This dissertation is addressed to project managers, engineering practitioners, and change agents in engineering organisations. As you are aware, engineering changes disrupt plans, can affect technical solutions negatively, and put project organisations under strain. However, engineering changes are a crucial part of the design process and a prerequisite in adapting to a dynamic project environment.

This research aims to mitigate the adverse effects of engineering changes and capitalise on their strengths. In such cases, when a change is raised, an ad hoc team of engineers is formed to manage it. This research results in an organisational-learning approach, developed to improve the performance of ad hoc teams in managing engineering changes.

The strength of the suggested process lies in its capture both of the specific and the practical. It is specific in the sense that it focuses on issues related to emergent changes and its sibling initiated changes to raise awareness of their differences and how they relate to possible opportunities within changes. It is practical in that it acknowledges the importance of an active line-management organisation that supports project planning, execution, and development to sustain a culture of learning as it relates to the engineering-change-management process, pre-, in-, and post-change. Through a systems view, the process also incorporates change types and the concept of change carriers.

This publication contains six separate articles based on the five performed case studies, a general summary of methods used and obtained results, and a prospective learning-organisation process and associated discussions.
TOWARDS A LEARNING PROCESS FOR AD HOC ENGINEERING CHANGE TEAMS

Peter Sjögren

2018

School of Innovation, Design and Engineering
TOWARDS A LEARNING PROCESS FOR AD HOC ENGINEERING CHANGE TEAMS

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Akademin för innovation, design och teknik
Abstract

Engineering changes disrupt plans, can affect technical solutions negatively, and put project organisations under strain. However, engineering changes are a crucial part of the design process and a prerequisite in adapting to a dynamic project environment.

Prior research has suggested the efficacy of the pre-emptive actions of reducing the number of, and front-loading, changes. However, pre-emptive measures to stop engineering changes from materialising are difficult to achieve if there are shortcomings in the project processes. Even with formal processes in place, they often fall by the wayside when changes occur, replaced by ad hoc practices. In such cases, when a change is raised, an ad hoc team of practitioners is formed to manage it. In the informal handling of the change that follows, practitioners tend to focus on risk aversion rather than weighing risks against the opportunities.

To improve the performance of ad hoc teams in managing engineering changes, an organisational-learning approach has been developed. This research is based on the fields of both project- and engineering-change management and applies a multiple case study design with cases from product development and engineering-type projects. Research results are based on data from over 40 interviews with project managers and engineers as well as over 100 change requests, the contents of which were analysed both qualitatively and quantitatively. The research methodologies both of soft systems and projects-as-practice were used to analyse results from qualitative data.

This research further develops the concept of ad hoc teams in the context of engineering design, thus contributing to the field of strategic guidelines and organisational issues regarding engineering-change management. The strength of the suggested process lies in its capture both of the specific and the practical. It is specific in the sense that it focuses on issues related to emergent changes and its sibling initiated changes to raise awareness of their differences and how they relate to possible opportunities within changes. It is practical in that it acknowledges the importance of an active line-management organisation that supports project planning, execution, and development to sustain a culture of learning as it relates to the engineering-change management process, pre-, in- and post-change. Through a systems view, the process also incorporates change types and the concept of change carriers. Finally, the suggested process includes practical management guidelines for emergent changes and initiated changes. To that end, this research specifies a workshop structure to heighten practitioners’ awareness of their practices and praxis in handling engineering changes.
Abstract

Engineering changes disrupt plans, can affect technical solutions negatively, and put project organisations under strain. However, engineering changes are a crucial part of the design process and a prerequisite in adapting to a dynamic project environment.

Prior research has suggested the efficacy of the pre-emptive actions of reducing the number of, and front-loading, changes. However, pre-emptive measures to stop engineering changes from materialising are difficult to achieve if there are shortcomings in the project processes. Even with formal processes in place, they often fall by the wayside when changes occur, replaced by ad hoc practices. In such cases, when a change is raised, an ad hoc team of practitioners is formed to manage it. In the informal handling of the change that follows, practitioners tend to focus on risk aversion rather than weighing risks against the opportunities.

To improve the performance of ad hoc teams in managing engineering changes, an organisational-learning approach has been developed. This research is based on the fields of both project- and engineering-change management and applies a multiple case study design with cases from product development and engineering-type projects. Research results are based on data from over 40 interviews with project managers and engineers as well as over 100 change requests, the contents of which were analysed both qualitatively and quantitatively. The research methodologies both of soft systems and projects-as-practice were used to analyse results from qualitative data.

