 219). The person who considers the change to be so important that it must be hand carried should also be responsible for the change order and make sure that its proceeds through the process. All persons involved in the process should have instructions of prioritising hand carried change orders and immediately take action when a hand carried change order arrives. While, fast change order should be handled by the regular organisation responsible for handling changes. Given that the change process is fast the number of hand carried change orders will be small. According to Watts (2012) a change classified as urgent might take longer time through the process since many companies have a quite complicated classification process resulting in time being wasted on classifying the change.

All requested changes are important to someone; hence the urgency classification scheme must be clear. One should avoid classification based on subjective terminology which could be subject of individual interpretations (Balcerak & Dale, 1992). Balcerak and Dale (1992) propose changes to be graded as follows. Firstly, changes in drawings or the bill-of-material due to errors which are the most urgent but simple. Secondly, changes derived from customer complaints regarding products not meeting the specifications have to be implemented immediately otherwise it is a risk of production being disrupted. Thirdly, all other changes should be implemented in the most economical and least disruptive fashion. These grades can be used to determine the urgency of the change.

3.1.2 Identification of possible solutions to change request (Step 2)

In step 2, the main task is to identify solutions to the problem and evaluate these, hence transform the idea to a change proposal (Tavcar & Duhovnik, 2005). Though, often only one solution is investigated due to for example time restrictions (Jarratt, Eckert, & Caldwell, 2010).

3.1.3 Risk and impact assessment of solution (Step 3)

Assessment of the risk and impacts of the suggested solutions is carried out in step 3. This step is one of the most critical steps since many factors need to be considered in the assessment. Factors evaluated in this step are for example the impact on production and supplier relationships (Jarratt, Eckert, & Clarkson, 2006).

Multiple dependence between the changed parts or products and customer requirements, logistics issues, personnel at different functions, and other products cause challenges when handling engineering changes and assessing the impact (Keller, Eckert, & Clarkson, 2005; Ström, Malmqvist, & Jokinen, 2009). Jarratt, Eckert and Caldwell (2010) mention three factors that govern the impact a change have on the end product; the complexity of the product, the architecture of the product and the degree of innovation within the product.

The change process often requires substantial amount of resources and time (Terwiesch & Loch, 1999a; Huang & Mak, 1999). A change may also result in substantial impact on the manufacturing process (Fricke et al., 2000). However, the change will hopefully provide benefits such as cost reductions in the long term and/or quality improvements. At first a change might seem beneficial but the final cost savings might be low and sometimes even result in a negative financial impact (Terwiesch & Loch, 1999a). The reason for this could be unforeseen effects of the change such as other parts needed to be redesign, new supplier relationships or interruptions in production. It is difficult but crucial to find logical ways to sort out unwise changes in order to avoid an inefficient and slow change process (Watts, 2012).

One aspect of evaluating the change request is to decide what change to carry out and what changes to reject. Fricke et al. (2000) advocate increased effectiveness and more specific assessment in the review of change requests. Potential benefits and resource consumption should be estimated for each change request. According to the study by Fricke et al. (2000) evaluation of change requests are in most cases mainly based on knowledge and experience of the employees. The authors recommend tools such as FMEA and Process Costing when evaluating change requests. In addition, introduction of a change board could facilitate the evaluation process (Fricke et al., 2000). This is in line with Balcerak and Dale (1992) who state that a change board should determine if a change is worthwhile.

3.1.4 Assessment and approval of a solution (Step 4)

The solution selected in step 3 must be reviewed before implementation starts. The approval could be made by a cross-functional change board consisting of representatives from for example; Product design, Manufacturing, Marketing, Supply, Quality assurance, Finance, Product support (Huang & Mak, 1999; Huang, Yee, & Mak, 2003; Jarratt, Eckert, & Caldwell, 2010). Some kind of cost benefit analysis should also be performed or updated by the board before the decision is made.

The responsibility of making decisions is discussed by different authors and their view on the decision process differs. Decision making is seen as a bottleneck in the Engineering Change Process and the efficiency is therefore important. Decisions can be more efficient if taken by one person, though the authors also bring up the issue of the cross-functional knowledge needed to make decisions (Tavcar & Duhovnik, 2005). Another way of handling the problem is to found a change board. Balcerak and Dale (1992) state that all changes do not need to be processed by the change board. ”Having determined which people needed to discuss which engineering changes, it [is] also necessary to establish their precise responsibility” (Balcerak & Dale, 1992, s. 129). This board should handle the most important changes and it is their responsibility to decide when the change should be implemented. Ström, Malmqvist and Jokinen (2009) also address the clarification of responsibilities and the need to provide the right information to the right persons. Ström, Malmqvist and Jokinen (2009) stress that another issue related to responsibilities and decision-making is the importance of the input provided to the decision maker(s). If the input is poor there is a risk of taking the wrong decision resulting in a need of iterating the process.

Watts (2012) presents a rather strict list of approvers for changes on products released on the market. Meanwhile, document changes and informal changes during the development phase require approvals from fewer functions and/or managers. The author states in the article; “Everyone wants to sign” (Watts, 2012, p. 236) and describes this as a problem because having too many approvers are not efficient and takes too long time. It is important to involve a team of people in the beginning, but it might not be necessary to let everyone in the team be a part of the approval process.

A negative aspect of a complex approval procedure is that it can result in long lead times (Terwiesch & Loch, 1999a). According to Terwiesch & Loch (1999a) the approval procedure could be improved through elimination of unnecessary bureaucracy and/or make the management responsible for controlling the final result instead of details.

3.1.5 Implementation of solution (Step 5)

There are different ways of implementing a change and it is dependent on for example where in the lifecycle the product is and the nature of the change. Providing manufacturing with relevant documentation is also an important aspect of this step (Jarratt, Eckert, & Caldwell, 2010). According to Wänström, Medbo and Johansson (2001), there are many difficulties when carrying out a change order. The cost of for example scrapping can be large if the implementation is not well planned, hence the effectivity of the change must be considered in advance (Watts, 2012; Wänström, Medbo, & Johansson, 2001).

3.1.6 Review of particular change request (Step 6)

The final step aims to evaluate if the implemented change resulted in the expected benefits. Through this step companies can learn how to improve the process; still not all companies evaluate the implementation of a change (Jarratt, Eckert, & Caldwell, 2010). It is important to ensure easy access to information to facilitate learning and improvement from gained knowledge (Ström, Malmqvist, & Jokinen, 2009).

3.2 Factors affecting the overall Engineering Change Process

Above a generic model and important activities within the Engineering Change Process have been described. Also, specific factors that are of importance for certain process steps have been presented. In the following section factors affecting the overall process are presented.

3.2.1 Understanding the process

Tavcar and Duhovnik (2005, p. 209) state; "Quick and reliable implementation of [Engineering Changes] requires a detailed process definition, which should be well understood by all participants". Each department should know their role and responsibilities within the change process. It is crucial that the departments/functions involved in the change understand the change process and know who should be involved (Dale, 1982; Watts, 2012). In addition, Jarratt, Eckert and Caldwell (2010) emphasise the need of visualisation of the Engineering Change Process and the importance of participants' understanding of the process. A lack of understanding regarding reasons behind the design of the change process can result in an unwillingness to use the formal process (Malmqvist & Pikosz, 1998; Dale, 1982). And a complex process might lead to a long learning process. Consequently, changes may be performed outside the formal process or avoided. To enable a common understanding the company must have firm rules regarding the basics of the process (Dale, 1982).

The design of the change process can be hard to grasp and it is common that employees do not understand the consequences of their action for others involved in the process. Terwiesch and Loch (1999a) noted that employees from one function did not understand the consequences of a change at other functions. For example, a change that seemed simple for the purchasing department might not be regarded as small by the production department since it would require costly changes at the production line. Huang and Mak (1999) experienced that the function which often was involved in the change process where wrongly blamed by other functions for introducing too many changes just because they were involved in the majority of the changes. This lack of understanding of the design of the process and consequences of changes might cause irritation and an unwillingness to make engineering changes within the organisation.

3.2.2 Process flexibility

Most companies have a standardised and documented change process (Fricke et al., 2000; Huang & Mak, 1999). The Engineering Change Process handles varying complexity, some changes might have low impact and risk resulting in a low complexity while other have high complexity due to for example interrelationships with other products. To handle the wide variety of changes some researches advocate the use of different processes depending on the change type while others argue that only one process shall be used. According to Malmqvist and Pikosz (1998), in order to save time companies often use a simplified change process when the change does not affect the form, fit or function of the product. Also Balcerak and Dale (1992) suggest that different processes should be used depending on type of change.

Watts (2012) on the other hand states that companies should have one fast, accurate and well-understood process for changing the design of a product and the related documents. The author argue that existence of more than one system for handling changes might be a symptom of problems such as a slow, unmanageable and/or painful change process. Since, if the process performs badly or do not provide the options necessary, people will find other ways of managing the changes, and thereby create their own systems for handling changes. For example, if the change is perceived as urgent by someone, that person might choose to process the change outside the formal process since the change process is assumed to take too long time. Or the process flexibility might be poor; hence some changes will be difficult to fit into the predefined process forcing people to make changes outside the process. Moreover, one process is easier to improve, maintain, operate and it causes less confusion and has the lowest cost (Watts, 2012).

However, Watts (2012) suggests that process steps can be bypassed depending on the classification of the change. To facilitate flexibility Ström, Malmqvist and Jokinen (2009) suggest a process with a fast and a full track option. The fast track option should handle minor changes while the full track option handles major changes. According to Fricke et al. (2000) the change process must be adjustable within certain boundaries to cope with all type of changes. For example it might be possible to bypass some steps in the process for certain types of changes and to adjust what information that is needed depending on the type of change. This is in line with Huang, Yee and Mak (2003) who emphasise the need of flexibility in order to efficient and effective handle changes of different complexity.

3.2.3 Communication within the process

Extensive communication between functions in the Engineering Change Process is crucial since all affected functions must be able to express their opinion regarding the requested change (Watts, 2012; Malmqvist & Pikosz, 1998). Cross-functional change boards are a commonly used method to facilitate the communication between functions.

Changes must be communicated well and quickly in order to avoid decisions being taken on obsolete information (Fricke et al., 2000). For example the Purchasing and Production planning must have knowledge about components being replaced in order to plan for phasing out of that component and avoid unnecessary scrapping. Moreover, the same forms and tools should be used throughout the organisation to standardise and ease communication (Ström, Malmqvist, & Jokinen, 2009). Scholz-Reiter et al. (2007) emphasise the need for different functions to understand what is communicated e.g. Production must understand the terminology used by R&D and vice versa.

According to a survey performed by Huang and Mak (1999) poor communication is one of the major factors influencing the management of engineering changes. Also Tavacar and Duhovnik (2005) mention poor communication as being the most common reason for problem.

The type of communication used within a company varies, though it can be of interest to investigate what channels, frequency and content that is suitable for supporting good communication within the company (Tavcar & Duhovnik, 2005). Also, the need of communication varies throughout the process and there are differences between the development phase and the production phase. During the ramp-up phase communication skills are key to speed up and improve the process (Scholz-Reiter et al., 2007). And when the product is delivered to customers it becomes more important to have product data gathered in one place for easy electronic access (Tavcar & Duhovnik, 2005).

3.2.4 Responsibilities within the process

Creating and implementing an engineering change impacts several departments within a company and therefore many functions are involved, sharing the responsibility for the Engineering Change Process (Huang, Yee, & Mak, 2003; 2001). Because of this shared responsibility many authors express the importance of clarifying the responsibilities within the process (Watts, 2012; Ström, Malmqvist, & Jokinen, 2009; Tavcar & Duhovnik, 2005; Balcerak & Dale, 1992).

One problem in the Engineering Change Process is the lack of coordination (Wänström, Medbo, & Johansson, 2001). The appointing of an Engineering Change Coordinator is one very important element of a formal Engineering Change Process (Huang, Yee, & Mak, 2003). Furthermore, as a result of Balcerak's and Dale's (1992) study an Engineering Change Coordnator was appointed. The coordinators role was for example to chair the cross-functional team responsible for handling the change requests.

In situations where many functions are involved the clarification of responsibilities is of extra relevance to secure that all required tasks are performed and all aspects taken into consideration (Keller, Eckert, & Clarkson, 2005). If the responsibilities are unclear there is a risk of overlooking important task and aspects since nobody perceive it to be within his/her responsibility. Examples of aspects that might be forgotten are aspects concerning documentation, legislative demands or implementation issues. To avoid confusion and misunderstanding the responsibilities for each person/function should be crystal clear (Watts, 2012). A predefined group of reviewers are important for securing the quality of the change and minimise the risk of errors.

3.2.5 Lead time

According to Terwiesch and Loch (1999a), the Engineering Change Process, as many administrative processes, suffers from long response times. The response time is the time between detection of and final implementation of the change and the major part of this time is spent waiting, resulting in a low percentage of value adding time (Terwiesch & Loch, 1999a; 1999b). The same authors bring up the problem of many, simultaneously open, changes causing coordination problems. This problem is a result of changes having long lead times. Also late implementation and changes in conditions during the lead time can be problematic. For example, customer requirements and market conditions might be changed during the long lead time; other examples are changes in legislation or additional change orders concerning the same product.

To reduce the response time Tavacar and Duhovnik (2005) recommend splitting the flow of changes early in the process and separating those into changes concerning the development phase and changes concerned with the production phase.

Another aspect affecting the lead time is the employees' individual prioritisation of each change request and change order, and between work tasks. Terwiesch and Loch (1999a) noted in their case study, that the engineers had problems with managing the priority between tasks and had to frequently switch between projects. Also many engineers had large backlogs of work causing long waiting times and consequently long response times.

3.3 Performance measurements

Measuring performance is not an easy task for companies and measuring the right aspect of a specific process such as the Engineering Change Process can be even harder. However, without measuring it would be impossible to determine whether the process performs well or not (Slack, Chambers, & Johnston, 2010). Furthermore a project or business is often focused on time and budget, but generally, these performance measurements do not give a full picture of a company's performance (Parmenter, 2010; Berman, 2007).

3.3.1 Why measure?

To be able to measure a process and the improvements of a process it is important to consider what to measure. The metrics should support monitoring and continuous improvements of the process (Anonymous, 2010). It is not the measure itself that is important but rather how the information from the measurement is used (Behn, 2003). Hence, measuring is not just a process of finding the right metrics but also to continuously work with these in order to achieve alignment within the process, which results in higher performance (Raynus, 2011; Starbird & Cavanagh, 2011). Starbird and Cavanagh (2011) also stress the importance of metrics driving the right behaviours among people. For example, if the goal is to hand in a certain number of documents per day, but does not say anything about the quality of the documentation, the goal can be reached but the actual outcome might be worse since documents handed in may be incomplete or even useless.

Another mistake is to define goals that are too low (Starbird & Cavanagh, 2011) since lack of incentives tends to make people perform less. This is also expressed as; "The motivation of employees impacts their individual performance, and consequently, organisational performance" (Samsonowa, 2012, s. 44).

The results from the measurement activities can be seen as a starting point for optimisation. Identification of strengths and weaknesses in the process can for example be an indication of where to focus the effort in order to improve (Kronz, 2006). This improvement cycle can be seen as an iterative measurement process resulting in higher performance (Raynus, 2011).

3.3.2 Measurement strategies and concepts

There are different ways of interpreting concepts, models and strategies for how performance could be measured. Different definitions of KPI (Key Performance Indicator) are used in literature. However, many authors seem to agree on the fact that KPIs are important measurements determining the progress towards goal or objective set by the company (Smith

& Mobley, 2008; Harman & Davenport, 2007; Raynus, 2011). Often the definitions relate to high level organisational goals. KPIs can be seen as broad strategy measurements assessing the strategic objectives (Slack, Chambers, & Johnston, 2010). The KPIs are broken down into concepts called “performance indicators” or “performance objectives” which are general for all processes. These indicators are discussed among authors and they are perceived slightly different, for example Slack, Chambers and Johnston (2010) consider quality, speed, cost, dependability and flexibility while Heckl and Moormann (2010) use four indicators; quality, time, cost and flexibility. These four performance indicators will be developed further in this thesis since these authors are looking specifically on process performance. These indicators help to determine the more specific metrics used to measure and visualise the performance of a process. Figure 5 illustrates the connection between KPIs, strategic objectives, performance indicators and more specific metrics described in this section.

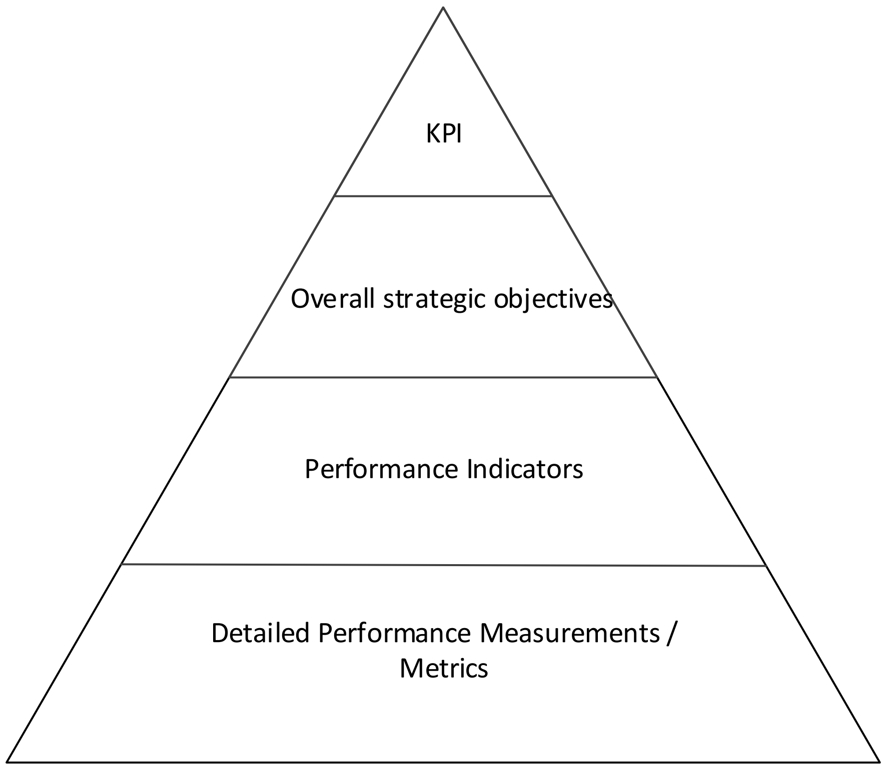

Figure 5. An illustration of the connection between KPIs and specific metrics. Inspired by Slack, Chambers, and Johnston (2010) and Heckl and Moormann (2010).

The quality indicator is often focused on measuring customer satisfaction (Heckl & Moormann, 2010). More specific measurements in the category are the mean time between failures, warranty claims etc. (Slack, Chambers, & Johnston, 2010). The time perspective is important since it relates directly to competitiveness and the time to respond to external customers is very important in this matter. Specific measurements for this indicator includes for example lead times, waiting times and process times. The third indicator, cost can be measured as; cost for service, failure, repair, product, etc. Cost is considered to be a general objective highly prioritised, but yet it is most relevant to companies competing on price (Slack, Chambers, & Johnston, 2010). The last indicator flexibility can, on the one hand be “the degree to which a production or service process can be modified, including the timeline and costs associated with restructuring the production or service process” (Heckl &

Moormann, 2010, s. 121). On the other hand, it can deal with output volumes or utilisation of resources (Heckl & Moormann, 2010) i.e. what is done in the process, when it is done or how it is done.

3.3.3 Measuring the Engineering Change Process

As previously stated, it is impossible to avoid changes in a competitive environment therefore it is important for companies to handle engineering changes in the right manner. According to Huang, Yee and Mak (2003) changes should be handled in a way that minimises the time, cost and effort. To do this the authors claim that it is central for companies to have effective and efficient management of engineering changes. To evaluate the current state of an Engineering Change Process it can be interesting to study three different measurements; the number of active changes (excluding already implemented changes and those rejected); the calendar time from creation to implementation of a change and finally the active time spent on each change per person involved (Huang, Yee, & Mak, 2003).

Other authors in the field of engineering changes claim that there is a "dominating culture of cost management and, at the same time, relatively little emphasis on time management" (Terwiesch & Loch, 1999a, p. 168). There has been a focus on cost but organisations are now also focusing on measuring lead times of change orders. Often there is a lack of economic models of the value of time which makes it difficult to estimate the costs.

The article by Wänström, Medbo and Johansson (2001) focusing on the logistic perspective of engineering changes suggest for example the following metrics to measure the performance of the Engineering Change Process; scrap materials, lead time, incorrect data and documentation, materials shortage, penalty cost for breaking contracts with suppliers, missed deliveries and quality losses.

3.4 Summary of the literature review

This chapter has described the Engineering Change Process from a theoretical perspective and also discussed factors that have an impact on the process. The discussed factors are summarised in Table 1 which presents a selection of a more comprehensive list of factors identified during the literature review (see Appendix A). The selected factors are of two categories; overall and specific. The overall factors have an impact on the entire process whilst the specific factors are regarded to mainly affect a certain step in the Engineering Change Process. These factors are a part of the basis for the analysis of Ascom Wireless Solutions' Physical Change Process.

Table 1. A summary of factors affecting the Engineering Change Process.