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Sammanfattning

Tekniska förändringar som uppstår i ingenjörsprojekt kan störa planering och stressar ofta projektorientationen. Förändringar kan t.ex. leda till fler förändringar, vilket i sin tur kan ha negativa effekter på de tekniska lösningarna som förändringarna krävt. Samtidigt är förändringar i projekt en förutsättning för att anpassa tekniken och dess flexibilitet efter den ibland snabba förändringshastighet som präglar projektmiljöer. God förändringshantering kan alltså också bidra till nya innovativa och viktiga lösningar.


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Gothenburg, September 2018

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Definitions

**Ad hoc teams:** exist for a finite period to solve problems, make plans, take decisions, or interact with clients or customers. In this, ad hoc project teams form out of “ongoing project teams” (Devine, Clayton, Philips, Dunford, & Melner, 1999).

**Change request:** the formal recognition and request for an engineering change that initiates the investigation of possible solution strategies.

**Change carrier:** the vehicle of an engineering change within a project. In this, both official and unofficial carriers are present. Official carriers (e.g. change requests), are those predetermined and recognised by the project organisations to evoke, control, and follow changes. Unofficial carriers have the same capabilities as official ones but lack formal status in the project (Sjögren & Fagerström, 2015).

**Effective engineering-change management:** the ratio of effort expended to benefits gained for each change (Fricke, Gebhard, Negele, & Igenbergs, 2000).

**Efficient engineering-change management:** the optimal use of resources in implementing changes (Fricke et al., 2000).

**Emergent engineering changes:** responds to a weakness in a product’s design (Eckert, Clarkson, & Zanker, 2004)

**Engineering change:** “…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” (Jarrett, Clarkson, & Eckert, 2005, p. 268)

**Engineering project:** treats the realisation and construction of larger, often one-off, engineering-to-order type of products (e.g. plants, heavy transport kinds, infrastructural installations).

**Initiated engineering changes:** planned changes aimed at correcting or improving a known factor of design (Eckert et al., 2004).

**Opportunity:** “Opportunities are factors, variations, and events that may lead to changes that make the project able to deliver the same quality in less time or to lower price than was agreed upon in the beginning of the project” (Krane, Johansen, & Alstad, 2014, p. 617).

**Organisation structure:** defines how activities are directed toward the achievement of organisational aims (Pugh, 1971).

**Practice and praxis:** praxis is the work performed to “get the job done”, and practice is what governs praxis, i.e. practices are built from praxes (Häggren & Söderholm, 2011).

**Practitioner:** in the context of this research, an engineer, project manager, or another project member that perform tasks (i.e. practices and praxes) in the current project.

**Process:** a series of actions, steps or phases taken in order to achieve a particular end.

**Product development project:** a project aimed at achieving a growth strategy in which the company develops new products for new and existing markets (Doyle, 2011).
List of appended papers

This research and its subsequent dissertation build on six articles. Peter Sjögren was the first presenter and author of the appended conference and journal papers, except for paper III, where Sjögren held the role as co-author. Sjögren performed the literature review, data collection, and analysis of all appended papers except paper III where he contributed to the analysis and authoring of all parts related to engineering-change-management processes. In the appended publications, co-authors have aided in all stages of the data collection, and analysis, as well as reviewing the paper drafts.


Additional publications


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1 Introduction

This chapter introduces the research and its background. The chapter presents a general description of the industrial and academic challenge. Also, the research objective, research questions, and the research boundaries are provided. The chapter ends with an outline of the dissertation.

1.1 Background

Engineering changes, as an adversary of steady project plans, have to be dealt with in virtually all parts of a project (Ahmad, Wynn, & Clarkson, 2011; Hamraz, Caldwell, & Clarkson, 2013). Planning is essential, owing to the complexity of developing and commissioning engineering projects. However, planning based on risk assessments and change propagation analyses can be ambiguous, and some changes are unavoidable (Dvir & Lechler, 2004; Lechler, Edington, & Gao, 2012). Being proactive is crucial, being reactive is indispensable (Fricke et al., 2000). In the later phases of a project, the complexity of implementing changes increases further as more and more project parameters are frozen. In this way, the product design, project organisation, and project planning are all put at risk by late changes (Eckert et al., 2004).

Primary project goals have to be addressed to surpass customers’ expectations. Engineering changes can stall the fulfilment of the primary project goals related to the triple constraint of time, scope, and cost. Missing the primary goals makes higher-order requirements related to quality and sustainability challenging to achieve (Hällgren & Söderholm, 2010). However, engineering changes are also a means to enhance projects flexibility. As the project environment changes, the project has to change with it. Furthermore, changes can harbour exploitable opportunities that were unknown before the change was raised (Krane et al., 2014; Olsson, 2007). In this respect, engineering changes are an enabler of quality enhancement in a project (Hutanu, Prostean, Volker, & Mnerie, 2016; Langer, Maier, Wilberg, Münch, & Lindemann, 2012; Wright, 1997).

Whenever changes challenge project plans, in operations (e.g. Huang & Mak, 1999; Wu, Fang, Lin, Yeh, & Ho, 2012), development (e.g. Munthe, Uppvall, Engwall, & Dahlén, 2014), or engineering projects (e.g. Ibbs, Wong, & Kwak, 2001; Park & Pena-Mora, 2003), the universal problem is the same. Project effort has to be expended to implement the change, otherwise the change itself might propagate uncontrollably, within the organisation, other projects and or products, thus increasing the risk in a project (Lindemann, Kleedörfer, & Gerst, 1998). The effort expended is often that of engineering practitioners working to resolve the changes in an as efficient and effective way as possible. Therefore, companies can deploy engineering-change-management strategies for the primary reason of reducing the workload on personnel (Acar, Benedetto-Neto, & Wright, 1998). Changes themselves are not necessarily malignant, but the increase in expended resources they cause can be (Lindemann et al., 1998).
The focus of previous research on engineering changes has often taken a product-development perspective (product view). Although this view is a multi-domain view, it is a view forged within the confines of the product (Ahmad et al., 2011). As of 2012, Hamraz et al. (2013) found that 74 publications, in the research area of engineering-change management, were product-centric in their approach, while 20 had a people, strategic, or organisational focus, combined. Furthermore, the overwhelming amount of research devoted to change-propagation analysis (48 out of 125) in the in-change phase of engineering changes field of research makes for a lopsided distribution in favour of a “hard” systems approach to managing engineering changes.

Conversely, the process view approaches issues with the logic that the process influences product and the context contributes to the product outcome (Blessing & Chakrabarti, 2009). Adopted in this research, the logic of the process view considers issues of the project organisation, strategy, and practitioners as critical to the outcome of product development projects.

Regarding observed practices used by practitioners, Fricke et al. (2000) found five strategies used to handle engineering changes: less; earlier; effectiveness; efficiency; and learning. Less (prevention) and earlier (front-loading) are strategies associated with plans and planning. Less aims to make as many unknowns known as possible before embarking on the project, while earlier attempts at making as many unknowns known as soon as possible once one has embarked on the project. Effectiveness and efficiency are essential in the “in-change” stage and aim to make the handling of a realised change as effective and efficient as possible (Fricke et al., 2000). As a subset of efficient change handling, opportunity detection is a valuable concept, i.e. the practice of identifying and exploiting opportunities in raised changes (Hutanu et al., 2016). Learning, on the other hand, is a “post-change” strategy aimed at understanding, analysing, and conveying changes to the benefit of future practitioners, lessons-learned, organisations, and processes (e.g. Wickel & Lindemann, 2014). Deubzer, Kreimeyer, and Lindemann (2006) observed similar practices, to those by Fricke et al. (2000), in early detection, fast decision making, and fast implementation.

From a projects-as-practice point of view, practitioner activities within projects are divided into practices and praxis. Practices represent both formal and informal ways of working, routines, and the processes followed, while praxis is the actions taken by the practitioners within those practices (Blomquist, Häggren, Nilsson, & Söderholm, 2010). From this perspective, for example, front-loading would be a practice that is populated by praxis to be effectuated by project practitioners. Furthermore, formal and informal project structures have been studied as they relate to project organisations in general (Rank, 2008) and engineering changes in particular (Eckert et al., 2004). Moreover, even though formal versus informal is a recognised aspect of engineering-change management (Eckert et al., 2004), it has not been studied as an aspect in its own right (Hamraz et al., 2013).

1.2 Problem statement

An industrial problem: this research reports on the research work performed in a collaboration between industry and academia. The author was employed by the case company as a researcher and engineer at the time of the research. The problem that stood out after the first explorative study at the case company was how engineering changes were interfering with project milestones and the quality of the delivery.
A recent broadening of the case company’s offering into the offshore wind energy sector increased its need for project-execution excellence in the area of engineering projects. The case company had a stable project management organisation and commissioned many projects with a similar order value in the past. However, fusing current industry knowledge with the addition of an entirely new field of business put a strain on the organisation. In the studied projects, engineering changes propagated and aggregated, uncontrollably, which led to complete redesigns, frustration among the engineers working on the projects, and, ultimately, judicial project negotiations.