Factors	Exemplifying the factors	References
Process input (specific)	• Standardisation of requested input • Important with proper documentation • How to collect the information?	Balcerak and Dale (1992) Ström, Malmqvist and Jokinen (2009) Tavacar and Duhovnik (2005) Watts (2012)
Classification and prioritisation (specific)	Classification • Changes can be classified by e.g. urgency and type • Different input is needed • Different process flows can be applied • Different persons need to be involved Prioritisation • All changes cannot be handled at once • Some changes might be of higher importance than others • Some changes should not be done at all	Balcerak and Dale (1992) Fricke et al. (2000) Malmqvist and Pikosz (1998) Scholz-Reiter et al. (2007) Ström, Malmqvist and Jokinen (2009) Watts (2012)
Understanding the process (overall)	• Lack of understanding of the design of the process might result in the use of informal processes • Awareness of consequences • Visualisation of the process	Dale (1982) Jarratt, Eckert, Caldwell and Clarkson (2010) Huang and Mak (1999) Malmqvist and Pikosz (1998) Tavacar and Duhovnik (2005) Terweisch and Loch (1999a) Watts (2012)
Process flexibility (overall)	• The wide range of engineering changes requires flexibility • Use of one or many processes • Possibility to bypass process steps	Balcerak and Dale (1992) Fricke et al. (2000) Huang, Yee and Mak (2003) Malmqvist and Pikosz (1998) Ström, Malmqvist and Jokinen (2009) Watts (2012)
Communication within the process (overall)	• The process requires extensive cross-functional communication • Efficient communication is crucial	Fricke et al. (2000) Huang and Mak (1999) Malmqvist and Pikosz (1998) Scholz-Reiter et al. (2007) Ström, Malmqvist and Jokinen (2009) Tavacar and Duhovnik (2005) Watts (2012)
Responsibilities within the process (overall)	• The responsibilities should be clear • All functions do not need to be involved every time • Need to have someone responsible for the coordination	Balcerak and Dale (1992) Huang, Yee and Mak (2001) Huang, Yee and Mak (2003) Keller, Eckert and Clarkson (2005) Ström, Malmqvist and Jokinen (2009) Tavacar and Duhovnik (2005) Watts (2012)
Lead time (overall)	• High degree of non-value adding time is common • Long lead times is problematic • Might take long time between detection and action	Tavacar and Duhovnik (2005) Terweisch and Loch (1999a) Terweisch and Loch (1999b)

Table 2 is a summary of the performance measurements regarding the Engineering Change Process discussed in literature. The identified performance measurements will, together with those identified in chapter 4, form the foundation for the recommendations to Ascom Wireless Solutions regarding how the company should measure their Engineering Change Process.

Table 2. A summary of performance measurements regarding the Engineering Change Process discussed in literature.

Identified Performance Measurements	**Explanation**	**References**
Process time	Active time spent on each change per person	Huang, Yee and Mak (2003)
Lead time	Calendar time from creation to implementation	Huang, Yee and Mak (2003) Terwiesch and Loch (1999a)
Number of active changes	Number of active changes, not including those implemented or rejected	Huang, Yee and Mak (2003)
Metrics related to logistics perspective	Costs for scrap materials, materials shortage, missed deliveries, penalty costs, quality losses etc.	Wänström, Medbo and Johansson (2001)

4 EMPIRICAL FINDINGS

This chapter aims to describe the current Physical Change Process at Ascom Wireless Solutions and to briefly describe the Engineering Change Process at the study visit companies. The chapter starts with an introduction to the Physical Change Process at Ascom Wireless Solutions. It is followed by a more detailed description of the Physical Change Process focusing on findings from the interviews, internal documents and the survey. The chapter continues with describing factors affecting the overall Physical Change Process. Next the results from the study visits are described. Thereafter information about how Ascom Wireless Solutions and the study visit companies measure the performance of the change process follows. Finally, in the end of this chapter, a summary regarding the most important challenges at Ascom Wireless Solutions and a table providing the performance measurements identified at the companies are presented.

If no other reference is provided, the empirical chapter is based on information from interviews conducted with employees, survey data, internal documents and information from the PLM-system.

4.1 Introduction to the Physical Change Process at Ascom Wireless Solutions

Figure 6 illustrates the relationship between the product lifecycle and the process structure. A product lifecycle is divided into five different phases; pre-production, active sustain, passive sustain, phasing out and terminated. In the pre-production phase the main part of the R&D is performed. The decision to change the lifecycle status from pre-production to active sustain is taken at a so called Product Acceptance Meeting organised by the Product Manager. Products in active sustain are approved to be sold on the market without financial discount. The last three phases in the lifecycle concerns the end of life process where the Physical Change Process is only applied in the phase passive sustain.

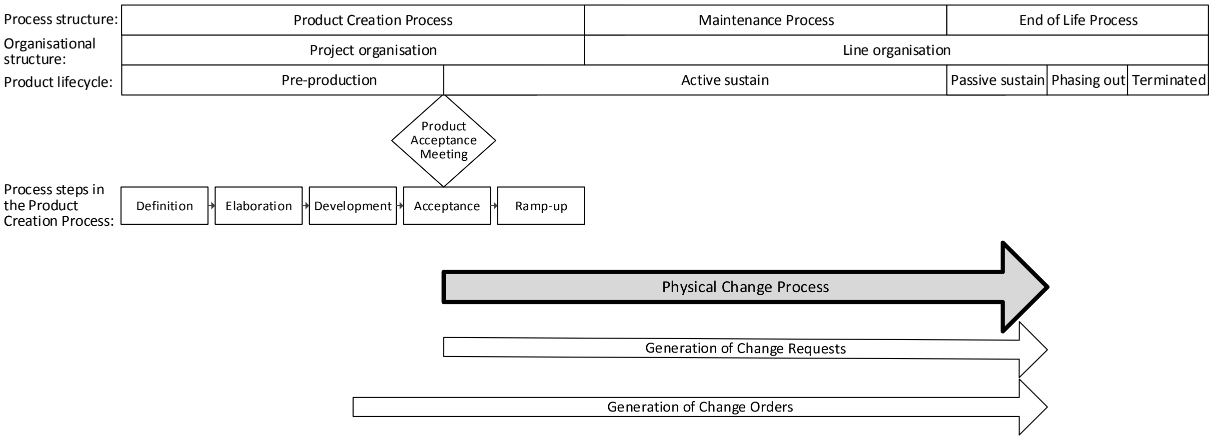

Figure 6. An illustration of the Physical Change Process and its context.

Changes to products in pre-production are handled in a simplified process in order to enable quick and frequent changes. The reason for this is that during product development the company needs to be able to make changes quickly and there are low requirements on traceability at this point. The possibility to generate change orders is introduced in the development stage in the Product Creation Process. During the pre-production phase two simplified change order workflows are applied (called fast approvals and zero series). As illustrated in Figure 6 the Physical Change Process is not utilised until the product has entered the lifecycle phase active sustain. When the lifecycle status is changed to active sustain a more strict change process is required to ensure traceability. This process is called Physical Change Process. Change requests are introduced in this process and the result from a change request is normally one or more change orders. These change orders are handled in a workflow called product changes. Change requests and change orders will be explained in more detail below.

4.2 The Physical Change Process at Ascom Wireless Solutions based on the generic Engineering Change Process model

The change process at Ascom Wireless Solutions has been developing over time and improvements are still made on a regular basis, the change requests were introduced about two years ago. The process is supported by a PLM-system and coordinators are responsible for managing the system. On the next page, Figure 7 illustrates the current Physical Change Process, which is described in more detail in the following sections. The empirical data regarding the Physical Change Process at Ascom Wireless Solutions is presented based on the generic Engineering Change Process model described in section 3.1.

4.2.1 Engineering change request raised (Step 1)

A change request is initiated by the need to make a change. This need comes from several sources, both internal and external. Almost all employees at Ascom Wireless Solutions can write a change request. Common reasons for changes are Last Time Buys, meaning that the supplier will no longer provide a certain component, cost reductions and quality issues.

When writing a change request one shall, according to the instructions, describe the request by entering information about the concerned item number, motivating why the change shall be done and suggesting a solution. Moreover, the reasons for change shall be motivated by a calculation of yearly cost savings and by stating benefits e.g. economical, lead time, or process/production advantages. However, interviewees claim that the input is incomplete and request explicit input concerning for example why the change is needed, what should be changed, who is affected by the change and what products or product families are affected by the change. This information is important for the receiver to get an overview of the change request and decide whether it concerns their interests. Moreover, a common statement during the interviews was that the quality of the input is dependent on the originator.

When the change request is written the next step, according to the instructions, should be a review of the information before the change request is set to “Investigation”, but this step is not performed in today’s process. The change request appears to be sent forward in the process without being reviewed by the CR-accountable. Criteria for evaluation mentioned in the instruction are for example; “Does the business case hold?”, “Should the change request be pipelined with other change requests?” and “Is the scope clear?”

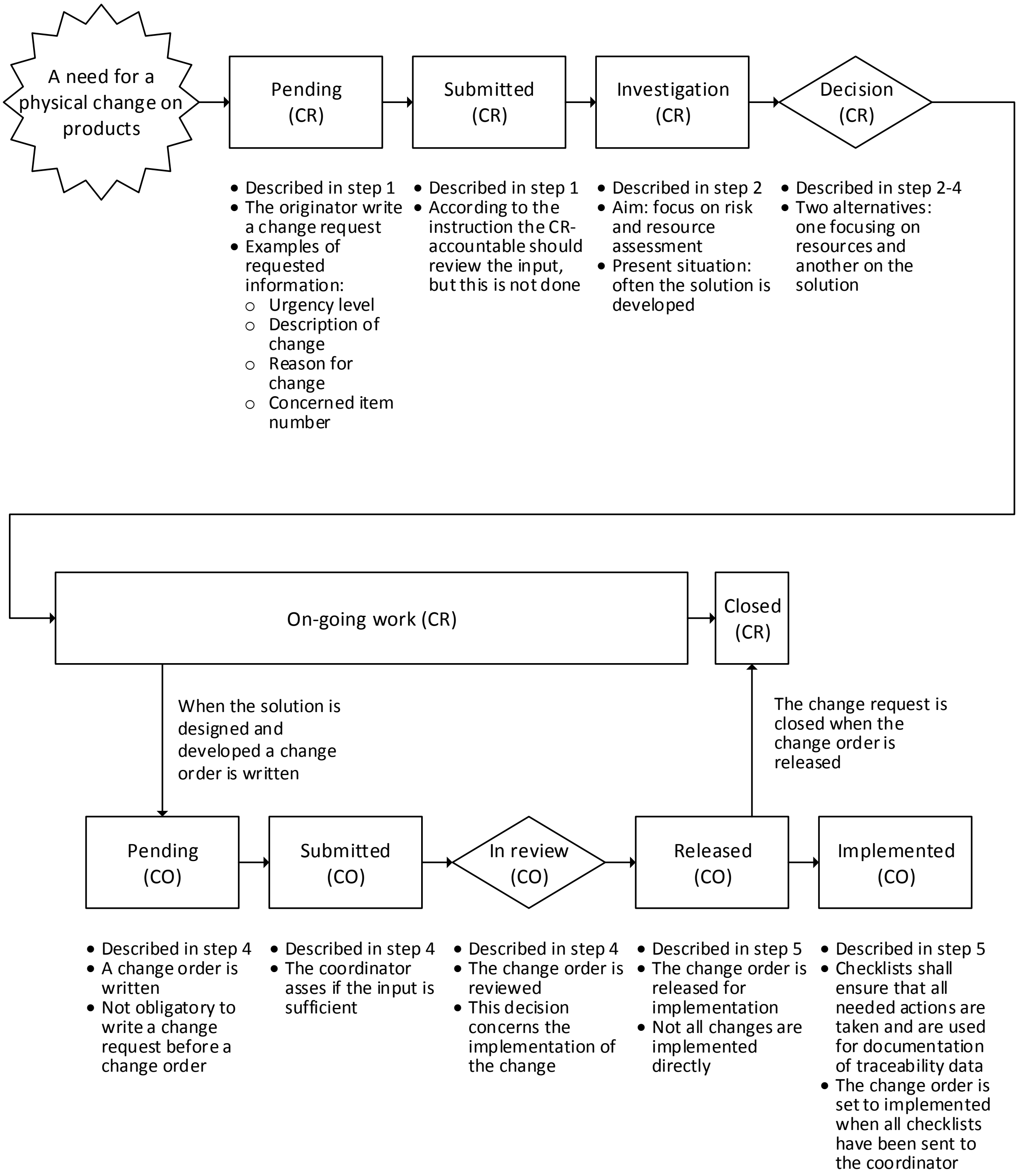

Figure 7. A description of the Physical Change Process at Ascom Wireless Solutions

The instructions claim that change requests lacking a favourable business case can be rejected or cancelled at any time. This was commented by a couple of interviewees saying that there are change requests (and also change orders) that are accepted too soon without sufficient information and/or evaluation. However there are change requests that are not driven by costs (e.g. regulatory changes and customer complaints) and must be carried out regardless of cost. A few comments also indicated that, even if a change request is rejected, it is pushed through the process.

4.2.1.1 Classification and prioritisation of changes

A parameter that has to be set by the originator is the urgency level of the change and there is an uncertainty of what urgency level to use. Ascom Wireless Solutions uses two levels for classifying the urgency of change requests and change orders; urgent and routine. Opinions about if the parameter is used correctly differ and there are no clear rules for when or why to set a change request or change order to urgent. Moreover, the urgency level of the change request is sometimes changed during the process. Reasons for changing the urgency level might be that the CR-accountable makes a different assessment of the urgency or that the most urgent stage of the process has passed.

A change request is also classified by “change type” and “reason code”. The change type regulates what functions the change request concerns e.g. Mechanics and/or Hardware. According to the instructions, the reason code should be set to cost reduction or improving source situation. Although, it is possible to select other options, such as non-conformance and correction/completion of item info, in the PLM-system.

4.2.2 Identification of possible solutions to change request (Step 2)

In the investigation step in the change request the aim is to focus on resources, but that is not always the case in the current process. Figure 8 is an illustration of two different scenarios, one focusing on resources and one on the solution.

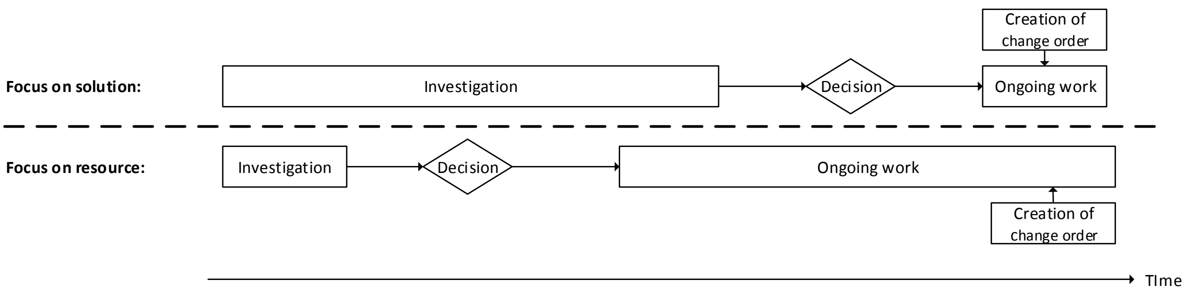

Figure 8. Illustration of two different scenarios in the change request. The workflow above the crosshatched line has a focus on the solution and below the line an example of a process having a resource focus is presented.

When focusing on the solution, the investigation phase is often longer since the work with solving the problem starts immediately, before the decision. Then, right after the decision in the change request is taken the change order is created. This decision is then closer related to the solution than resources. In the case of resource focus, the decision concerns what and how much resources that are needed to solve the problem and if that resources are available. A commitment from functional managers to dedicate resources is a part of the decision in this case. If the resource decision is approved the work with developing a solution starts and when this work is ready the change order is created.

4.2.3 Risk and impact assessment of solution (Step 3)

There seems to be no systematic risk or impact assessment conducted in the Physical Change Process. The investigation step in the change request does not seem to handle risks or impacts of the solution and the review of change orders appears to be more about an individual approval and contains no common risk or impact assessment. However, there is a document called TRC (Time Risk Cost) that should be used to estimate working hours, risk with the solution and fixed costs related to the change request. This document is rather comprehensive since it is developed for project planning and not adapted to the Physical Change Process. Hence, the reviewed change requests often lacked the TRC document.

4.2.4 Assessment and approval of a solution (Step 4)

The product structure results in a large number of interdependencies and hence changes must often be evaluated and approved by several functions. A change in hardware can for example affect mechanical parts and/or regulatory issues. Also Production Engineering at the in-house production site and representatives from the department handling outsourced production may need to be involved in the change process.

A first assessment and approval is done in the change request. As mentioned in section 4.2.2 this decision can be focused on either resources or solution. For this assessment it is not clear who should be involved in the approval process. According to internal documents, the choice of decision makers should be based on type of change and a pre-defined list but in the reality it is done by experience and gut feeling. However, if the change is assumed to require more than 40 work hours from one or more functions involved, the decision regarding if the requested change shall be conducted or rejected is escalated to the concerned product line.

After the change request is approved normally a change order is written. However, there are two ways of initiating a change order. First, a change order can be written when the change request is in “On-going work”. The second alternative is to directly write a change order without first writing a change request. There are no formal rules saying that a change request needs to be written before a change order is created, consequently some change orders are not preceded by a change request. This is a decision made by the originator.

Problems concerning the input in a change order are of the same character as for change requests. Many interviewees are asking for higher requirements and better specifications of the input. Also the issue about variations in quality depending on the originator can be seen in the case of change orders. Since a change order often include technical details and information, it might be hard for people not familiar with the technical language or details such as specific item numbers to understand what the change order implies.

After the change order is written it is submitted to the coordinator who assess if the input is correct and sufficient. If not, the change order is sent back to the originator or the coordinator can choose to complete the change order. There are no formal rules defining “sufficient information” hence it depends on the coordinator’s assessment. The coordinator is thereafter responsible for sending the change order to “In review” and decides who shall be involved in the approval process. According to internal documents the change order does not have to go through the step called “In review” (Figure 7). Whether it is necessary or not is a decision made by the coordinator. Though, there seems to be no instructions what to evaluate or consider when choosing the simplified workflow excluding “In review”.

Another problem related to the approvals was the difficulty to make the decision. The major reason was that it is not formally defined who is responsible for approving what. Some interviewees expressed an uncertainty concerning if all aspects in a change order was approved since they found it difficult to know what aspects their colleagues approved. Other interviewees did not recognise this problem and had no problem to approve change orders. In these cases, the explanations to why they had no problem approving were, either experience of the task or that they considered their approval responsibilities described in their job outline.

Some employees expressed that they sometimes received a message to approve a change order that they were forced to reject because they had not been involved from the beginning of the change process. Hence, their interest had not been considered and the change order did not align with the requirements from the function.

The decision regarding implementation of the change is taken in the step called “In review”. When the coordinator sends out the change order for decision the Approvers, Observers and Notified are chosen based on a pre-defined list. Approvers are people that need to approve or reject a change order. Observers on the other hand have the opportunity to act on a change order if they recognise errors or have other input. The third group is notified and they can only make comments and have nothing to say about the decision. The coordinator specifies these roles and all Approvers, Observers and Notified persons get a PLM-system-generated e-mail with a link to the change order. The interviews indicate that only approvers assimilate the information, observers and notified avoid these e-mails and often delete them without reading.

There is a rather general opinion among employees involved in both change requests and change orders that they are asked to make the same decision twice. There are others knowing the difference between those decisions and have no difficulties with two decision points.

4.2.5 Implementation of solution (Step 5)

Implementation of the solution starts once the change order is released. Though, a decision to implement does not always imply an immediate change in production since the implementation depends on previous decisions about urgency, scrapping of inventory etc.

The functions affected by the change use checklists to make sure that they perform all necessary actions for realising the implementation and for documentation of traceability data. The checklists are developed by each function in order to support each function’s needs. When a checklist is filled in it is sent to the coordinator via e-mail. The coordinator then attaches the checklist to the change order, and enters the traceability data into the PLM-system. When all checklists are e-mailed to the coordinator the change order is set to

“Implemented”. Hence, if any checklist is missing the change can be implemented in production but not set to “Implemented” in the PLM-system.

4.2.6 Review of particular change process (Step 6)

No specific questions about follow up on particular changes were asked during the interviews nor did the interviewees mention anything about follow-up, metrics or standardised ways to learn from old cases.

4.3 Factors affecting the overall Physical Change Process

Factors affecting the overall process are; understanding the process, process flexibility, communication within the process, responsibility within the process and lead time. These factors will be discussed below.

4.3.1 Understanding the process

Several people involved in the Physical Change Process lack a general understanding of the process. One issue concerns the uncertainty of how to handover the task to the next person in the process and who that person is. Another problem is that the participants understand the process step(s) that they are personally involved in but do not fully understand the consequences of their actions for other functions. For example one function might request a change in order to reduce cost, but the cost reduction might be so small that the cost for evaluating and implementing the change eliminate the potential savings.

The interface between the lifecycle phases pre-production and active sustain is another issue causing confusion. After the Product Acceptance Meeting the product’s lifecycle status is changed to active sustain, but the development project is still running. At the same time the production is ramped-up (see Figure 6). In this phase the division of work between the coordinators are clear. Once the lifecycle is changed to active sustain all change requests and change orders concerning the product are handled by the coordinator responsible for products in active sustain. But the division of work and responsibilities between the line organisation and the project organisation are vague for some people.

Another aspect that became clear during the interviews was the inconsistencies regarding names on the different workflows, processes, activities, requests and orders. Different words were used to describe almost the same thing and often names were used incorrectly. This issue is related to the difficulty to understand the relationship between change requests and change orders i.e. when in the change request a change order is written and what activities that shall be conducted during certain steps (see section 4.2.2).

4.3.2 Process flexibility

Regarding the flexibility in the Physical Change Process, one aspect that has been mentioned in the interviews was the possibility to directly write a change order. The motive is that it goes faster than writing a change request first.

When looking at the entire process, including all lifecycle phases, the change orders are handled differently depending on the requirements related to the different phases of the product lifecycle. There are three workflows for change orders called; zero series, fast approvals and product changes. These three types of change orders have different levels of flexibility; however the workflow product changes should be used in the Physical Change Process. All workflows for change orders have the same flow. However, some steps in the process are simplified or by-passed for changes on products in the lifecycle phase pre-production. As an example, less people is involved in the review. Also, change requests are not used during this lifecycle phase.

4.3.3 Communication within the process

The Physical Change Process is supported by the Physical Change Forum. The Physical Change Forum is a cross-functional meeting where incoming and active change requests are processed. However, it is relatively often that representatives from e.g. Hardware are not present at the forum meetings. At the meetings there is no time to discuss problems with specific change requests since all change requests should be addressed and the date for next checkpoint is set. This date is based on an estimation of the time needed to perform the work that should be conducted before the request needs to be processed at the Physical Change Forum. During these meetings the participant can note if his/her function needs to be involved in any change request. The opinions about this Physical Change Forum differs and some participants appreciate the meetings as they are and some request another structure of the meeting allowing discussions and problem solving related to complicated change requests.

Another problem of communication is the lack of understanding between functions. Information in the change request/order may be clear to the originator's colleagues but impossible to understand for people from other functions, causing frustration and dely.

4.3.4 Responsibility within the process

All products have a responsible Product Manager. The Product Manager owns the final decision for changes regarding the products within his/her responsibility and sometimes takes the role as the owner of the change request/order. Though, Product Managers do not have an interest in changes that do not affect the form, fit or function of the product i.e. changes not affecting the customers. There is an uncertainty regarding who owns a change request and change order. The interviewees did not share the same picture; some considered the owner to be the originator, others the Product Manager, the CR-accountable or the person currently working with the change request/order.

Moreover, many interviewees are unsure if there is an owner of the Physical Change Process, and if so who the owner is. Some wrongly consider the CR-accountable to be the owner of the process. Ascom Wireless Solutions has quite recently made some organisational changes and the current owner of this process has not clearly communicated the ownership.

Ascom Wireless Solutions aims to send the approvals to a group of people. An exception is the OEM-accountables who receive an individual notification. Sending out e-mails to a group results in that individuals receiving a large number of PLM-system-generated e-mails, that is relevant for only one person in the group. This is perceived as a problem, especially for Product Managers since they have different responsibilities within the group and almost all changes affect at least one of the Product Managers. Some functions solve this issue by assigning a coordinator distributing the approvals to the "right" person.

A feature in the PLM-system, called “transfer authority”, can be utilised to transfer authority to approve change request/change orders during planned absence such as vacation. Besides the possibility to transfer authority the functions can also make a decision to create an escalation to for example the manager if no one has approved the change request/order within a certain time period. These functions of transfer authority and escalation are utilised by a few, but others had never heard of it.

4.3.5 Lead time

The general impression is that the Physical Change Process is considered to be complicated and slow. The long lead times can be a problem since old and new changes may overlap regarding both time and scope. Another concern is problems for the people involved to stay informed during the entire lead time. Also, unsolved quality problems may result in additional costs such as costs for repair and warranties since produced products will be of poor quality until the change is implemented. Though, if a change is urgent the time to issuing and implementing the change can be short, but to speed up the process extensive communication is needed resulting in a lot of phone calls. In addition, work is sometimes done outside the process since people consider the process to be too slow. For example, the change request might be written after the change is implemented.

Changes handled in the Physical Change Process are prioritised differently among employees. Some checks the e-mails from the PLM-system on a regular day-to-day basis while others may store the e-mails in a separate folder which they check once a week or once every second week. Therefore the process is stagnated for a shorter or longer period of time depending on who is involved in the current issue. The alternative is that someone makes a phone call to remind the person to complete his/her obligations.

As can be deduced from Figure 9 and Figure 10 the value adding time in the Physical Change Process is small compared to the throughput time. The collection of data resulting in the Value Stream Maps is described in section 2.3.6. This is also supported by some of the interviewees who expressed that the Physical Change Processes contain a large amount of waiting time and that the process is generally slow. Long lead times when for example ordering samples and new tools affects the lead time for the change process but cannot fully explain the long throughput time. A number of interviewees expressed a need to work ahead of the process or outside the process due to the long lead times.

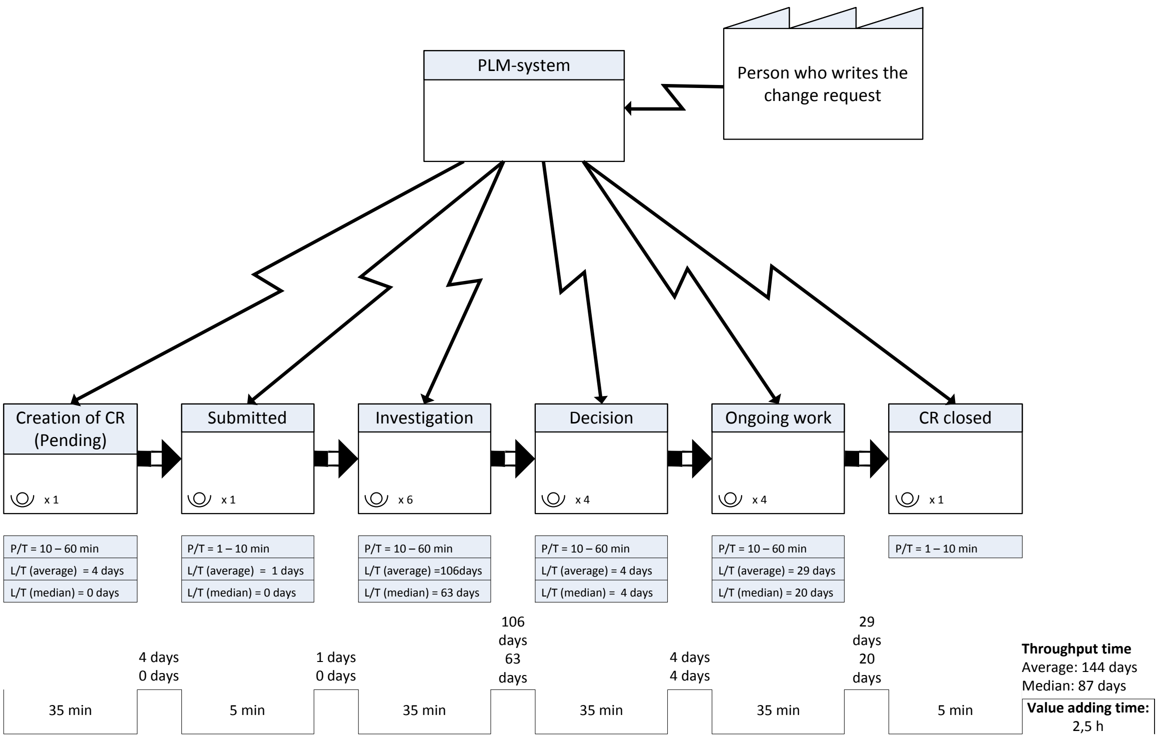

Figure 9. Value Stream Map of change requests.

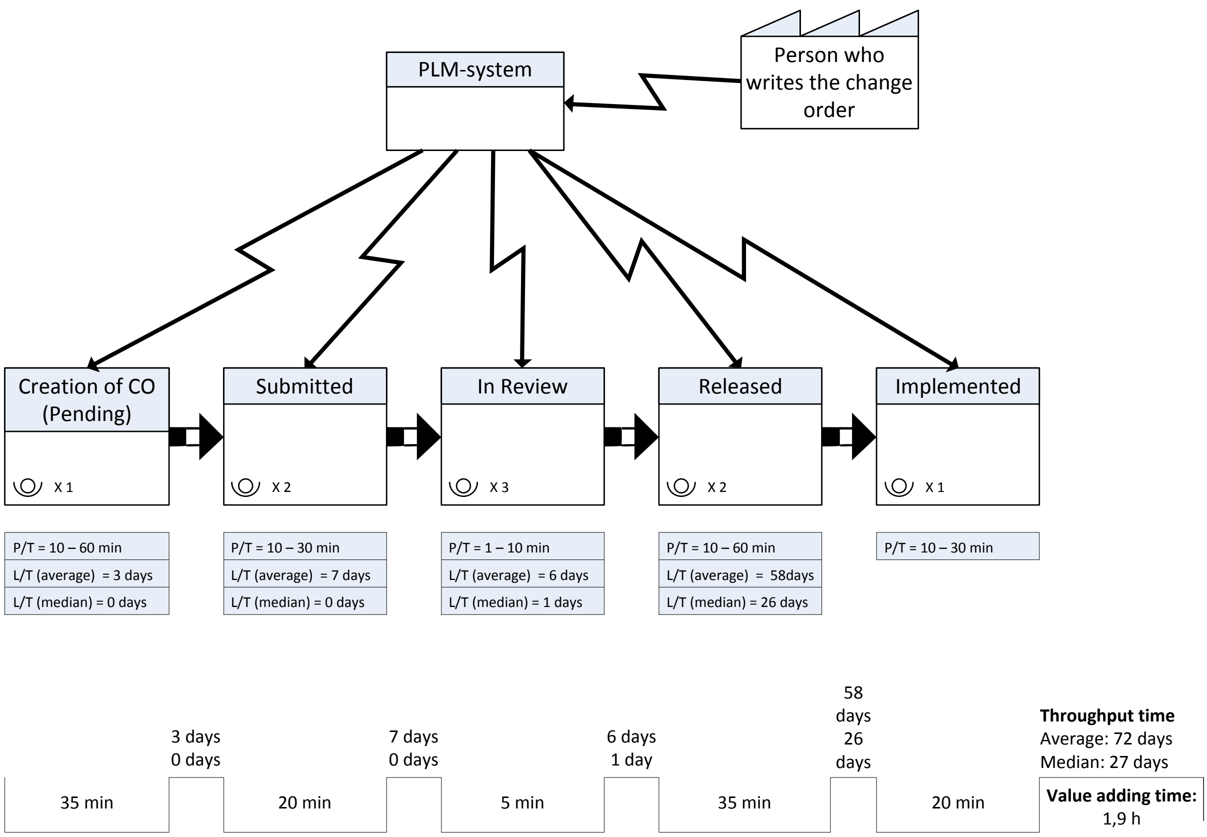

Figure 10. Value Stream Map of change orders.

The lead time for a change order, from “Pending” to “Implemented”, is highly dependent on the submission of checklists to the coordinator. It might take many months before one change is implemented in the production since it for example can be decided that the previous version of the component should be used until it is out of stock. Moreover, the change can be implemented fast, but if the checklists are missing the change is not set to “Implemented” in the PLM-system.

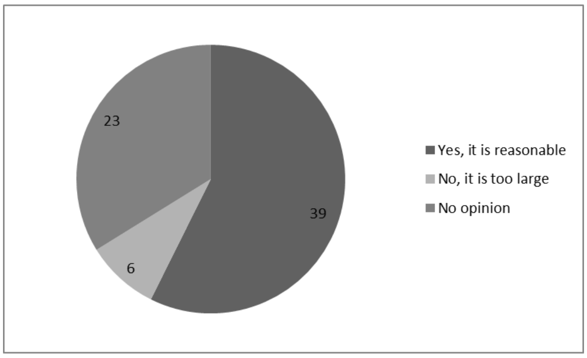

Figure 11. Result from the survey question: “Do you think that the time you spend on a change request is reasonable?”

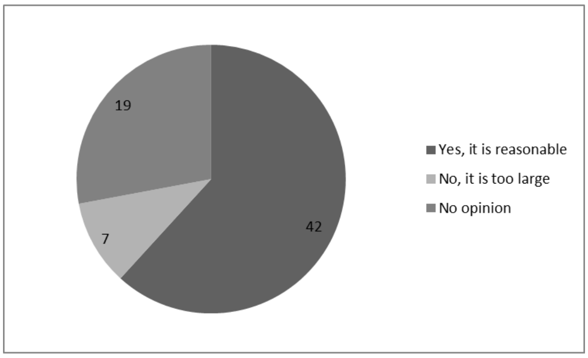

Figure 12. Result from the survey question: “Do you think that the time you spend on a change order is reasonable?”

According to the survey (see section 2.3.5), the majority of the respondents did not perceive the process time (the active time spent on each change per person) as too long for change requests or change orders (see Figure 11 and Figure 12). One should have in mind that the process time differs between the change requests/change orders due to differences in complexity of the problem, quality of the input etc. Even though the process times differ one may assume that the non-value adding time is always much longer than the value-adding time. The work is assumed to be done in parallel hence the actual process time might be slightly higher since some tasks must be done serially. For further discussions about the results see section 2.3.6.

4.4 Study visits

Findings from the study visits are presented in this section. The companies are operating in diverse industries and are of different sizes. However, all of them have a formal Engineering Change Process. Short descriptions of the context and summaries of the findings from each study visit are presented below.

4.4.1 Engineering Change Process at Company 1

In comparison to Ascom Wireless Solutions this company is significantly larger. However, both companies produce and develop electronic devices. The process reviewed at this company is applied in the product development phase, and is a formal change process (see Figure 13). A general process is used throughout the company but slight differences exist between the divisions, thus noteworthy is that only one division has been reviewed. The change process is handled from one location, while development project can be conducted at several locations worldwide.

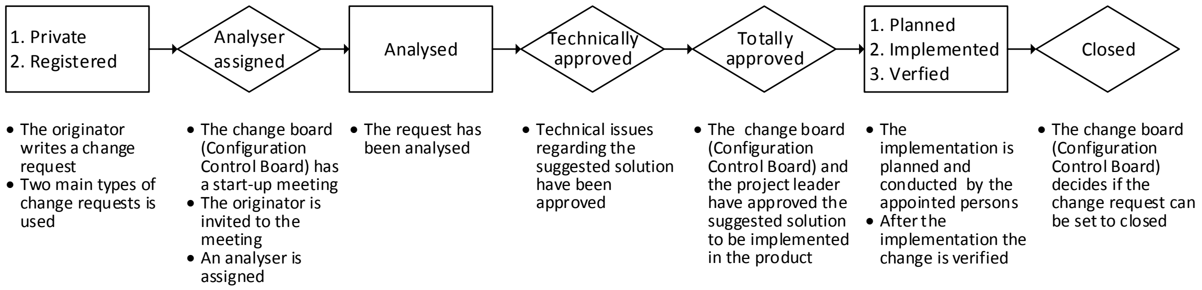

Figure 13. The studied change process at study visit Company 1.

Two main types of change requests are used, one for technical changes and one for document changes in the baseline report, which is the document controlling technical documentation related to the products. The baseline report provides access to the latest revision of the documents and change requests related to the product. The process for changes in the baseline report is somewhat simplified with less persons involved in the analysis and in the process after approval. A disadvantage with the baseline report is that it must be updated manually, which increases the risk of errors.

In general, everyone can write a change request but usually the requests are written by a designer from one of the development projects. All information in the form is not always needed, though the obligatory fields are clearly marked. If additional information is needed, it is gathered at the start up meeting or the originator is asked to provide it.

The CCB (Configuration Control Board) is a cross-functional team which has the authority to change the configuration of items. There are several CCBs within the company and each has a manager leading the work. The studied CCB has regular meetings every week. All change requests are handled at the first CCB meeting and change request of type Baseline Request are approved at the this meeting. Other change requests are approved at the second CCB meeting (see Figure 13). The originator of the change request is always invited to the meetings concerning his/her change request.

The process contains four decisions points. The first decision concerns the division of work, and the CCB decides who shall do the analysis, planning and verification. During the second decision phase the analysis is reviewed by the board and if approved the solution is technically approved. Thereafter the change goes from technically approved to totally approved, i.e. the Project Manager has approved the change to be implemented, in the third decision point. The fourth decision concerns if the change request can be closed.

4.4.1.1 Factors affecting the overall Engineering Change Process at Company 1

Company 1 has experienced difficulties since many employees are involved in the change process occasionally and therefore often lack knowledge on how to proceed and what is expected from them. This has resulted in a delayed process since some people have deleted e-mails because they did not consider the e-mail to concern them. In order to gain a deeper understanding of the process and to inform employees about the process the company has designed an information guide, describing the activities within the process.

It is uncommon that a change request is rejected. According to the interviewee the reason is that the change is discussed before a change request is written. Further, the company experience problems regarding change requests that take long time before they are closed. According to the interviewee, some reasons for this might be the lack of understanding of the process, but also the geographical distances and low prioritisation by the Project Managers responsible for development projects.

4.4.2 Engineering Change Process at Company 2

This company is a global manufacturing company with production in 19 countries. The size of this company is significantly larger than the size of Ascom Wireless Solutions. For this thesis, the business unit responsible for developing and manufacturing powertrains has been studied.

The company has a highly standardised process for product development and for conducting projects and all employees are educated in this process. For engineering changes during the maintenance phase, often a simplified, but standardised process is used. The business unit has a department working only with maintenance, quality and cost reductions and the department manager is the owner of the process equivalent to Ascom Wireless Solutions' Physical Change Process.

The change requests can be initiated through different sources; quality issues, saving potentials, troubles in production and suggestions from other internal sources. The input to the process comes from different sources and is handled in different processes depending on what type of change it is. For example, high priority issues are handled in a flow which is faster. The cross-functional team handling such changes always consists of the same representatives, which facilitates the communication between functions. Large and complex changes are handled in projects which follow the same process as for product development hence require a time plan, budget and a project team. However, the focus in this thesis is the process handling Product Change Requests (see Figure 14).

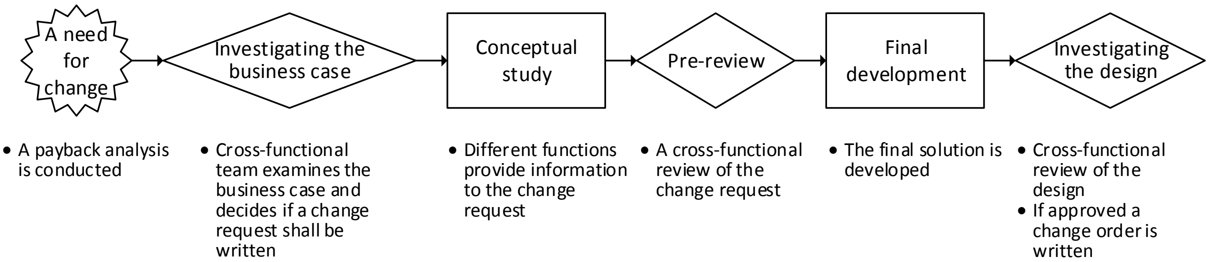

Figure 14. The studied change process at study visit Company 2.

To be able to initiate an engineering change, it is necessary to provide a business case to proceed with the suggested change. It is the originators' responsibility to formulate the incentives if the request is to be handled further in the process. Also, a payback analysis and a calculation of the Internal Rate of Return have to be attached to the request.

A cross-functional team with representatives from Aftermarket, Production, Purchasing, the responsible engineer and the Product Manager is responsible for investigating the suggested change. The cross-functional team has a start-up meeting and before identification of possible solutions the cross-functional team takes a decision whether the suggestion for a change shall result in a change request or not. After the cross-functional team has decided that a Product Change Requests shall be written, a conceptual study is initiated. A template with all necessary information is filled in by the functions involved and what part of the template that each function is supposed to fill in is clearly stated. When the conceptual study is completed, a pre-review is conducted before the process continues to the final development of the solution.

The company uses a computer system to send out Product Change Requests for review and approvals, and the issue is sent out to a group of individuals within the same function or to individuals. To reduce the dependence on individuals the group e-mail is preferred. The approvers have three weeks to review a Product Change Requests. Moreover, the Product Manager shall approve all changes concerning the product within his/her responsibility. Also the company emphasise the importance of using the formal process and correct information, hence the information in the Product Change Requests is rigorously examined and cross-checked so all internal demands has been complied. In the final decision the suggested design is reviewed and if approved a change order is written.

Changes resulting in cost reductions that affect the production are grouped and implemented at four occasions per year. The number of slots has been discussed since there is a trade-off between implementation cost including disruptions in production and loss in savings potential. Changes concerning quality issues as well as Product Change Requests are not grouped but implemented continuously. The implementation of Product Change Requests could be improved according to one interviewee, e.g. Product Change Requests could be grouped together with changes concerning cost reductions.

4.4.2.1 Factors affecting the overall Engineering Change Process at Company 2

Due to the large number of people involved one interviewee perceived the process as slow and bureaucratic. Since the process is updated on a regular basis it might be challenging for those who only work within the Engineering Change Process a couple of times per year to stay informed of new rules and routines. However, all changes are reviewed and if something is missing or wrong it will be detected, although it is time consuming to iterate the process.

Further, this company utilises a large number of computer systems supporting the change process resulting in additional work according to one interviewee. For example, the same information has to be filled in at least twice since there is no synchronisation between the IT-systems.

This company’s development and change processes were dependent on the size of the change/modification/development request. The process was flexible and changes were handled differently depending on for example the size of the change and the number of involved production sites. Larger projects have to go through a more extensive assessment including a large number of control activities.

When it comes to reviewing and approving changes, this company experiences the consequences of too many people wanting to be involved in the decision, one interviewee called this “over administrative decisions”. Cross-functional teams are well-functioning, and the teams are considered as well-defined and trusted within the organisation. This team enables the company to take tough decisions further down in the organisational structure, since senior management rely upon this team to make correct decisions.

One interviewee emphasised that the generic process for how to run projects could not explain how people should perform certain activities in the process handling Product Change Requests. To clarify responsibilities and rules in this process the company has more comprehensive documentation concerning each step including; roles, rules and deliverables for different roles/functions/departments.

4.4.3 Engineering Change Process at Company 3

The third company is the most similar to Ascom Wireless Solutions when it comes to the number of employees. This company manufactures fork lifts, products are standardised and customised based on modules. One difference that can be mentioned is that this company’s R&D is located at one site.

The process consists of the phases described in Figure 15 and is used regardless of the complexity of the change. Though, for minor changes the work within the phases is simplified and the number of people involved is reduced. Most often it is suggestions from Aftermarket or ideas from Production that initiate the Engineering Change Process. A change can also be driven by new technology, new requirements, Last Time Buys or cost reductions.

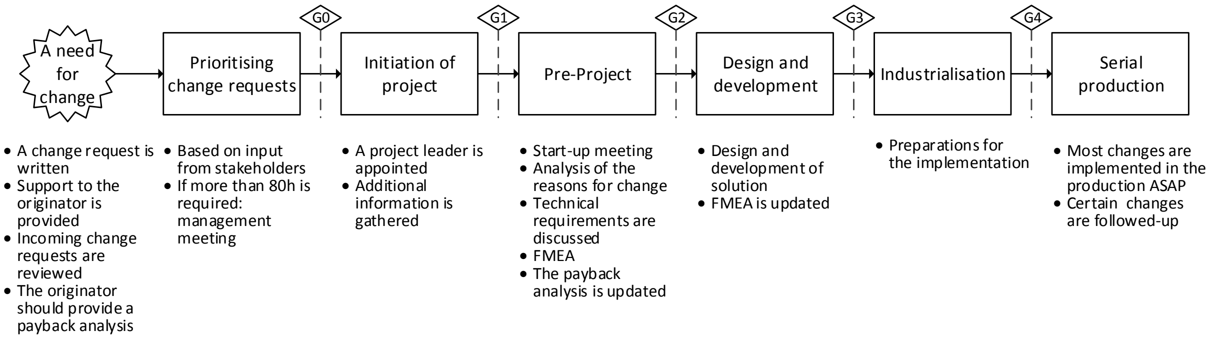

Figure 15. The Change Process at study visit Company 3.

There are certain requirements on the input to the process. For a change to be handled the following information has to be provided before the pre-project is initiated:

- Reason for change: statistics and facts are used to motivate why a change is needed.
- Suggestions for solution
- Delimitations
- Preliminary payback analysis
- Suggestion of project leader/group

The interviewees stated that the originators did not always provide the required input. Also conducting the payback analysis might be difficult for the originator. If the input in the change request is insufficient additional information is gathered during the initiation phases. To ensure a high input quality, the company has checklists regulating what to include in each step. Another way they work with securing input quality is that the Maintenance Organisation provides support to the person initiating the change request and they also review all change requests. The Maintenance Organisation has dedicated resources to handle change requests; however other functions are also involved in the change process.

There is always a project leader appointed regardless of the size of the requested change. The project leader, often a design engineer, owns the request and is responsible for the outcome. Appointing a project leader is a way for Company 3 to ensure that the change request is not stagnated in the process.

Change requests are prioritised during the initial phase of the process. The prioritising is conducted based on information from the stakeholders; Aftermarket, Purchasing, Marketing, Production and Design. If the change is estimated to take more than 80 hours the decision has to be taken at a management meeting. The prioritisation should not only result in execution of large changes solving complex problems expected to result in great positive effects. Also minor, more simple problems should be prioritised since they generate value faster and do not require as much resources. The balance between prioritising complex and simple changes is important to Company 3. Some changes have to be carried out even if they do not seem profitable in the short term.

During the pre-project the reason for change is analysed and technical requirements on the solution is discussed. FMEA (Failure Modes and Effects Analysis) is used to evaluate risks concerning the change. The FMEA is conducted by a cross-functional group of at least three persons. The risk evaluation should include assessment of how the change affects modules, product structures, technical documentation and the production. Moreover a verification plan and time plan is created and the preliminary payback analysis is updated. The next step is to design and develop the final solution.

When the design is finalised, the risk assessment is updated. Before continuing to industrialisation, there are many aspects to take into consideration such as decisions concerning make-to-order, plans for scrapping or use-up of material and implementation. The effects on documentation, prices and modules are again considered.

In the industrialisation step, the implementation of the change is prepared, for example material and logistics planning activities are performed. When the preparations are settled the change is implemented in the production. The changes affecting the current price list are released at specific time slots two times per year. Though, these kinds of changes are only representing two per cent of the total amount of changes. Other changes are implemented as soon as possible.

After each change has been implemented there is a follow-up to gather knowledge gained from the change process. Each department has the opportunity to give their input and opinions on what went wrong and/or what went well in the process. However, this evaluation is not conducted for all changes. The selection of what changes to review depends on the complexity of the change and if the change could be of interest from a learning perspective.

4.4.3.1 Factors affecting the overall Engineering Change Process at Company 3

The interviewees emphasise the need for individuals to understand the process, each person involved in the process must understand the consequences of a certain decision in order to have a well-functioning process.

Cross-functional teams are applied in the Engineering Change Process. The people attending the cross-functional meetings differ, but the company considers it rather easy to determine who should be involved in what change with an exception; when a change affects many models. There is also a group of experts that can be consulted in difficult situations, most often in the decision before moving on to the industrialisation phase. This group consists of 6-7 key persons experienced in their specific area and the group is consulted when the project team needs their expertise.

Often there are many individuals involved in the decisions, though it is sometimes sufficient to involve only a Design Engineer and a Production Engineer. The number of people involved and which functions to involve depend on the type of change. However, the Product Manager responsible for technical issues is always involved in the final decision. This person is also responsible for the follow-up of changes.

There is one decision called gate (go/no-go) between each step in the process. The sooner in the process that a change request is rejected the better, but sometimes it is impossible to forecast the results from a request or the outcome of an external test. The decision can also be to iterate the process.

This company does not have a PLM-system to fully support their Engineering Change Process, though they use an older computer system, but still there is a lot of manual work.

4.5 Performance measurements

Measuring the process performance of the Engineering Change Process is important in order to evaluate the process. The following sections describe how Ascom Wireless Solutions and the three study visit companies measure their Engineering Change Processes.

4.5.1 Measurements at Ascom Wireless Solutions

There is a lot of data stored in the PLM-system, which could be used for measuring performance. However, there is only one metric measuring the process for the moment and that is the number of open change orders. Approximately once a month, a list of open change orders is compiled by the coordinator. This is a way to remind the different functions to hand in checklists since the checklists are needed to set the change order to “Implemented” in the PLM-system.

Moreover, the interviews revealed that the purchasing department measures the number of written change requests. The change request created at this department often aim to reduce purchasing cost hence the number of written change requests can be related to cost savings for the department. However this measure is not actively used at the moment.

4.5.2 Measurements at the study visits companies

At Company 1 the number of open change requests per month is measured and this measurement is also divided into the different process steps. Furthermore the lead time from a change request is registered until it is totally approved and from registration to closing of the request is measured (see Figure 13).

One parameter that is measured in Company 2 is the lead time through the process. The total lead time is measured but also the lead time per department and process step. For each workflow the company has a target time. The target is the maximum number of days the process should take to perform. This number is identified through statistics from previous change requests and internal benchmarking. There is also a follow-up on these targets. This company uses these measurements as a way to motivate people to complete their tasks on time. One interviewee said that late approvals and delays is visualised through the metrics.

Further, Company 2 measures if the deadlines for change orders are reached. The company also follows-up the origins of the change requests, and the reason for change. It is possible for the manager to delegate the responsibility to approve change orders, but since this possibility is used in a too large extent the percentage of change order signed by the head of the sections is also measured.

A metric called “direct runners” is used at Company 2 as a way of measuring if a new product passes the development process without being iterated i.e. going through the same step twice. This metric is applied after a specific stage in the process where the design is rather set and not during the early stages of the development process.

Company 3 finds it relatively difficult to measure this process. Today, the company measures number of performed changes on department level, but the interviewees can see some difficulties with this measurement since there are prerequisites at the departments which inhibit their performance. Another measurement that the company utilise is punctuality i.e. if they deliver the changes on time, according to the set deadlines. The company expresses an interest in assessing the effort needed to perform the change versus the value generated by implementing the change, but stresses the difficulty to estimate the value.

4.6 Summary of empirical findings

The aim of this chapter was to describe the Physical Change Process at Ascom Wireless Solutions and to identify challenges within the process. The identified challenges are the essence of the summarised interview data in Appendix E. The challenges at Ascom Wireless Solutions are summarised in Table 3.

Table 3. Summary of challenges in the Physical Change Process at Ascom Wireless Solutions.

Challenges	Description
Long lead times	• Higher process costs • Work is performed outside the process • Overlapping changes
Uneven quality of input	• Input is dependent on the originator • Input is often written without considering who should read and understand the information later on • Unclear instructions on what to include in the input
Unclear responsibilities	• Unclear if all aspects of a change is reviewed and approved • The process halts if no one is responsible for the next action • Unclear instructions regarding responsibilities within the process • Unclear who the owner of change request/orders and the Physical Change Process is
Work is performed outside the process	• The complexity of the process makes people work outside the process e.g. making phone calls for additional information and bypassing the change request • Result of long lead times
Lack of overall understanding of the process	• Difficulties to understand the purpose of activities • Difficulties to see the consequences of actions • Lack of overall process description
No standardised assessment of incoming change requests	• Difficult to know if the change will result in any benefits for the company • Errors are discovered late in the process e.g. functions are involved to late in the process • No standardised classification or prioritisation of change requests/orders

There are some differences and similarities in how the reviewed companies measure their processes, for example lead time and number of open changes are measured in more than one company. The performance measurements applied at the companies are summarised in Table 4. The challenges and the performance measurements will form the basis for the analysis.

Table 4. Summary of performance measurements identified from interviews at Ascom Wireless Solutions and the three study visits.

Identified Performance Measurements	Explanation
Lead time per process step	The time it takes to complete one step in the process e.g. writing a request
Total lead time	The total response time from writing a request until it is implemented
Direct runners	Products that pass the development process without being iterated i.e. going through the same step twice
Punctuality	If working with deadlines or target dates the punctuality is measuring if the change is implemented on time
Number of open changes in total	Total number of changes created but not implemented
Number of open changes per process step	Same measurement counted per process step
Number of open changes per department	Same measurement counted per department, i.e. where the change is "stuck"
Number of changes created per department	How many change requests that one department initiate
Percentage of change orders signed by the manager	How many change orders that the manager signs without delegating the responsibility

5 ANALYSIS

In this chapter the empirical findings is analysed based on the findings from the literature review and the study visits. The analysis is structured based on the challenges identified in chapter 4 (see Table 3). Based on literature and empirical findings solutions for each challenge are suggested. The analysis reveals suitable proposed solutions to solve a certain challenge for Ascom Wireless Solutions.

A specific solution, aiming to solve a certain challenge will have synergy effects on other factors affecting the performance of the Engineering Change Process. These relationships between challenges, solutions and factors are illustrated in Figure 16 and will be decomposed and explained further in the following sections.

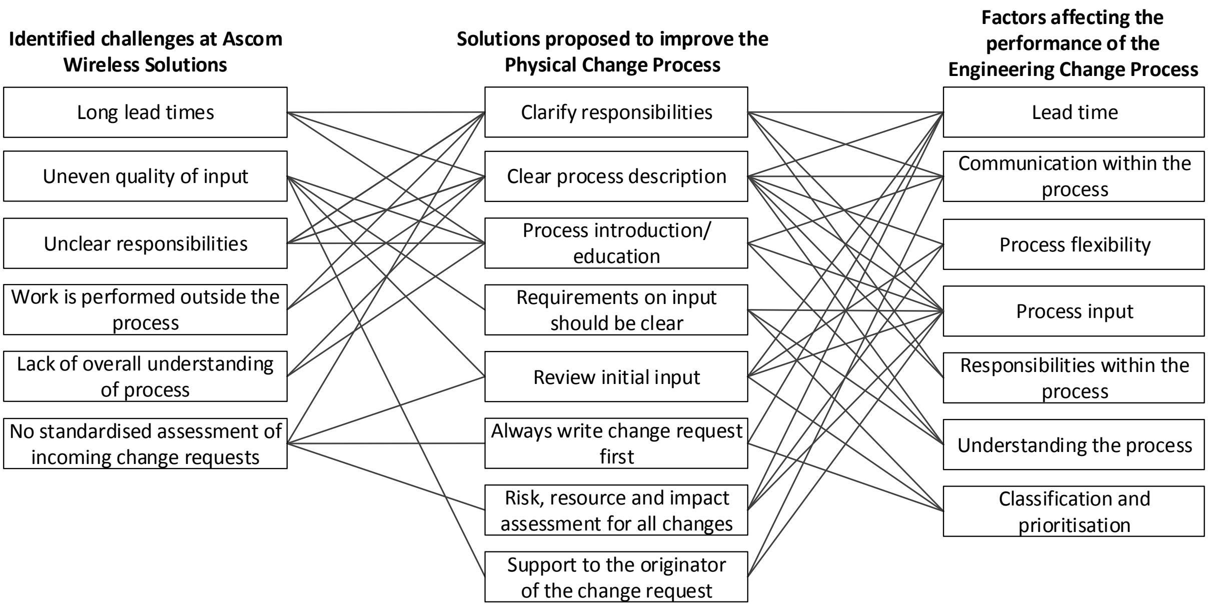

Figure 16. The relationships between challenges, solutions and factors.

5.1 Challenge 1: Long lead times

The Engineering Change Process was regarded as slow at most of the reviewed companies in this thesis as well as at companies studied by other authors. A risk of a slow process is the use of informal processes to handle changes; also delayed implementation can cause additional work and adds costs (Terwiesch & Loch, 1999a; 1999b). Hence, the lead time of the Engineering Change Process is crucial. A clear process description is suggested to decrease the lead time (see Figure 17) which contributes to easier understanding of the process for the participants (Tavcar & Duhovnik, 2005).

Concerning the active process time spent in the process most respondents from Ascom Wireless Solutions did not perceive the active process time as too long and at the same time they considered the throughput time to be too long. Hence the non-value adding time in the process can be expected to be extensive which was also supported by the result of the Value Stream Mapping. Therefore one should focus on reducing the non-value adding time before effort is made to reduce the value-adding time. Though, there will always be some waiting time in the Physical Change Process due to lead times from suppliers etc.

A common understanding of the process would have a positive effect on the lead time (Tavcar & Duhovnik, 2005) since the risk of individuals delaying the process unintentionally will decrease, as described by Company 1. Common understanding is facilitated by a clear process description, clear responsibilities (Watts, 2012) and by educating the participants in the Physical Change Process. These solutions will together impact most factors as shown in Figure 17. As summarised in Figure 17 the factor "Clear process description" alone affects several factors. This indicated that this solution will generate a relatively large positive impact on the overall Physical Change Process.

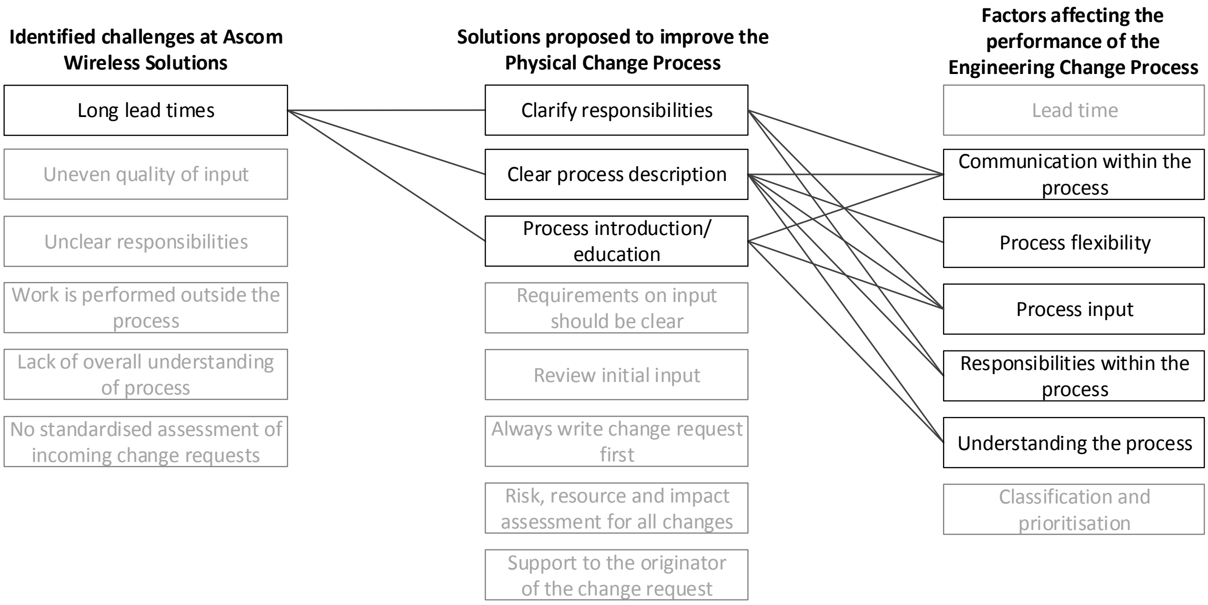

Figure 17. Illustration of what solutions are suggested to the challenge "Long lead times" and the interplay with the factors.

However, some of the suggested solutions such as adding a "Risk, resource and impact assessment for all change requests", "Review of input" and "Always write a change request first" (see Figure 16) will, on the one hand, probably increase the process time. On the other hand, the positive effects will be that the total lead time would decrease as process uncertainties are reduced through a clear process description communicated through some form of education to all participants.

5.2 Challenge 2: Uneven quality of input

The requirements on input to the change requests did not differ much between the companies. The input was mainly regarding affected functions, incentives and reasons for change. At times it was unclear what information was required and this resulted in the originators providing wrong or insufficient input to the change requests. Usage of clear, straight forward questions in change request/order forms can avoid such issues (Watts, 2012). Requirements on input may improve classification and prioritisation since all change requests will contain the same information.

One reason resulting in poor quality of input is that the originators often cannot answer all questions. This lack of cross-functional knowledge can be bridged by requesting the concerned departments to cross-check the input provided by the originators (Watts, 2012). For example, Company 1 and 3 used cross-functional teams to ensure that all required input is provided. Further, Company 3 provided personal support to the originators when creating the change requests. Another possibility is to let each function provide information regarding their area of competences, as practiced at Company 2. These solutions contribute to the challenge of “Uneven quality of input” at Ascom Wireless Solutions. This will further enhance communication between teams and departments (see Figure 18).

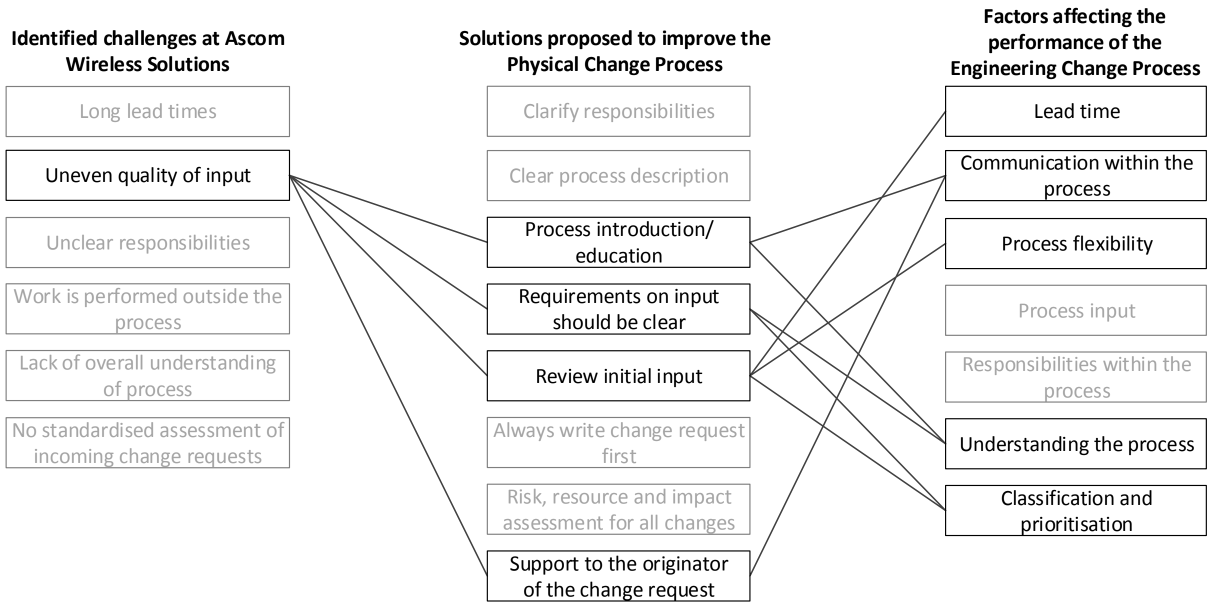

Figure 18. Illustration of what solutions are suggested to the challenge “Uneven quality of input” and the interplay with the factors.

The quality of input is dependent on originators; hence a review of the input is needed for increased accuracy. A higher quality of input, to each step in the Physical Change Process, will assumingly decrease the number of change requests going backwards in the process. The need to iterate the process, in order to refine the input, will be reduced and hence the total lead time would decrease. Ascom Wireless Solutions could improve the Physical Change Process, especially regarding initial input to the change request.

Moreover, all studied companies used standardised forms and tools to handle the change requests/orders which are in line with Ström, Malmqvist and Jokinen (2009). However, Ascom Wireless Solutions have faced difficulties when employees were not able to understand the technical terms used in the change requests/orders originated from other functions. A method to address the problem of understanding the input is to ensure the originators are aware of who the readers are and what information is needed. This could be facilitated by educating the participants as per Company 2’s practice and/or cross-check the input in the change requests/orders before they are submitted (Watts, 2012). The solution “process introduction/education” may affect the factors “communication within the process” and “overall understanding”.

5.3 Challenge 3: Unclear responsibilities

It is important to have clear responsibilities within the Engineering Change Process (Watts, 2012; Ström, Malmqvist, & Jokinen, 2009; Tavcar & Duhovnik, 2005; Balcerak & Dale, 1992). Company 1 and 2 had instructions of who was responsible for what in the process. The uncertainty of what to review in change requests/orders would be reduced and the decision will be easier to make for individuals if there was a clear process description providing a clear division of responsibilities. Also the solutions “clear process description” and “clarify responsibilities” would increase the quality of the output from the change process since the risk of aspects being overlooked would decrease (Keller, Eckert, & Clarkson, 2005). If this risk is decreased it is more likely that the input to the next step in the process is of higher quality. Another issue at Ascom Wireless Solutions concerned the incomplete or missing information in the change requests/orders and who was responsible for correcting and/or completing the input. One possibility would be to state which function that should provide a certain input in the change requests/orders as practiced at Company 2.

An appointed project leader for each change request is one way to handle uncertainties concerning responsibility practiced at Company 1, 2 and 3. Appointing a project leader may be a suitable solution for Ascom Wireless Solutions in order to clarify the ownership of a change request/order. A solution defining the ownership of a change request/order might also decrease the number of requests getting stuck in the process and thereby decrease the lead time.

Decisions in the process were sent out for review and/or approval to individuals or to a group of people at Ascom Wireless Solutions, Company 1 and 2. Since the decision making process is seen as a bottleneck in the Engineering Change Process (Tavcar & Duhovnik, 2005) it is important to have an efficient decision-making process in order to make a positive impact on the factor “lead time” (see Figure 19). Sending decisions directly to individuals may result in faster responses since they know it is their responsibility to approve. But it can also be the other way around, if for example a person is absent for a couple of days or longer the approval will be delayed and it may delay the entire process. Sending to a group may result in confusion of who should take the decision if not sufficiently clarified. Company 2 supports the alternative of sending out group e-mails in order to reduce the dependencies on individuals.

Another example of unclear responsibilities was the uncertainty of who was responsible for conducting the Time Risk Cost assessment in the Physical Change Process at Ascom Wireless Solutions; hence the assessment was not done. At Company 2 and 3, the originator was responsible for providing a payback analysis, but it was often considered to be a difficult task. The solution to this problem would be to clarify who is responsible for conducting this assessment and the clarification will impact the factor “process input” positively.

One person cannot possess all the knowledge and information needed to perform a change taking all relevant aspects of the change into consideration. Hence the originator must communicate to collect the data needed for the change request (Watts, 2012; Malmqvist & Pikosz, 1998). As suggested in literature, all studied companies used cross-functional teams to ensure that relevant aspects regarding a suggested change were taken into consideration. These teams also facilitated the communication between people involved in the change process. However, Ascom Wireless Solutions used the change board as a forum for reminding participants of what actions to perform and to assure that no change requests get stuck. So in order to improve communication the company should change focus of the board meetings to discuss problematic change requests. To support cross-functional communication it is necessary that all functions are represented in the change board, which was not always the case at Ascom Wireless Solutions.

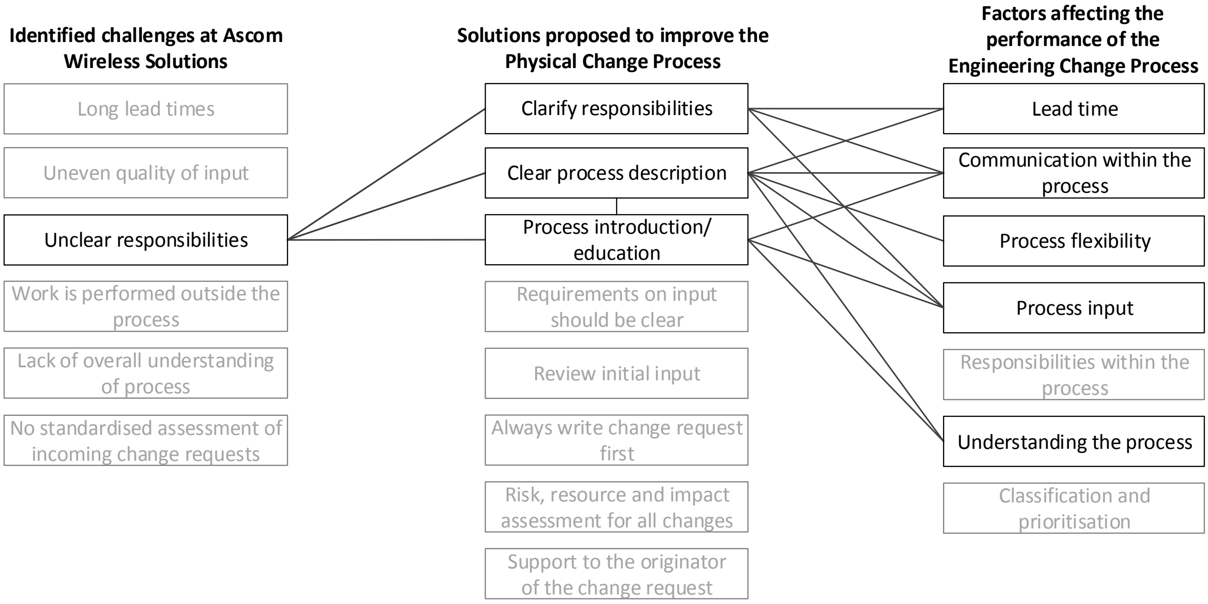

Figure 19. Illustration of what solutions are suggested to the challenge "Unclear responsibilities" and the interplay with the factors.

5.4 Challenge 4: Work is performed outside the process

The wide variety of changes requires a flexible process, otherwise the formal process will not be used and work is performed outside the process. There are two solutions supporting use of a formal Engineering Change Process. The first solution is to have one process and allow by-passing of certain steps depending on the classification of the change (Watts, 2012; Fricke et al., 2000). The second solution is to have different processes depending on the classification of the change (Balcerak & Dale, 1992; Malmqvist & Pikosz, 1998). Though, the difference between the solutions is vague and both alternatives advocate formal, and flexible processes. In general, there is one workflow handling changes in the Physical Change Process at Ascom Wireless Solutions but it is flexible since it is possible to by-pass certain steps. One example is the possibility to directly write a change order without first submitting a change request. This flexibility could be perceived as a consequence of the lack of regulations and standards regarding when the change request can be by-passed rather than flexibility within the formal process.

To solve the problem of people working outside the process, Ascom Wireless Solutions should look at how this problem is solved elsewhere. On the one hand, Company 1 and 3 used one formal process respectively for all changes. However, certain steps could be by-passed or simplified depending on the type of change. A single process is also easier to maintain and improve (Watts, 2012). On the other hand Company 2 used different processes depending on the size of the change. Consequently, the base of the process must have firm rules (Dale,

1982) and should only be adjustable within certain boundaries (Fricke et al., 2000). Hence the solution is a “clear process description” describing what flexibility that is allowed within the formal process according to Company 3’s practice. Figure 20 summarise the suggested solutions to improve the challenge “Work is performed outside the process” and the synergy effects on other factors. How the two proposed solutions impact the factors have been discussed earlier and are therefore not repeated.

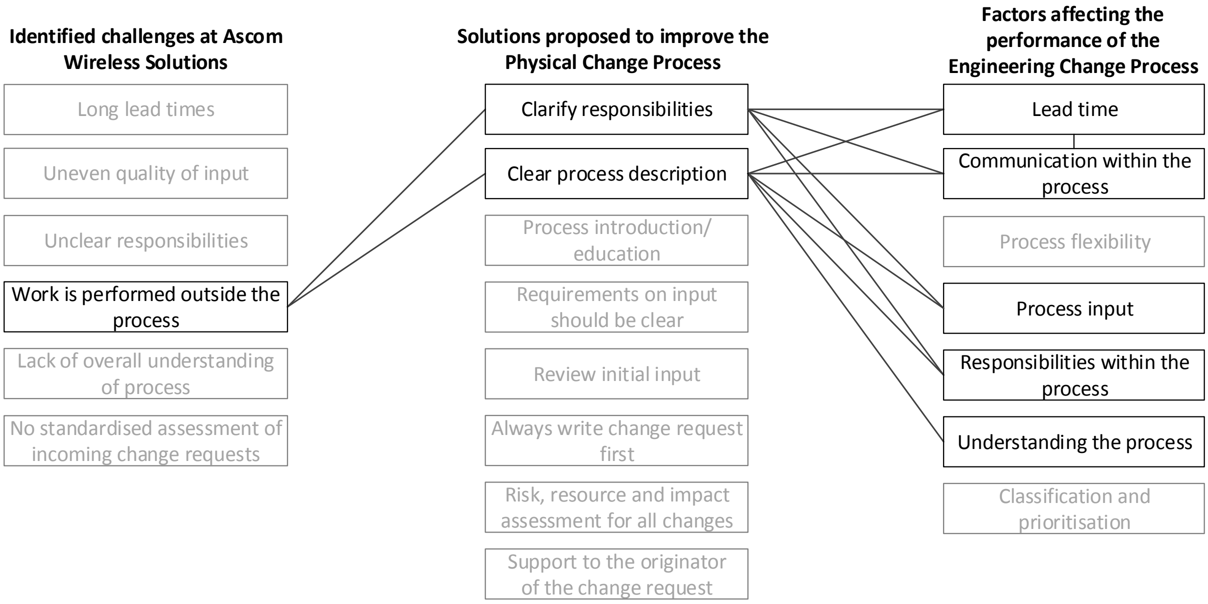

Figure 20. Illustration of what solutions are suggested to the challenge “Work is performed outside the process” and the interplay with the factors.

5.5 Challenge 5: Lack of overall understanding

One of the main reasons why Ascom Wireless Solutions is facing the challenge “Lack of overall understanding of process” may be the lack of an overall and clear process description. In order for Ascom Wireless Solutions to improve the speed and content of each step the company needs to focus on making the process less complex (Terwiesch & Loch, 1999a) for example by clarifying the input needed to enable correct decisions (Ström, Malmqvist, & Jokinen, 2009).

There was a problem identified at Ascom Wireless Solutions regarding the information concerning if the change had been implemented or not. There are many difficulties regarding implementation of a change (Watts, 2012; Wänström, Medbo, & Johansson, 2001) and for Ascom Wireless Solutions one problem related to this challenge was checklists. Checklists that were submitted too late caused confusion since a change implemented in reality could be “released” in the PLM-system, i.e. not yet set to “implemented”. To solve this problem it is important to state the purpose of the checklists as the purpose of the checklists seemed unclear to certain departments.

All study visit companies emphasised the need of understanding the process. However, there were some difficulties to obtain a common understanding of the process, especially if the process is continuously developed as in Company 2. The overall understanding could also be obstructed by geographical distances as for Company 1. To increase the overall understanding of the process Company 2 provided education to all participants in the process. Education would also lead to enhanced communication between participants within the process and understanding of required input.

Company 1 facilitated the understanding through an information guide containing information regarding the design of the process and descriptions of the activities in each step. In Ascom Wireless Solutions' case, the understanding of the process could be improved by visualising the process (Jarratt, Eckert, & Caldwell, 2010) and by educating the participants, as per Company 2's practice. To obtain a common understanding, an explicit description of the process must be used and understood by the participants (Tavcar & Duhovnik, 2005). The challenge's relationships to the suggested solutions and the affected factors are illustrated in Figure 21.

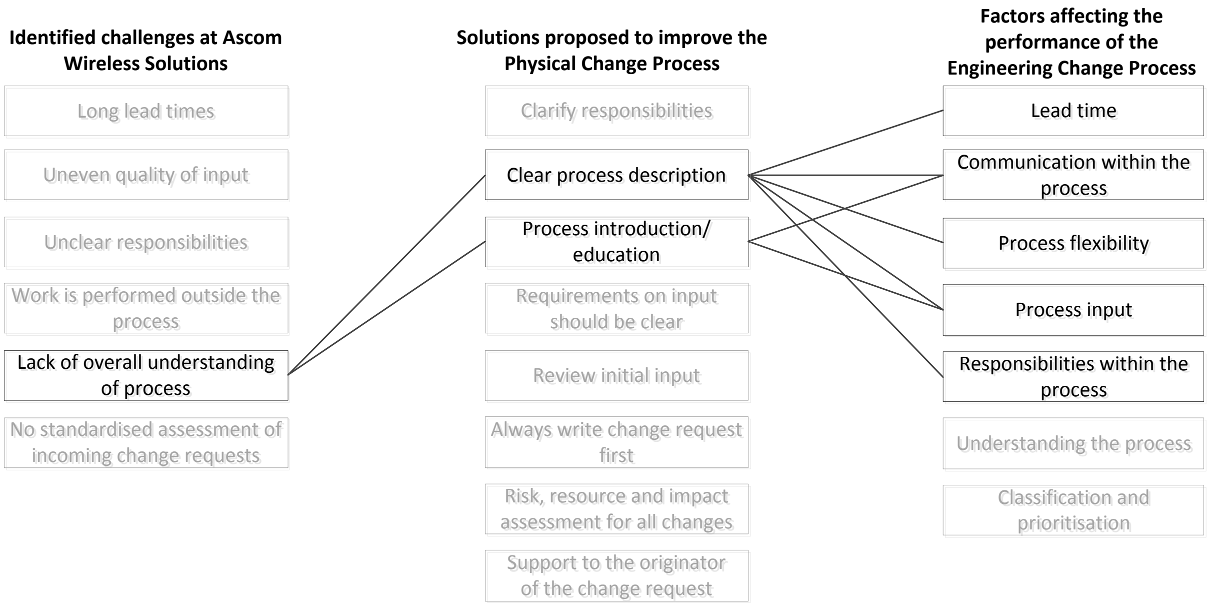

Figure 21. Illustration of what solutions are suggested to the challenge "Lack of overall understanding of the process" and the interplay with the factors.

5.6 Challenge 6: No standardised assessment of incoming change requests

Ascom Wireless Solutions classified changes based on urgency. To make the classification clearer it is important to distinguish between the two urgency levels so the classification is perceived in the same way by everyone involved, i.e. define the urgency levels by using non-subjective terminology (Balcerak & Dale, 1992). Ascom Wireless Solutions also collects information about type of change and reason for change. This information can be used to prioritise the changes based on three priority levels (Balcerak & Dale, 1992). Firstly, simple and urgent changes should be prioritised (e.g. changes to bill-of-material). Secondly, changes due to product not meeting its specifications should be handled. Finally, the remaining changes are prioritised. In the last group the profitability of the change is of higher importance than it is for other changes since those changes are optional and should only be conducted if they are profitable for the company.

One effort that could improve the preconditions for a standardised assessment at Ascom Wireless Solutions would be to always write a change request before writing a change order. "Always writing a change request first" could also imply better possibilities to classify and prioritise changes since all changes are initiated in the same manner. This solution could also support correct and sufficient involvement from the beginning of the Physical Change Process, resulting in fewer people needed to be involved in the final decision (Watts, 2012).

All study visit companies performed an initial assessment of the change before it was passed forward in the process. Company 3 required the originator to provide a payback analysis and Company 2 wrote the change request first after an initial assessment of the business case. Ascom Wireless Solutions required a Time Risk Cost assessment from the originator, but this assessment was often incomplete, hence the consequence was that the evaluation was not performed. The CR-accountable who is supposed to review the input and complete the change request did not take that responsibility thus the initial input was not reviewed before moving onwards in the Physical Change Process. To cope with the challenge "no standardised assessment of incoming change requests", Ascom Wireless Solutions could improve the factor "Process input" (see Figure 22) either through supporting the originators as mentioned above or by improving the review of initial input supposed to be done by the CR-accountable. A suggestion is to put higher requirements on input quality and bring up uncertainties for discussion on the Physical Change Forum. This solution probably requires more resources and time in the beginning of the Physical Change Process, but it may decrease the total lead time of the process due to clearer and more accurate input.

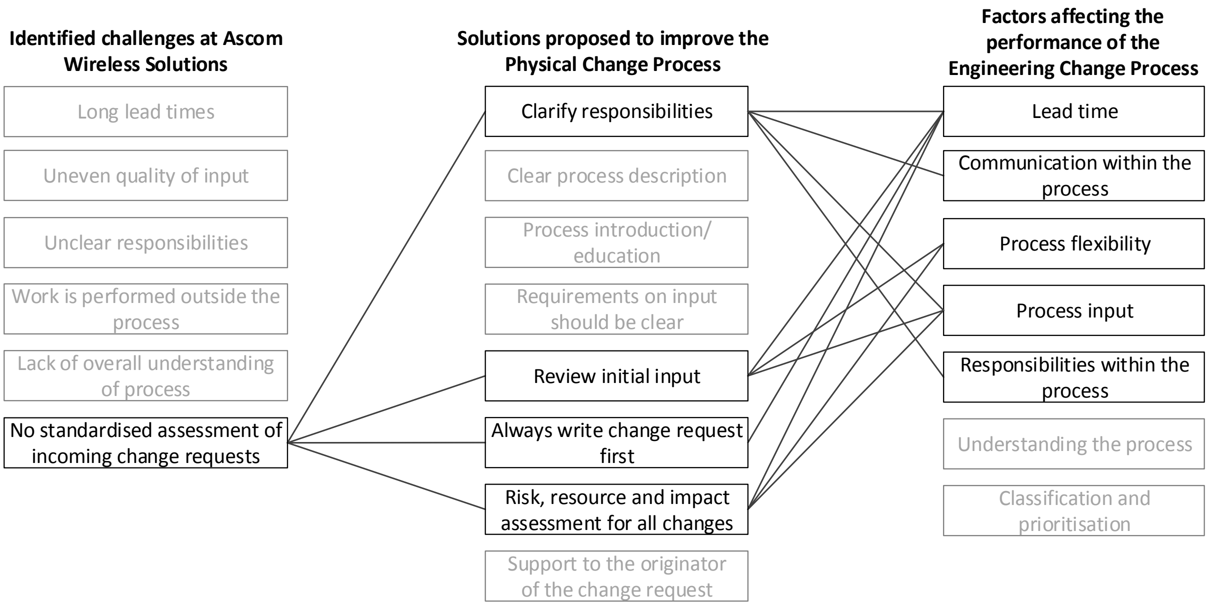

Figure 22. Illustration of what solutions are suggested to the challenge "No standardised assessment of incoming changes requests" and the interplay with the factors.

To have a standardised assessment of solutions is difficult, but important in order to achieve a fast and efficient Engineering Change Process (Watts, 2012). A risk, resource and impact assessment was not mentioned by the interviewees from Company 1 or 2 though Company 3 described its process as standardised. The challenge for Ascom Wireless Solutions is that the company does not have a standardised way to perform the risk, resource and impact assessment. Resource consumption and potential benefits should be assessed for each change request (Fricke et al., 2000). These assessments would give Ascom Wireless Solutions the ability to sort out unwise changes and prioritise the resources correctly and efficiently, though it is difficult. FMEA was used as evaluation method in Company 3 which is also supported by Fricke et al. (2000). It is feasible to involve a cross-functional team in the evaluation process (Balcerak & Dale, 1992).

5.7 Performance measurements

Measuring the performance of the Engineering Change Process can be difficult and literature in the area is not comprehensive. Since Ascom Wireless Solutions only measures one aspect of the Physical Change Process there are many benefits that can be expected through implementation of additional performance measurements (Raynus, 2011; Starbird & Cavanagh, 2011; Samsonowa, 2012). It is important to state the purpose of the metrics and also set and update the goals. If the implementation of metrics is successful, it is assumed to impact the total lead time and increase the motivation of employees. Measuring the process activities also give incentives to develop and improve the Physical Change Process continuously (Anonymous, 2010).

Huang, Yee, and Mak (2003) state that it is of interest to measure the number of open change requests/orders in order to evaluate the current state of the Engineering Change Process. This measurement is used at Ascom Wireless Solutions. Though, it is not measured regularly and the purpose of this performance measurement does not seem to be clear. To make this metric meaningful it should be measured on a regular basis, for example every month. It should also be presented to all participants and the purpose should be clarified and visible. This measurement, presented on a departmental level, is also used at Company 1.

Another measurement, identified in the literature (Huang, Yee, & Mak, 2003; Terwiesch & Loch, 1999a) and used as a metric at Company 1, 2 and 3, is lead time. Lead times can be measured in different ways, for example Company 1 measured total lead time and Company 2 measured lead time per step and per department, total lead time and target times. Company 3 measured if changes met the deadlines. Regarding Ascom Wireless Solutions it would be appropriate to measure the total lead time from submission of a change request to the release (or implementation) of a change order. This measurement contributes to the overall understanding of the process. This measurement can, over time, give an indication (trend) on how the process performance regarding lead time develops.

The target times can be difficult to estimate without previous data and statistics concerning lead time. Hence, if target times are a desirable metric for Ascom Wireless Solutions the average lead time need to be measured before a suitable estimation of target times can be set. Also, it is important to define different targets for different types of changes.

Direct runners as used at Company 2 are not applicable to the Physical Change Process since this process does not include new product development. However, a modification of the concept direct runner could be used in the Physical Change Process at Ascom Wireless Solutions. A direct runner is defined as; “a change request that pass through the change request workflow from pending to closed without going backwards in the process" (see Figure 23). Thus, this definition contains all steps inside "ongoing work" i.e. the change order workflow from pending to released. This measurement could be interpreted as a measure of quality of input to each process step because if the input is correct, the process should not have to be iterated in order to correct mistakes due to poor input.

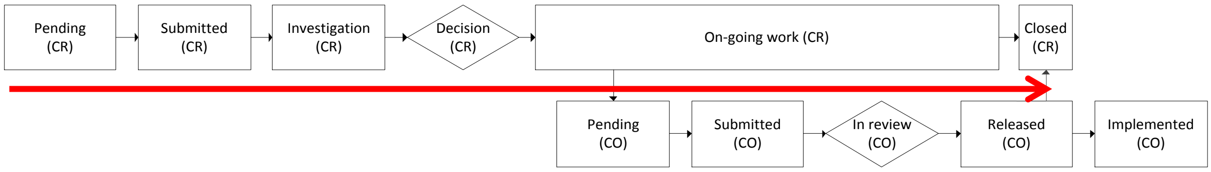

Figure 23. Illustration of a direct runner.

The final measurement related to lead time identified at the study visits companies was meeting deadlines. There are no final deadlines set for change requests at Ascom Wireless Solutions; however the decision regarding next checkpoint made at the Physical Change Forum can be regarded as a deadline in the Physical Change Process. If the work is not finished until the next checkpoint it could be regarded as the deadline is not met. Moreover, missed deadlines could mean more resources are needed than estimated. This could be an indication of a bad forecast or an inefficiently performed task.

Huang, Yee, & Mak (2003) indicate that the active process time spent on each change request is of interest, though this has not been measured at the studied companies. It can be assumed that this is not measured because of the complexity to collect the data needed; mainly working hours per change requests. Also, during discussions with Ascom Wireless Solutions it was clear that it is time consuming for employees to report the time spent per change. Hence, it is not possible to make measuring worth the effort. Time is also related to cost and cost is of high interest to many companies, though it is difficult to measure cost in this process. The major reason for the difficulties of measuring costs is assumingly the difficulties to measure the time spent on each change request and also the problem of giving time a value (Terwiesch & Loch, 1999a).

6 DISCUSSION

The Physical Change Process is an important process within Ascom Wireless Solutions where improvement potentials are anticipated. The company did not provide any predefined improvements areas, not limiting potential areas of improvement; hence this study has been narrowed down progressively. A number of challenges within the Physical Change Process and related processes have been identified. Also a number of factors affecting the Engineering Change Process were identified in literature and during the study visits.

The challenges we decided to focus on mainly concern the overall process and the overall understanding of the process. This decision was based on the need of understanding the current state of the change process at Ascom Wireless Solutions. We wanted to emphasise the need to improve the general understanding of the process and develop an explicit process description before improving process details. Some of the suggested improvements may seem basic and obvious to the reader, nevertheless they are considered needed and will serve as a foundation for further improvements.

Ascom Wireless Solutions is not the only company suffering from the identified challenges. Several cases studies (see for example Terwiesch & Loch, 1999a; Huang, Yee, & Mak, 2003; Ström, Malmqvis, & Jokinen, 2009) discuss the same issues and also the study visit companies experience similar problems. It might be difficult to solve challenges through making changes to the Engineering Change Process due to its complexity (Ström, Malmqvist, & Jokinen, 2009). This complexity results in a difficulty to design a standardised, but still flexible process without making it too bureaucratic and slow. Though, as this thesis has concluded, there are some basic answers on how to improve the Engineering Change Process.

A generic Engineering Change Process model based on Jarratt, Eckert and Clarkson (2006) and Jarratt, Eckert, and Caldwell (2010) has been used in this thesis. Based on this model, the change processes at the studied companies were analysed. However, one difference between the model and the studied companies was that most companies did not review and evaluate each change order. This finding was unexpected since we believe that this information is important for companies in order to improve the Engineering Change Process. At the same time, the procedure to collect relevant data seems to be difficult for the studied companies. Moreover, some clarifications regarding the generic model would be of interest. For example, should a solution to the requested change be fully developed before assessments of the requested change are conducted? We would like to suggest an initial assessment of the change requests before a solution is developed because all changes are not worthwhile (Balcerak & Dale, 1992).

Both our empirical findings and previous research indicate that there is no accepted best-practice within the area of Engineering Changes and the process must be adapted in its contexts. For example the need of communication varies during a product's lifecycle (Scholz-Reiter et al., 2007; Tavcar & Duhovnik, 2005). However, cross-functional teams are often used to facilitate communication and to assure that no relevant aspects of the change are disregarded. Moreover, the quality of the input has a significant impact on the process performance since all participants must understand the input in order to make the right decisions. Also, if the input is incomplete or wrong the process might have to be iterated, which prolongs the lead time and increases costs.

To evaluate the result of the improvements, one has to measure the change process. Though, it is difficult to define what to measure and how to measure. The literature review revealed that there is a lack of performance measurements specifically adapted to the Engineering Change Process. Some performance measurements were mentioned in literature e.g. lead time (Terwiesch & Loch, 1999a) and number of open changes (Huang, Yee, & Mak, 2003) but only lead time was explained in detail and further discussed. The empirical research identified additional performance measurements used in the industry. Since a aim of the Engineering Change Process is to ensure that changes are profitable, a performance measurements which compares the effort against value gained would be preferable. However, the value of the change is difficult to estimate since it could be for example additional sales which might be problematic to relate directly to the change. Also the resource consumption during the change process is difficult to assess and would require extensive collection of work hours.

To conclude, this thesis has contributed to the scholarly knowledge with additional information regarding Engineering Change Processes in general and the following factors have been identified to impact the process; classification and prioritisation, process input, understanding the process, process flexibility, communication within the process, responsibility within the process, and lead time. Also, findings regarding performance measurements related to the Engineering Change Process have been presented and analysed.

6.1 Further studies

In general, the number of changes within the Physical Change Process at Ascom Wireless Solutions is perceived to be largest at the beginning of the product lifecycle and is assumed to decrease during the product lifecycle phase active sustain. This perception is supported by Bhuiyan, Gatard and Thomson (2006). It could be possible to reduce the number of changes in the beginning of the lifecycle phase active sustain, by improving the product development. The product development could be improved using cross-functional teams (Watts, 2012) or batching of changes (Bhuiyan, Gatard, & Thomson, 2006) in the ramp-up phase. However, after a couple of years the number of change requests increase again. The reason is mainly that components included in a product need to be exchanged since old parts are no longer produced by the supplier. Other actions that can be executed to decrease the response time are to give the development more time to make it right the first time (Terwiesch & Loch, 1999a). Also, if it is not possible to commit the extra time in development, detection of changes early in the product lifecycle is important because the cost and effort typically increases the later in the product lifecycle a change is implemented (Malmqvist & Pikosz, 1998; Frick et al., 2000).

In order to find the best solution for Ascom Wireless Solutions, one has to investigate the possibility to reduce the number of changes early in the product lifecycle and to evaluate the right time to phase out products. Hence, it would be of interest to study these areas.

The three solutions further developed in chapter 8 are mainly applicable at Ascom Wireless Solutions. However the challenges identified at Ascom Wireless Solutions seem to be similar to the challenges at the study visit companies and companies studied in literature. To validate the similarities regarding challenges in the Engineering Change Process a multiple case study would be of interest. Moreover, the identified factors affecting the performance of the change process can be assumed to be valid for companies using formal Engineering Change Processes. Though, there might be other factors important for the performance of the process not investigated in this thesis such as limitations regarding the PLM-system, accuracy of the R&D and geographical distances.

7 CONCLUSIONS

The purpose of this thesis is to provide recommendations on how the Engineering Change Process can be improved and relevant performance measurements for this process. A case study has been conducted at Ascom Wireless Solutions in order to fulfil the purpose. Through answering the research questions below the purpose has been achieved.

7.1 RQ1: What are the challenges in the current Physical Change Process at Ascom Wireless Solutions?

The identification of challenges was initiated early in the research process since it serves as the basis to the second research question. The challenges were identified through interviews with employees at Ascom Wireless Solutions and the main challenges are; long lead times, uneven quality of input, unclear responsibilities, work is performed outside the process, lack of overall understanding and no standardised assessment of incoming change requests. These are explained in more detail in section 4.6.

7.2 RQ2: How can the Physical Change Process be improved at Ascom Wireless Solutions?

To answer this research question, two sub-questions were phrased and answered below. The answer to RQ2 is the synthesis on the two sub-questions presented in section 7.2.5.

7.2.3 RQ2a: What factors are important for the performance of the Engineering Change Process according to the theory?

The factors important for the performance of the Engineering Change Process according to literature are; communication within process, cross-functional teams, process flexibility, process lead time, responsibilities within the process, understanding the process, classification and prioritisation, process input, complexity of process, company culture, efficiency, organisational structure, product complexity, R&D process and convenience of the system support. RQ2a was answered through a literature review. A more comprehensive table is presented in Appendix A.

7.2.4 RQ2b: What factors are important for the performance of the Engineering Change Process according to practitioners?

The information needed to answer RQ2b was collected through study visits at three different companies. The factors important for the performance of the Engineering Change Process at these companies are; communication within process, cross-functional teams, process flexibility, process lead time, responsibilities within the process, understanding the process, process input, ability to learn from mistakes, decision process, level of experience, geographical distances, classification and prioritisation, product complexity, amount of resources available and convenience of system support.

7.2.5 Synthesis on RQ2

The Physical Change Process at Ascom Wireless Solutions is facing the challenges identified in RQ 1. To improve the process a selection of possible solutions has been suggested. These are; clarify responsibilities, clear process description, process introduction/education, requirements on input should be clear, review of initial input, always write a change request first, risk, resource and impact assessment for all changes and support to the originator of the change request. These have been identified through input from study visits and a literature review. The solutions are further specified and exemplified in chapter 8.

7.3 RQ3: What performance measurements are relevant for Ascom Wireless Solutions when measuring the performance of the Physical Change Process?

To answer this research question, two sub-questions were phrased and answered below. The answer to RQ3 is the synthesis on the two sub-questions presented in section 7.3.3.

7.3.1 RQ3a: What performance measurements are used to measuring the performance of the Engineering Change Process according to theory?

According to theory, the performance measurements relevant to the Engineering Change Process are; process time, lead time, number of active changes and metrics related to the logistics perspective. RQ3a was answered through a literature review.

7.3.2 RQ3b: What performance measurements are used to measuring the performance of the Engineering Change Process according to practitioners?

The performance measurements used by the study visit companies are; lead time per process step, total lead time, direct runners, punctuality, number of open changes in total, number of open changes per process step, number of open changes per department, number of changes created per department and percentage of orders signed by the manager.

7.3.3 Synthesis on RQ3

The performance measurements both described in literature and identified at the study visits are considered as the most important measurements. Taking the overall perspectives into account relevant performance measurements for Ascom Wireless Solutions would be to measure the total lead time of the Physical Change Process. Another relevant measurement would be measuring the number of open change orders and/or change request. This is what Ascom Wireless Solutions already measure, though we advocate the relevance of stating the purpose with this performance measurement and to measure on a regular basis. We also consider our definition of direct runners (see section 4.5.2) to be suitable as a basis for a measurement since it can be perceived as measuring the quality of the input to each step and the clarity of the process.

8 MANAGERIAL IMPLICATIONS

This chapter will provide Ascom Wireless Solutions with our recommendations to the company and serve as an executive summary of the findings.

Ascom Wireless Solutions uses several processes for handling changes on products. In this thesis, the suggested improvements are applicable to the Physical Change Process. This process handles changes which affect physical products, i.e. hardware, mechanical parts and labels, which are in the lifecycle phases active or passive sustain. And, the size and complexity of the requested change is assumed to be manageable within the process i.e. a project does not need to be initiated to solve the requested change.

8.1 How to improve the Physical Change Process

Due to dynamic contexts, one cannot avoid product changes during the product lifecycle and those changes can be made in a formal, standardised manner or by using informal, uncontrolled processes. Although a standardised change process is not required to make changes, it is necessary to ensure qualitative output from the process. High output quality mainly concerns making the right changes, resulting in retained or improved profitability of the product. The decision to change shall be based on accurate and current information and all relevant aspects of the change should be considered during the change process. The vision is to handle product changes in a process that is quick, clear and resource efficient.

A literature review and interviews at three other companies have identified seven success factors[2] within the change process, see Table 5.

Table 5. Success factors related to the Physical Change Process.

Success factors	Explanation
Process input	One needs to have access to correct and updated information in order to make adequate decisions. In addition the input must be understood by all participants. High quality input will result in a high quality output and a reduced need of iterating the process.
Classification and prioritisation	Change requests need to be classified due to the large variety of changes. Depending on the classification different requirements on lead time, response time, reviews, traceability etc. can be applied. All changes are not beneficial for the company and hence an initial prioritisation is needed. Also, a change might have higher urgency or requires less resources compared to the value it will generate and hence should be prioritised.
Understanding the process	Quick and reliable implementation of changes requires that all participants understands the process and the process design. If the process is well-understood, the risk of employees performing work outside the process is reduced.
Process flexibility	The large variety of changes handled in the process requires a flexible process and a possibility to by-pass and/or simplify certain steps in the process.
Communication within the process	Cross-functional communication is key since changes impact several functions and the cross-functional knowledge is crucial to ensure that all aspects of the change are considered. Also, the

[2] The success factors are named factors in other chapters in this report.

	change needs to be communicated well and quickly, by using common language and tools.
Responsibilities within the process	The responsibilities within the process must be clear to ensure that all relevant aspects of a requested change are reviewed and approved. Moreover, clear responsibilities facilitate the overall understanding of the process.
Lead time	Long lead times in the change process results in added costs, problems related to coordination of simultaneously open change requests/orders and a risk of employees working outside the process.

In the interviews with employees involved in the process, several problems[3] regarding product changes at Ascom Wireless Solutions were identified. A summary of the identified problems are presented in Appendix E. Since it was neither possible nor desirable to address all identified problems, we had to select some areas of focus. This selection was based on the need of a standardised and well-understood process to enable continues improvements. Table 6 summaries the most fundamental problems related to the Physical Change Process.

Table 6. Identified problems related to the Physical Change Process.

Identified problem	Description
Long lead times	• Higher process costs • Work is performed outside the process • Overlapping changes
Uneven quality of input	• Input is dependent on the originator • Input is often written without considering who should read and understand the information later on • Unclear instructions on what to include in the input
Unclear responsibilities	• Unclear if all aspects of a change is reviewed and approved • The process halts if no one is responsible for the next action • Unclear instructions regarding responsibilities within the process • Unclear who the owner of change requests/orders and the Physical Change Process is
Work is performed outside the process	• The complexity of the process makes people work outside the process e.g. making phone calls for additional information and bypassing the change request • Result of long lead times
Lack of overall understanding of the process	• Difficulties to understand the purpose of activities • Difficulties to see the consequences of actions • Lack of overall process description
No standardised assessment of incoming change requests	• Difficult to know if the change will result in any benefits for the company • Errors are discovered late in the process e.g. functions are involved too late in the process • No standardised classification or prioritisation of change requests/orders

Based on findings from the literature review and the three study visits, we have proposed the solutions presented in Table 9. These solutions aim to solve the problems presented above and serve the vision of a quick, clear and resource efficient process. The suggested solutions may

[3] The identified problems are named challenges in other chapters in this thesis.

seem basic and obvious; nevertheless, they are needed since there is a lack of a holistic and standardised view of the Physical Change Process. And the suggested solutions will serve as a foundation for continues improvements. All suggested solutions could not be further developed and hence we have chosen to elaborate the three most important solutions described below.

8.1.1 Solution 1: Clarify the responsibilities within the process

When everyone is responsible, no one is responsible; hence someone needs to take the responsibility of the Physical Change Process. Also, the lead time will be reduced if everyone knows what to do, who to turn to and what input to provide. And by clarifying the responsibilities, one will assure that all aspects of a change is reviewed which will increase the output quality from the process

Currently, participants are unsure of who the owner of the Physical Change Process is and who the owner of each change request/order is. This results in a risk that no one takes responsibility for certain change requests/orders or for updating related documents etc. Below the suggested actions are presented.

Action 1: Appoint a process owner with operational knowledge of the Physical Change Process. This person shall be responsible for:

- the overall process and to make sure that no sub-optimisations are made in the process, i.e. facilitate an activity for a certain function which causes problems later or for other functions.
- updating instructions
- measuring the process
- continuous process improvements

Action 2: The project organisation shall be responsible for change requests until the product has been handed over to the line organisation.

Action 3: Each change request/order shall have an appointed owner. This person is responsible for delegating the work and assures that the required tasks are performed.

Action 4: Clarify responsibilities during decision making and reviews. First, one must decide if the decision in the change request shall concern resources needed to solve the requested change or if it shall be an approval of a suggested solution. We recommend that this decision shall concern the resource decision and that it shall be taken by the managers from the functions involved in the change request. Second, according to instructions, all change requests shall be reviewed by the CR-accountable before submitted in the PLM-system (Agile). However, this is not done. We suggest that a review is conducted by the Physical Change Forum. Thirdly, cross-functional knowledge is highly important in this process and cross-functional teams facilitate communication of such knowledge. Thus, the Physical Change Forum has a central role in the Physical Change Process and we recommend this forum to concentrate on discussions concerning complex change requests which require cross-functional involvement. This forum shall not waste time on controlling that the required actions have been performed; this should be the task of the owners of the change requests/orders.

8.1.2 Solution 2: One clear process description

An explicit process description will serve as a base for continuous improvements. It will in addition facilitate the overall understanding of the process, assuming the process description is well-communicated to the participants. A common understanding of the process is important in order to avoid work being performed outside the process. Moreover, a clear process description will enable flexibility without jeopardising the quality of the output since the steps that can be simplified or by-passed and when should clarified in the process description. Also a positive effect on the lead time is expected since a process description will facilitate the communication of consequences of one's actions to the participants.

As of today, an explicit description of the process is missing. Some internal documents describe parts of the Physical Change Process and related issues, but most of the documents are incomplete and/or contains obsolete information. Moreover, the process is not standardised and it is uncertain what actions to take in a certain process step e.g. if the decision in the change requests concerns resources or approval of the suggested solution. We have studied this process for three months, and occasionally we are still unsure of the activities in certain steps of the process. As a first step to improve the situation we suggest the actions described below.

Action 1: Clarify when the Physical Change Process is applied. As illustrated in Figure 24, the Physical Change Process is applied for physical changes made to products in the lifecycle phases active and passive sustain.

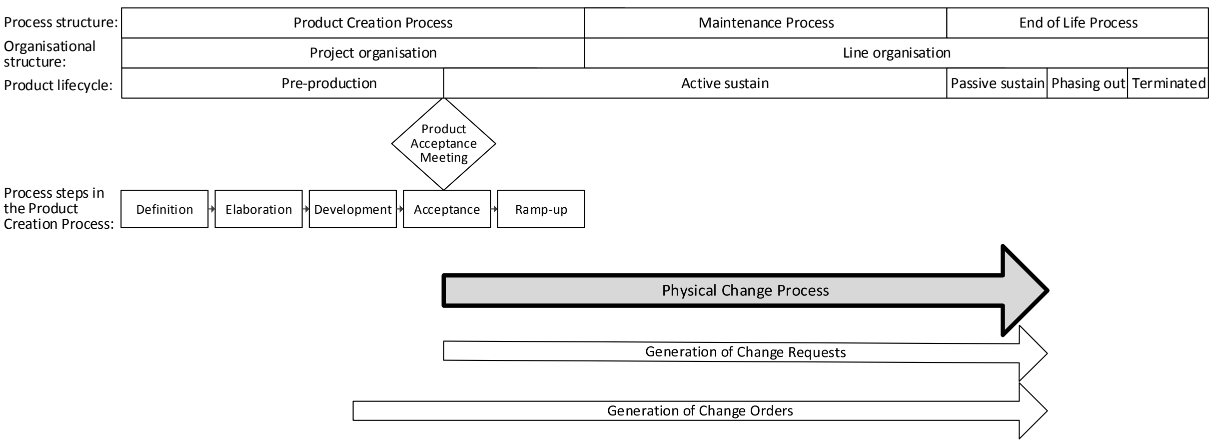

Figure 24. The Physical Change Process and its context.

Action 2: Clarify the relationship between change requests and change orders. It should be obligatory to write a change request first i.e. the originator should not have the option to directly write a change order. However, depending on the change type the formal process should be flexible and provide a possibility to simplify and/or by-pass certain steps in the process. Though, this decision should be made during the assessment of the incoming change request and according to the predefined process.

Change orders are applied both in the Physical Change Process and in the Product Creation Process when the product is in the lifecycle phase pre-production. Though, different workflows are applied for those change orders and to highlight this difference we recommend that Ascom Wireless Solutions rename the change orders and assign different terms for change orders in the Physical Change Process and during the lifecycle phase pre-production. A suggestion is to use names related to the lifecycle phase in which the change order is applied.

Action 3: Clarify the activities within each step of the Physical Change Process by rename the steps. We recommend the titles presented in Table 7

Table 7. Proposed titles of the process steps.

Current title	Proposed title
Investigation	Resource and risk assessment
Decision	Approval of change request
Ongoing work	Solve the requested change
In review	Review of change order

8.1.3 Solution 3: Clarify what input that is needed

If the originator understands what information that is required and why it is needed, he/she would probably provide it. And, if correct information is provided the need of iterating the process will decrease, hence the lead time will be reduced. Also, the possibility to classify and prioritise the change requests will be improved.

The information provided in the change requests/orders is often incomplete or difficult to understand and the process is sometimes iterated due to lack of information and/or approvers rejecting change request/orders due to misunderstanding of information. Additionally, the change request/order forms contain a large number of fields and almost all of them are mandatory, forcing the originator to fill in information he/she does not possess or are uncertain about. Moreover, there is a risk of information overload due to the large amount of e-mails sent from the PLM-system and some groups of receivers spend large amount of time on sorting the e-mails. We suggest the following actions to improve this situation.

Action 1: All change requests/orders shall contain information regarding the affected product family. And if possible, the product family shall be stated in the e-mail subject. This will ease the sorting of change requests/orders for the participants.

Action 2: Clarify what information is mandatory to enter as an originator of change requests/orders. Firstly, use the asterisk (*) to mark the mandatory fields in the form. Secondly, the originator of a change request cannot have all information required. Hence, information such as whether or not the change concerns Ex or Safety shall be answered by the regulatory department rather than the originator. Also, information regarding next checkpoint shall not be filled in by the originator. Thirdly, all information needed in a change order shall be generated by the change request i.e. issues such as implementation occasion and scrapping or use-up shall be decided when working with a change request.

Action 3: Rephrase the questions in the template regarding "Description of change" and "Reason for change" since it is difficult to understand the difference between the questions. The suggested change is presented in Table 8.

Table 8. Proposed improvements of the change request template.

Current formulation	Proposed formulation
Why shall we do this CR – What's in it for Ascom?	Why is the change needed?
What are the benefits?	What are the benefits of the change?

Action 4: Define the urgency classification. Urgent could be defined as: "Risk for disruptions in production or supply chain". And consequently all other issues are routine. The same process shall be used irrespective of the urgency. Though, requirements on response time from approvers and lead time shall differ.

8.1.4 Summary of the suggested improvements

Table 9 summaries all improvement suggestions and the expected effects, the three most important are presented first. Together, these improvement suggestions aim to solve the problems presented in Table 6 and serve the vision of a quick, clear and resource efficient process.

Table 9. Proposed improvements.

Proposed improvements	Expected effects
Clarify responsibilities	• Reduced lead time if everyone knows what to do, who to turn to, what input to provide etc. • All aspects of a change will be reviewed →higher output quality • Decreases the uncertainty during decisions and reviews
Clear process description	• Increases the overall understanding of the process and the reasons behind the design of the process • Reduced risk of working being performed outside the process • Reduces the lead time of the process • Enables flexibility without jeopardising the quality of the output
Requirements on input should be clear	• Will help the originator to provide the required input • Correct input will shorten the process' lead time • Enables classification and prioritisation of change requests
Process introduction/education	• Facilitates the understanding of the process and communication of the purpose of the process • Better understanding of consequences for others involved in the process, e.g. awareness that the process is delayed if one does not approve the change request/orders on time
Review initial input	• Insure the quality and relevance of the input • Correct input will shorten the process' lead time
Always write a change request first	• The standardisation of the process will increase • Enables prioritisation of all changes • Possibility to involve affected functions early in

	the process
Risk, resource and impact assessment for all changes	• Facilitates the prioritisation of changes • All requested changes shall not be implemented
Support to the originator of the change request	• Support to the originator will increase the quality of the input • Eases the work in the process for employees seldom involved in the process

8.2 How to measure the Physical Change Process

Our recommendation to Ascom Wireless Solutions is to focus on few KPIs[4] measuring the most important aspects of the process. We want to emphasise the benefits of using few, understandable and measurable KPIs in order to focusing on what is important and to enable clear communication and visualisation of the KPIs.

The aim is to ensure that all changes contribute to profitability thus a performance measurement which compares the cost/effort for a change with the value of the change would be preferable. However, the value of a change is difficult to estimate since it could be for example additional sales which might be problematic to relate directly to the change. Also estimation of resource consumption per change is problematic and would require extensive collection of data regarding working hours. It is still important to measure the process using KPIs.

It is crucial to know why something is measured and measuring KPIs can be a starting point for optimisation. Identification of strengths and weaknesses in the process can for example be an indication of where to focus the improvement effort. Another issue concerning the suggested KPIs is the way the measurements should be presented and communicated. One must clarify the purpose of the KPIs from the company's point of view in order to prevent the measurements from being used in an inaccurate manner.

We believe, and research supports us (see section 3.3.1), that using the suggested measurements will support monitoring and continuous improvements of the process. We also stress the importance of metrics driving the right behaviours among people. Another mistake is to define goals that are too low since lack of incentives tends to impact the employee's performance and make them less motivated.

In the following section the three most important performance measurements will be presented. These KPIs will help Ascom Wireless Solutions evaluate and identify improvement potentials in the process and bring the company closer to the vision of a quick, clear and resource efficient change process. The three KPIs presented are; lead time, direct runners and number of open changes. All measurements need to be consistently monitored over time and when calculating the results it could be appropriate to exclude the extreme values, e.g. when measuring lead time exclude the fastest and slowest 10 per cent. Thereby the robustness of the measurements will be improved.

[4] In this sections is KPIs used as a synonym to performance measurements

8.2.1 KPI 1: Lead Time

Lead time should be measured from pending (CR) to released (CO) (see Figure 25). The implementation of the change is not included since it has different preconditions depending on the change. This KPI is suggested to be measured once a month.

Lead time is the most commonly measured KPI according to this study, and it is probably not a coincidence. The purpose of this measurement is first to create an awareness of the lead time in the process. Second, if measured regularly, the results will show whether the process tends to be faster or slower or for example how different improvements or changes in the process impact lead time. Third, the measured lead times can be used to create a better forecast of lead times in the future. Also, by means of this information target times (see section 5.7) for different change types may be set.

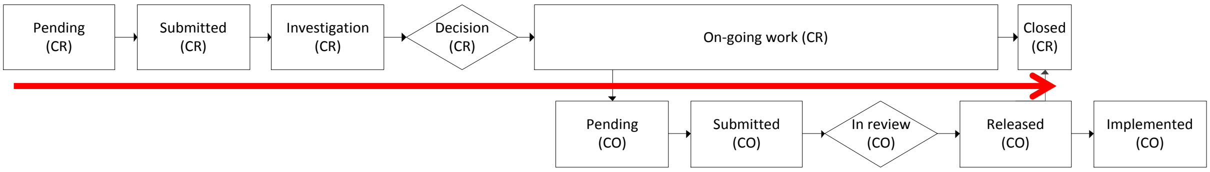

Figure 25. Illustration of how to measure the lead time in the Physical Change Process.

8.2.2 KPI 2: Number of open changes

This is one of the KPIs used at Ascom Wireless Solutions today, hence there is knowledge of how the data needed to measure this is collected and presented. Since we emphasise the importance of one process including both change requests and change orders, we also suggest measuring the number of open change requests and change orders.

Measuring the number of open changes once a month would only indicate if the quantity of open changes is increasing or decreasing. However, it could in some cases be interesting to see the reason behind the number of open changes. In that case the number of initiated change requests during the same period could be measured in order to understand if there are many new change requests entering or if many old changes are stuck in the process. If the explanation is many new changes the reason for having many open change requests might not be a slow Physical Change Process but rather the development process, implementation issues or low quality of previous changes.

This measurement, as defined here, requires a change request first, though it is possible to measure number of open change orders or change requests separately without always writing a change request first.

8.2.3 KPI 3: Direct runners

A direct runner is; “A change request that pass through the change request workflow from “Pending” to “Closed” without going backwards in the process” (see Figure 26). Our suggestion is to measure the percentage of direct runners of all change requests that are set to closed (not those rejected or cancelled).

We perceive this KPI as measuring the clarity in the process. If the quality of the output is sufficient and correct from each step in the process, no one should have to reject a change request/order due to poor information and the process should not have to be iterated in order to correct mistakes. The quality of output put requirements on the quality of input. However, it must be clearly stated what information to provide when in the change process in order to give the participants the opportunity to perform the activities properly.

The drawback with this measurement is that the change must be initiated through a change request which is not the case today; hence if Ascom Wireless Solutions wants to include all changes in this measurement all changes have to go through a change request. Moreover, this KPI can be measured today, but not in an efficient manner as far as we know. It is possible to access the data in the workflow-tab in each change request in the PLM-system (Agile), though it is not efficient to review all change requests in this way. However, we do not see data mining as a constraint that would prevent Ascom Wireless Solutions from using this measurement in the future.

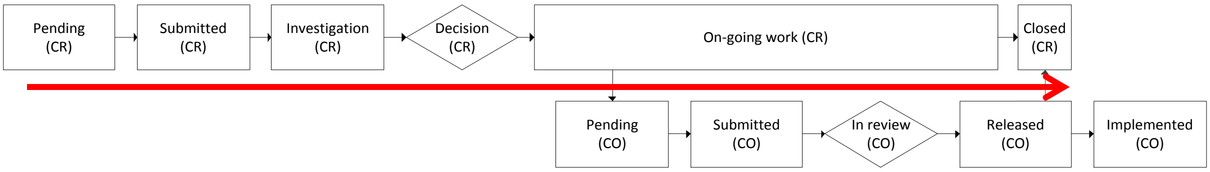

Figure 26. Illustration of the concept "direct runner".

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Appendix A: Summary of factors affecting the Engineering Change Process

In this table are factors identified in the literature review and during the study visits summaries. Also, the factors in scope are classified and commented. The factors elaborated in the thesis are marked with bold letters.

Factors	Mentioned in literature	Mentioned at study visits	In scope	Type of factor	Comments
Ability to learn from mistakes		x			
Amount of resources available		x			
Classification and prioritisation	**x**	**x**	**x**	**Specific**	**Classification of input is a part of the process, step 1**
Communication within the process	**x**	**x**	**x**	**Overall**	**Communication is relevant for the entire process**
Company culture	x				
Complexity of process	x				
Convenience of system support	x	x			
Cross-functional teams	**x**	**x**	**x**	**Overall**	**Is seen as a solution to communication and responsibility and therefore not handled as a separate factor in this report**
Decision process		x			
Efficiency	x				
Geographical distances		x			
Level of experience		x			
Organisational structure	x				
Process flexibility	**x**	**x**	**x**	**Overall**	**It is a question of how the overall process can be used for different types of changes**
Process input	**x**	**x**	**x**	**Specific**	**Specific factor dealt with in step 1**
Lead time	**x**	**x**	**x**	**Overall**	**Concerns the lead time of the change process and consequences related to long lead times**
Product complexity	x	x			
R&D process	x				
Responsibilities within the process	**x**	**x**	**x**	**Overall**	**Concerns the division of responsibilities**
Understanding the process	**x**	**x**	**x**	**Overall**	**Concerns the holistic overview of the process and the awareness of consequences etc.**

Appendix B: Interview guide used at Ascom Wireless Solutions

The interview guide used during interviews with employees at Ascom Wireless Solutions is presented below.

General interview guide

This interview guide was used at the interviews with employees at Ascom Wireless Solution. Note that some questions might not have been applicable to all interviews since the interviewees have different responsibilities within the process.

Initial questions

1. Can you describe your role at Ascom Wireless Solutions?
2. Can you describe your responsibilities within the change process?

Input

3. Do you have access to the input needed to perform your task?
4. Do you feel that you have enough information for taking adequate decisions?
5. How are you notified that you received a change request or change order that you shall work on?

Performing the task

6. How do you prioritise your work tasks?
    - Do you handle urgent changes?
7. Do you feel confident working within the change process?
    - Do you know what you are supposed to approve in the change requests/orders?
    - Do you know what is expected from you?
8. Does the process differ between the lifecycle phases?
9. When your department gets a change request/change order, how do you know who shall work on it?
    - Is it always obvious who is responsible?
10. Lead time
    - Is the lead time an issue?
    - What factors affects the lead time?
11. Checklists
    - What is your opinion regarding the checklists?
    - What is their contribution to the process?

Approval of change request/change order

12. Who approvals the change requests/orders at your department?
13. How do you know which part of the change request/order you are supposed to approve?
14. Do you sometimes hesitate to approve a change request/order?

The PLM-system

15. How do you like working in Agile?
16. Does the system give you the support that you need?
17. Have you had any education/training?

Process bureaucracy / improvements

18. Have you used the written instructions when working with the Physical Change Process?
19. What is your opinion about the written instructions?
20. Do you always follow the formal process?
21. What are the benefits and disadvantages with product releases from your perspective?
22. In what way can the process be improved and what should be kept as it is?
23. Is there a need to improve the process?

Additional questions to the coordinator

In addition to the general interview guide, the following questions were asked to the coordinator.

Initial questions

1. Who is the customer in the change process?
2. What happens if you are on leave for a longer period of time?

Input

3. Change orders
    - Who writes the change orders?
    - Does it happen that you need get back to the person who wrote the change order?
    - Do people start to solve the problem before the decision has been taken to do so?
    - How do you decide if a change is urgent or not?

Performing the task

4. Lead time
    - Do you use deadlines for change orders?
        - Are the deadlines kept?
    - Is 48h a suitable time before an approval reminder is sent?

Approval of change request/change order

5. Do you feel confident choosing the Approvers, Observers and Notified?
6. Are the “right” people always involved?

Process bureaucracy and improvements

7. What is your opinion regarding the use of many different workflows?
    - Good or bad to have different workflows?
8. Is it always necessary to first write a change request and then a change order?

Additional questions to the CR-accountable

In addition to the general interview guide, the following questions were asked to the CR-accountable.

Initial questions

1. Who is the customer in the change process?
2. Change request
    - What is the aimed output from the process?
    - How do you judge if the change request is okay to set to Submitted?
    - Does it happen that you need to get back to the person who wrote the change request?
    - Who sets the checkpoints?
3. The document: Physical Change process incl LTB
    - Who is responsible for entering the information marked “skip this”?
    - Is it any differences between the Agile and the “non”-agile process described in the document?
4. How do you decide if a change is urgent or not?

Physical change forum

5. Does the forum work as you would like?
6. How could the forum be improved?
7. Is all departments needed present on the forum meetings?

Performing the task

8. Lead time
    - Are the deadlines kept?
        - Why/why not?
    - Is 48h a suitable time before an approval reminder is sent?
9. Checklists
    - Is checklists used in for change requests?

Approval of change request/change order

10. Do you use Approvers, Observers, Notified in the change request-process?
    - If so: Do you feel confident choosing the Approvers, Observers and Notified?
11. Are the “right” people always involved?

Process bureaucracy / improvements

12. What happens if you are on leave for a longer period of time?
    - Can someone else perform your work?
    - Would the process work without you?
    - What is your opinion about the written instructions?
13. Is it always necessary to first write a change request and then a change order?
14. What is your opinion regarding the use of many different workflows?
    - Good or bad to have different workflows?

Appendix C: General interview guide used at the study visits

This interview guide was used at the interviews with one or two employees at three different companies. Note that some questions might not have been applicable to all interviews since the companies have different prerequisites.

Introduction

1. Please describe your role at the company

Process/Flow

2. Can you describe the Engineering Change Process in your company? From change trigger to implementation of change.
3. What are the phases/steps in the Engineering Change Process?
    - Is there any pre-defined workflow?
4. What functions/people are involved in the process?
5. Do you work with change requests?
    - How many requests per year?
    - When in the product's lifecycle?
    - How many are people involved in general?
6. Do you work with change orders?
7. Do you have different flows for different types of changes?
8. Are you at any time "forced" to make exceptions from the process?
9. Is the process supported by a PLM-system?
10. Do you work with cross-functional teams in the process?
    - What issues is brought up during these meetings?
    - How often?
    - Who is involved?

Input

11. What are the sources of input to the process? Who is the initiator of the change request?
12. When the order is created, is there any review of the input before it is pushed forward in the process?
13. Are there any owner/responsible person for each change request/order?
14. Do you find the input sufficient to create an understanding of the problem?
    - How have the company worked to improve the input quality?

Classification/Prioritisation

15. Do you classify and/or prioritise the change requests/orders?
    - Who is responsible for making the classification?
    - When in the workflow is the change classified?
    - Are there any official or unofficial "rules" for how to make the classification?

Approval of changes

16. How do you decide who should be involved in the Engineering Change Process?
17. Is it obvious what the approver is supposed to approve?
    a. Where can he/she find information about what to approve and what information that is approved by others?
18. Is the process dependent on specific individuals? E.g. approvers? Can the process halt if someone is absent?

Release planning

19. Do you have problems with many minor changes regarding the same product structure within a short time frame?
20. Do you work with release planning?
    - Why/why not do you work with release planning?
21. Is there occasions when you make changes outside the planned release?
    - Why?

KPI

22. Do you think the Engineering Change Process works well in your company?
    - Any specific parts of the process?
23. Do you measure the Engineering Change Process?
    - What KPIs do you use?
    - Why have you chosen theses KPIs?
    - What KIPs could be interesting to measure?

Appendix D: Interviewees

Interviews have been conducted with the respondent presented in the table below.

	Company	Department and/or position	Date
1	Ascom WS	After Sales and Product Manager	26-02-2013
2	Ascom WS	Coordinator	28-02-2013
3	Ascom WS	CR-accountable	27-02-2013
4	Ascom WS	OEM-responsible	13-03-2013
5	Ascom WS	Product Manager	15-02-2013
6	Ascom WS	Product Manager	20-02-2013
7	Ascom WS	Production Planning	27-03-2013
8	Ascom WS	Purchasing	18-02-2013
9	Ascom WS	Purchasing	28-02-2013
10	Ascom WS	Purchasing	25-02-2013
11	Ascom WS	Purchasing (External Produced Products)	14-02-2013
12	Ascom WS	Product Quality (Manager)	09-04-2013
13	Ascom WS	Product Quality	19-03-2013
14	Ascom WS	R&D Hardware (ECAD)	14-02-2013
15	Ascom WS	R&D Hardware (Manager)	12-03-2013
16	Ascom WS	R&D Hardware (Component Engineer and coordinator)	22-02-2013
17	Ascom WS	R&D Mechanics	26-02-2013
18	Ascom WS	R&D Mechanics (Manager)	22-02-2013
19	Ascom WS	R&D Software	26-02-2013
20	Ascom WS	R&D Software	27-05-2013
21	Ascom WS	Regulatory and IP	13-02-2013
22	Ascom WS	Regulatory and IP	21-02-2013
23	Ascom WS	Production Engineering	25-02-2013
24	Ascom WS	Production Engineering	28-02-2013
25	Ascom WS	Product Portfolio Manager (Process owner)	10-04-2013
26	Company 1	CM Radio HW	26-03-2013
27	Company 2	Design Engineer Hardware	27-03-2013
28	Company 2	Manager for maintenance, quality and cost reductions (Process owner)	03-04-2013
29	Company 3	Controller for Products	02-04-2013
30	Company 3	Manager Maintenance Department	02-04-2013

Appendix E: Summary of the interview and survey data

The result from the KJ-analysis of the interview data and the data gained from open questions in the survey is presented below. From this data a selection was made to focus on certain categories. The chosen categories have a focus on aspects concerning the overall process and the steps within the change process. Some aspects were excluded from further work in thithesis due to lack of relationship to the process itself. The following aspects were excluded; external aspects, the PLM-system as such, handling of product revisions and implementation. The motivations for the choices are presented in Appendix F.

<table>
<tr><th>Category</th><th>Main issues</th></tr>
<tr><td>Approvals</td><td>
Some employees do not understand why the same issue first is approved in the change request and then has to be approved once more in the change order.
What is the difference between the decisions?
What is the point of approve that the change is performed in a certain way if the change per se is approved?
Approvers need to approve the change request/change order, but observers and notified often do not understand their roles and feel they get unnecessary information.
Approvers are unsure about what part of the change request/orders they approve and what parts that other approvers are responsible of.
Does every aspect in the change request/order get an approval?
If the change request/order is unclear it will take longer time to review and approve.
Occasionally errors are discovered after the review.
It is hard to understand the information provided in a change request/order and the approvers often have to collect additional information to be able to make the approval.
It is unclear who should be involved in a decision. The approvers/reviewers for change requests are chosen based on experience.
Some perceived that the change is performed even if someone rejects the change.
Some departments/groups of individuals would like to get personal e-mails when a change request/order concerns them, and not as it is today get all e-mails concerning the whole group/department.
This would result in more work for the Agile-coordinators.
If a change request/order concerns more than one person in a group of approvers, there is a risk that no one takes action and coordinates the joint approval. Would be better if each person could make an individual approval.
</td></tr>
<tr><td>Checklists</td><td>
Some checklists are perceived as pointless
What is the purpose?
Better to have documents supporting the approval process than having checklists filled out after the decision.
</td></tr>
<tr><td>Physical Change forum</td><td>
Good with cross-functional meetings
Differences in the interpretation of the purpose of the forum
</td></tr>
<tr><td>Change requests and change orders</td><td>
Unclear what should be decided upon in a change request investigation
Some perceive the change requests as means to secure the resources needed.
Unclear if there is an owner of a change request/order and if so, who the owner is
Some of the changes should have been rejected at an early state.
Change issues from external and internal sources should be gathered in a common way.
Termination of products decreases the need for changes.
</td></tr>
<tr><td>External aspects</td><td>
.pdx-packages are large and might be difficlut to interpret
Some believe it would be better if the suppliers and external producers had
</td></tr>
</table>

	access to Agile • A large number of changes at Ascom = a large number of changes at the suppliers and/or producers • Manual handling of information between Ascom and the suppliers = risk! • The ease of implementing changes at the production site is dependent on the contact person at the producer and the length of the cooperation with that particular person
Handling product revisions	• It is difficult • Lack of standardisation

Implementation	• The use-up of components is problematic
	    • Who has the responsibility?
	    • Some people mean that more components should be scraped.
	    • The quality department would like to be involved in the decision regarding use-up and scraping
	    • Deviations are hard and time consuming to handle due to a lot of manual work
	    • Even if the component should be used-up some scraping should be allowed to safeguard for errors in the forecast and a cost centre for the scrap should be stated in the change order.
	• The long time period between the decision and the implementation makes it difficult to keep track of the change orders and the need to collect traceability data
	• Some departments lack feedback regarding if a change has been implemented or not
	• It takes long time before traceability data is added to the change order in Agile, and it is difficult to find.
	• Difficult to decide upon the level of traceability needed.

Input	• In general, it is difficult to understand the change requests and change ordesr
	    • Why is the change needed?
	    • What should be changed?
	    • Who is affected by the change?
	    • What end-products are affected by the change?
	• The requested input should be specified in a clear way
	• Some expect the coordinator to get back to them if they have missed any necessary information.
	• Product name and product family should always be specified
	• The quality of the input is dependent on the author of the change request/order
	• Does it matter if the author knows who the receiver/reader is?
	• Difficult to judge if the change affects form, fit or function and sometimes the wrong assumption is made. In case of contingency it better to inform about the change then not to.
	• The change orders concerning new products lack information regarding if the product should be MTO or MTS

Interface between development project and the line organisation	• The development projects works well since there is an appointed project manager • Unclear division of responsibilities when the product lifecycle statusis set to active sustain but the development project is still running (i.e. the product is not yet handover to the line organisation)
Lead time	• Long time between change request and change order leads to additional time required for gaining insight in the change twice • The process is sequential • The process is too slow • The non-value adding time is significant • Mechanical changes have long lead times • Long lead time due to suppliers in Asia • The work with change request/order is not a priority for some departments/individuals. • No information about the expected response time or deadlines • Takes long time to implement the change and collect the checklists

Dependent on individuals	• Some departments have a coordinator • The process halts if someone is absent • The escalation and transfer authority functions are not used
Prioritising	• The work with change request/order has different priority among employees. Hence the process might be slow. • What is meant by classifying a change request/change order as urgent? • When shall a change request/order be classified as urgent?

Release planning	• Benefits
	  • Eliminated the need of minor changes
	  • Less deviations
	  • Beneficial from the coordination’s point of view
	  • Ease the planning of the work hours on an individual level
	  • Increased possibility to give notice to the suppliers regarding changes in advance
	  • Ease the communication with customers and sales units
	  • East the implementation at the production sites
	  • A deadline will push people to take actions in time
	  • Possibility to reduce the need of scrapping by planning in advance
	  • The total administrative time will decrease
	  • The number of times a product needs to be sent for verification/test at an external auditor might decrease.
	• Disadvantages
	  • Employees are familiar with the current process
	  • Is it Lean to batch the changes?
	  • Not suitable for all products
	    • Some has too low volume/too few changes
	  • Is it acceptable to have lower quality until the release?
	  • Poor quality results in increased warranty compensation costs and cost of bad will.
	  • Every change is (or will be) urgent, cannot wait until the next release
	    • Eg. Quality issues and changes due to business on new markets
	  • Hotfixes cannot wait until the release
	  • Will require a large amount of planning
	  • Do the suppliers have the resources needed to handle product releases?
	  • Can result in a large amount of information to review at the same time
	  • How will product releaser affect the use-up of materials?
	  • A risk that changes not will be implemented
	  • The process flexibility will decrease
	  • The lead times are long as it is, and might be even longer with product releases.
	  • Testing and troubleshooting will be more complex if many changes is implemented at the same time
	• Other remarks
	  • The opinions about number of releases per years vary (from 2 to 6).
	  • Most changes concerning the same product are perceived to occur during the ramp-up.
	    • Maybe possible to only use batching of changes during the ramp-up?
	  • Long lead times to get approvals from OEM-customers
	  • Might be able to use the same release process as for softeware (PCP agile)

The PLM-system (Agile)	• The PLM-system is in general viewed as an appropriate tool since it supports traceability and gather all information in one place • Difficult to search for and/or use data in Agile • Difficult to remember to follow-up issues if one do not have an action since one do not gets an auto generated notice when information has been updated in the system. • The transparency in Agile is poor, due to inexperience and the way the system is structured

	• There is a need for educating Agile-users • The information in Agile is not 100 per cent correct and updated • Some departments lack super users.
The process	• Work is performed outside the pre-defined process • The pre-defined process is not optimal for all departments and tasks have to be performed in advance • A lot of work is performed before the change request is sent for review • Lack of explicit understanding of the process • Is one aware of the amount of work a change request/order causes at different departments? • People appreciate that it is possible to write a change order without first writing a change request • There is a need to educate participants about the process in order to gain an understanding regarding the effects of once actions. • Different opinions regarding who the owner of the process is, if any. • Improved communication to the customer is important. Must communicate; why/why not the change will be made? • Cost reductions: No follow-up of the actual savings after the implementation. • The process owner should both have detailed knowledge about the process and a holistic view point. Might be better to have an operational process owner.
Written instructions	• The written instructions are poorly utilised • Some means that the written instructions are obsolete and need to be updated • Some do not know where to find the written instruction • People would like the have the instruction integrated in the PLM-system

Appendix F: Selection of focus issues

The motivations behind the choice of issues to focus in this thesis are summarised below.

Category	Why?	Why not?
Approvals	Approvals are related to the Physical Change Process and a prerequisite for it to function. Furthermore, many problem areas have been expressed regarding approvals which make it an interesting topic to elaborate.	
Checklists	It is important to be aware of the role of the checklists to understand the overall process.	The checklists are designed by different departments which make it hard to control and manage.
Physical Change forum		A small part of the Physical Change Process, which has an accountable leader continuously working with improvements. Hence there is less need to focus on this issue.
Change requests	The change request is one of the fundamental activities in the process. To understand the process the change request is an important part.	
External aspects		External aspects are not regarded as a part of the Physical Change Process itself and therefore not further elaborated.
Handling product revisions		Also a part of Agile (see the PLM-system)
Implementation		Implementation of a change is very much related to certain departments which makes specific issues relating to the actual implementation less important for the entire process.
Input	The input category regards the input to all stages of the Physical Change Process. The input is of highly interest since it is affecting the following activities and the outcome of the process. And the varying quality of input has a large impact on the overall process hence this aspect will be developed.	
Interface between development project and the line organisation	To be able to improve the Physical Change Process it is important to know where it starts and who has the responsibility and make this clear to the organisation.	The project phase itself is not included in the scope of the thesis.
Lead time	Lead time is an issue that has been brought up in several interviews and the Value Stream Mapping show that a large part of the throughput time is non-value adding time.	
Person-dependencies	Interesting with this category is how the process is dependent on specific individuals. To make it less dependent it is important to understand the dependencies today.	
Prioritising	This became a separate category since many respondents highlighted this issue. Prioritising and classification can be regarded as input and is therefore included.	
The PLM-system (Agile)		The PLM-system itself can be difficult to change and that is not the aim of this thesis.
The process	Most of the comments in this category were related to	

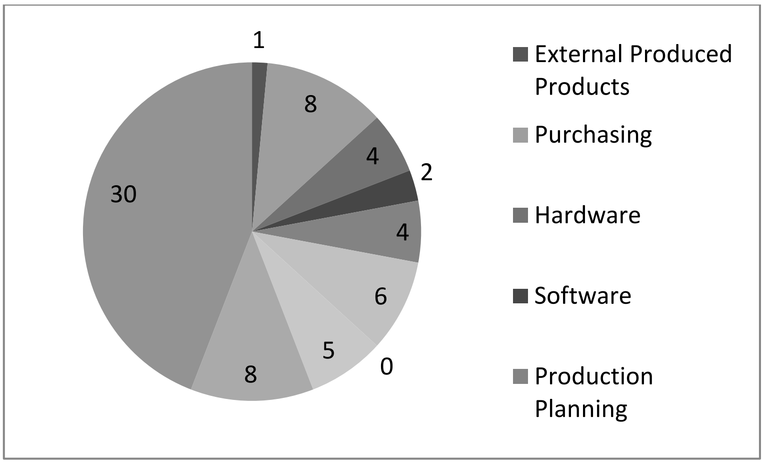
	the lack of explicit understanding of the process. To improve the process it is important to understand it, hence this category is important for the result of this thesis.	
Written instructions	In order to facilitate the overall understanding the written instructions must be correct.	No refining work on written instructions will be made, though the result from this thesis can be the basis for new instructions.

Appendix G: Survey

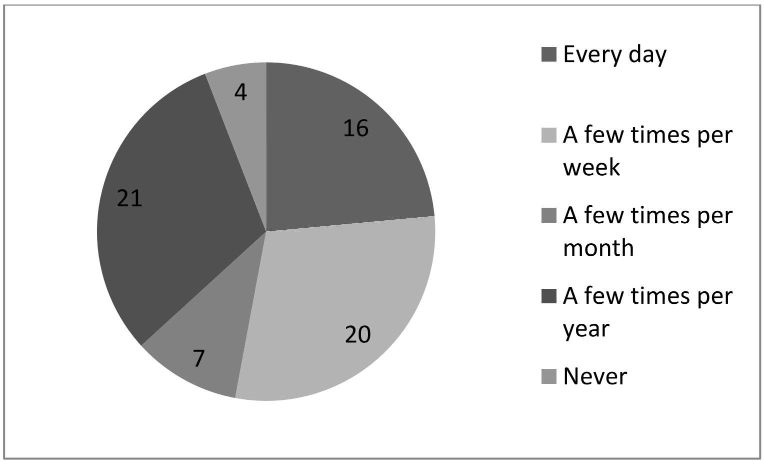
Questionnaire

A Swedish version of the questionnaire below was sent out to respondents at Ascom Wireless Solutions. The answers to the open questions are summarised in Appendix D.

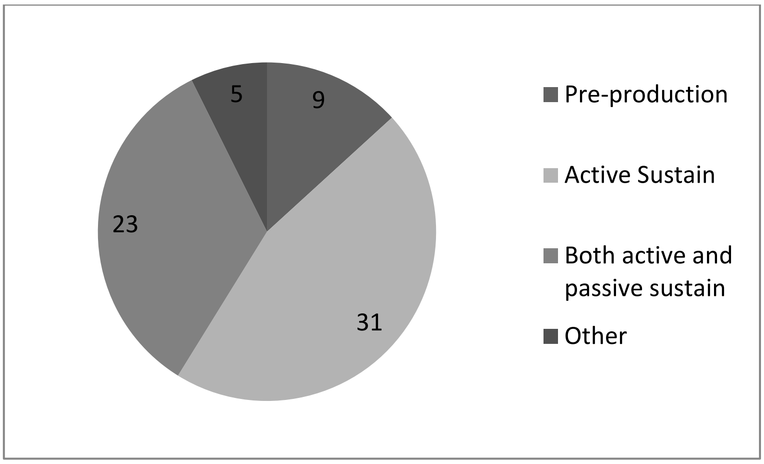
1. What is your area of responsibility?
    a. Answer:



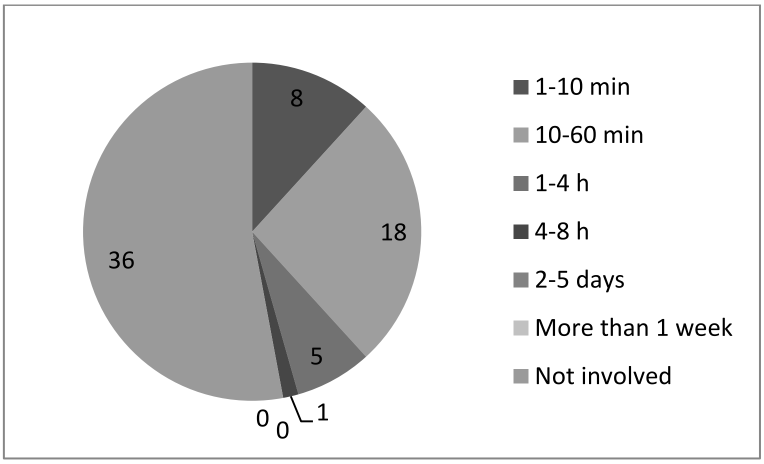
2. How often do you work with product changes in Agile?
    a. Answer:



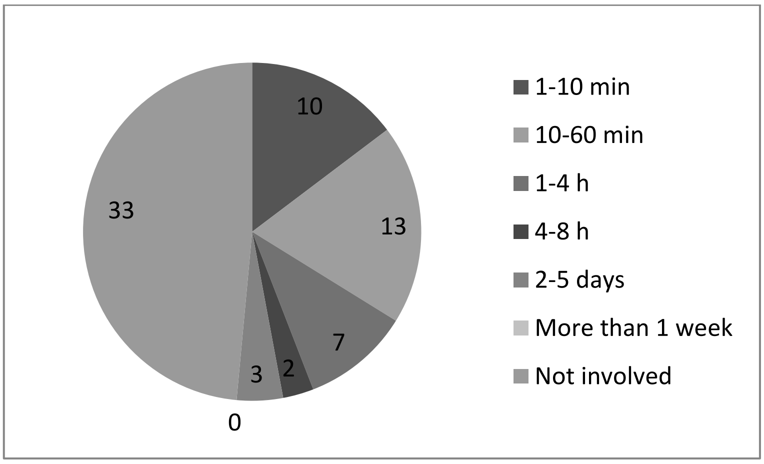
3. In general, where in the product lifecycle are you involved in the change process?
    a. Answer:



4. What is your average process time for the following steps for a change request?
    a. Create a new change request
        i. Answer:

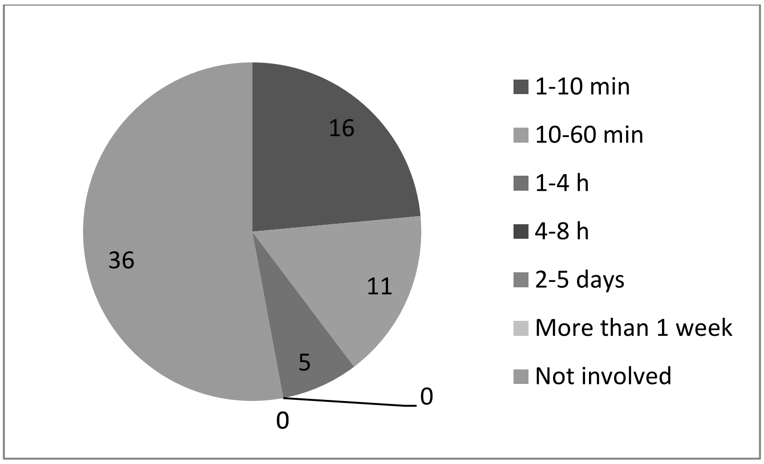


    b. Investigation
        i. Answer:



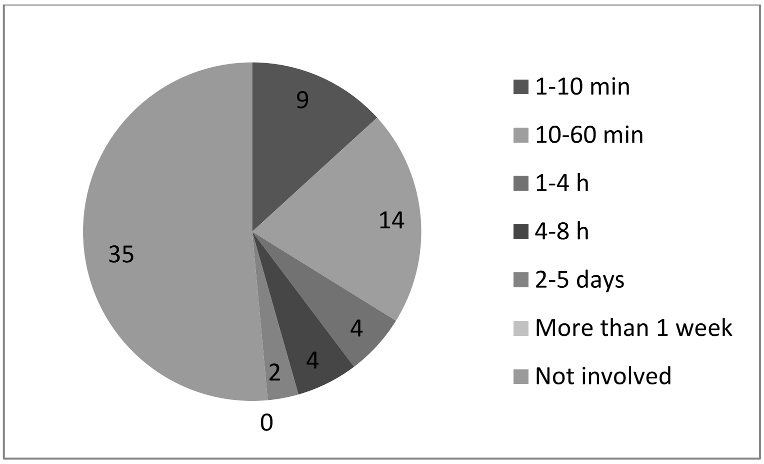
c. Decision

i. Answer:



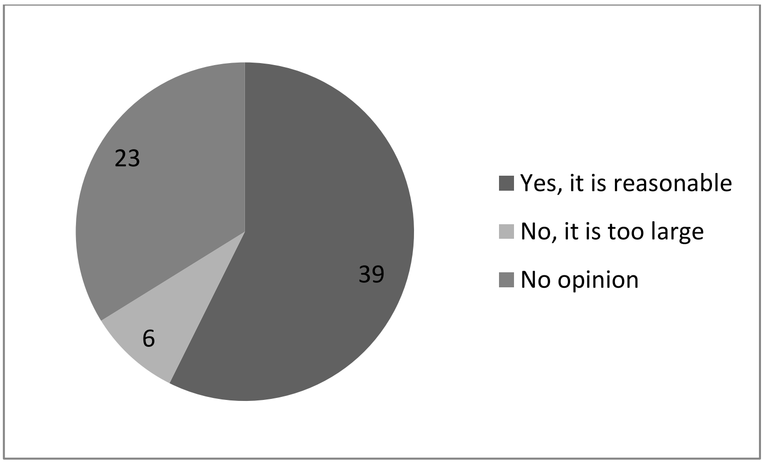
d. On-going work

i. Answer:



5. Do you consider the process time for change requests reasonable?

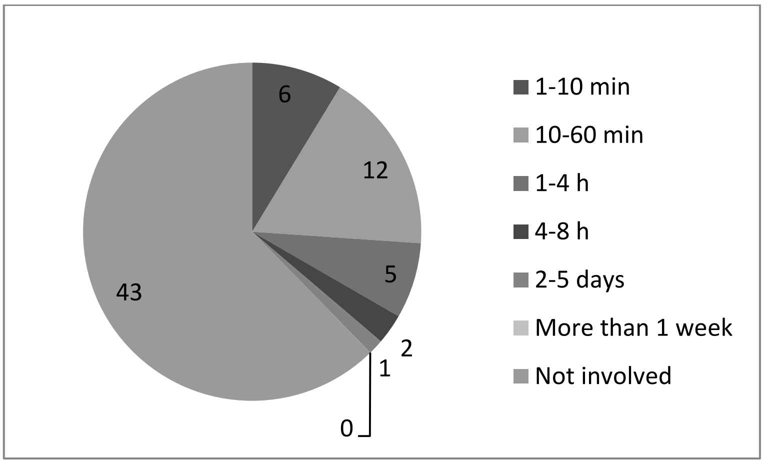
a. Answer:



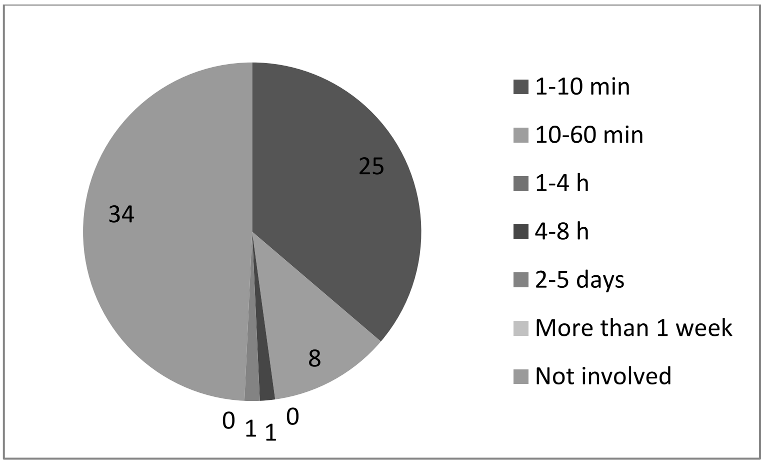
6. If not: What factors makes the work with change requests too time consuming?

a. See Appendix D

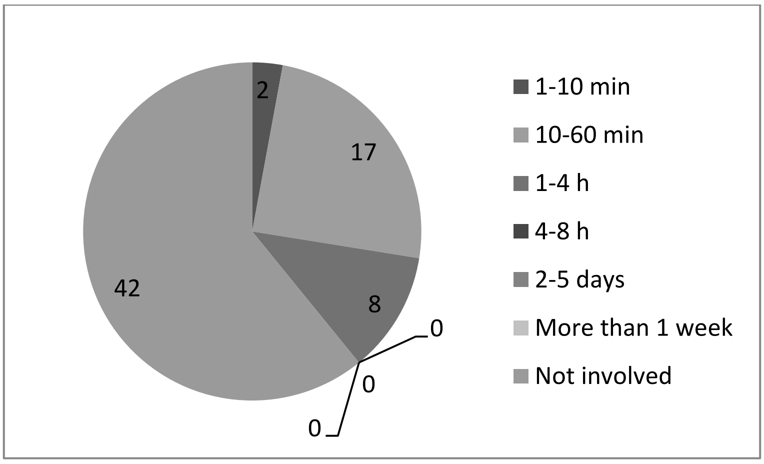
7. What is your average process time for the following steps for a change order?
    a. Create new change order
        i. Answer:



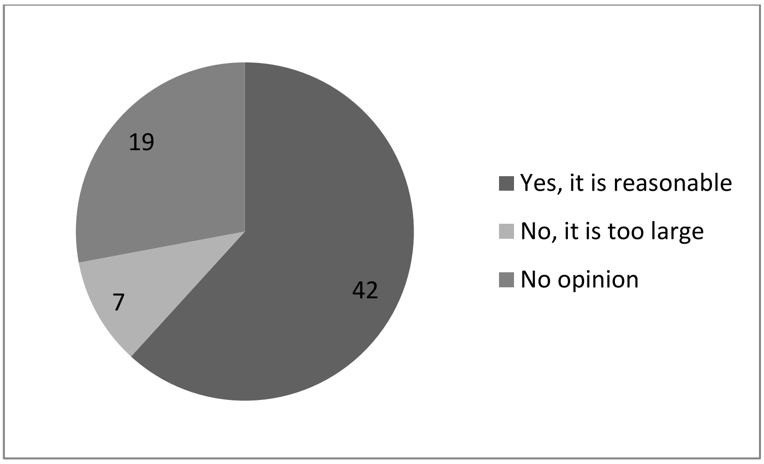
    b. In review
        i. Answer:



    c. Released
        i. Answer:



8. Do you consider the process time for change orders to be reasonable?
    a. Answer:



9. If not: What factors makes the work with change requests too time consuming?
    a. See Appendix D
10. What in the Product Change Process works well?
    a. See Appendix D
11. What could be improved in the Product Change Process?
    a. See Appendix D
12. Additional information
    a. See Appendix D
    b.

Response rate

According to Bryman & Bell (2003) the response rate is calculated as below.

$$Response\ rate = \frac{Number\ of\ usable\ questionnaires}{Total\ sample - Unsuitable\ or\ uncontactable\ members\ of\ the\ sample} \times 100$$

$$Response\ rate = \frac{68}{119 - 1} \times 100 = 58\ \%$$