The case company is a Fortune Global 500 company and, as it began its new business, there was no lack of funding or optimism in the new endeavour. However, as an industry that is mainly project-based, the stakeholders were many, and the layers of sub-suppliers were countless. These factors increased the complexity of the project execution. The case company had the project-managing role among the sub-suppliers, ultimately employed by the customer, and at the end of the day, the case company had to answer to the project customer. In the studied projects, there were several engineering-change-management systems in place to keep track of changes. Unfortunately, the many project phases (front-end engineering design, design, construction, and commissioning) and a plethora of involved stakeholders made for a challenging environment for synchronising engineering data in general and changes in particular. At the same time, the practice of forming temporary ad hoc teams to handle engineering changes, as they aggregated to bundles of change requests, was common informal practice in the projects. Whether or not this was a symptom of the breakdown of formal structures or an essential way of managing changes in the projects was uncertain. Regardless, the practitioners’ actions were a significant part of the day-to-day handling of engineering changes.

Current research: The research field of engineering-change management has primarily focused on change-propagation analysis and its software support, as shown by Hamraz et al. (2013) in their extensive literature review. Ullah, Tang, and Yin (2016) used the category “people domain” for the literature on the organisational issues of engineering change, an area in which little work has been done. Hamraz et al. (2013) refer to such research as “people-oriented”. This aspect of project management is relevant to the current research in establishing engineers’ ways of working as part of ad hoc teams in product development and engineering projects.

As more and more company tasks are executed within the confines of a project, reliance either on strong project-management offices or effective autonomous project teams is essential (Portny, 2013). Prior research has highlighted the difficulties faced by organisations when utilising engineering-change methods and tools developed in academia (Wickel & Lindemann, 2014). Start-up companies and smaller operations, often project-based endeavours, have a particularly tough time implementing product-architecture systems and change-propagation analysis capabilities (Becerril, Heinrich, Böhmer, Schweigert, & Lindemann, 2017). The spectrum ranges from companies that are highly stable and are involved in operations and with a low degree of product customisation to primarily project-based companies with a high degree of product customisation or even one-off deliveries (Veldman & Alblas, 2012). The former can more confidently rely on software and established company routines (e.g. Huang & Mak, 1999; Huang, Yee, & Mak, 2001; Koch, Michels, & Reinhart, 2016) than the latter (e.g. Han, Lee, & Nyamsuren, 2015; Jarkas & Mubarak, 2016). In today’s business climate, few companies operate in any of the two extremes. Companies thus have
Engineering changes can be categorised as emergent or initiated. Initiated changes are raised to improve a design, while emergent changes respond to an identified weakness in the product (Eckert et al., 2004). Despite the large volume of research devoted to engineering-change management (over 400 articles published by 2012 acc. to Hamraz et al., 2013) more work is needed to help firms manage knowledge associated with engineering changes (Ullah et al., 2016). This research aims to contribute to this field. As noted by Alblas and Wortmann (2012), the management of “large” compared to “small” engineering changes was vastly different in a studied firm. This phenomenon was also highlighted by Langer et al. (2012), who called for further research into the management of critical changes that often disrupt projects more than smaller changes.

Furthermore, case studies and reports from industry have been requested within the field of engineering change management (Ahmad et al., 2011). There is, therefore, a need to extend the knowledge of how project-intensive firms handle engineering changes in dynamic project environments. Thus, this research focuses on how engineering practitioners manage engineering changes in formal and informal processes in a given project environment.

1.3 Research objective

In project-driven organisations, managing engineering changes in ad hoc teams is a common practice (Engwall & Svensson, 2004; Munthe et al., 2014). The ad hoc team’s way of working is highly individualised and dependent on the competence of the team members (Hållgren & Maaninen-Olsson, 2009). Engineering changes as redesigns present a unique opportunity for understanding many of the parameters that govern the project situation. Engineering changes can lead to more redesign with uncontrolled change propagation, suggesting the process that ad hoc teams follow needs to be better supported.

The objective of this research is, therefore, first to describe the practices of engineering-change handling by ad hoc teams in the product development and engineering projects of engineering-procurement- and commissioning-type corporations in Europe. The following objective is to develop a process that improves engineering change management with the practitioners’ perspective as a point of departure while also accounting for the different demands that the initiated and emergent changes imposed on the engineering process.

1.4 Research questions

As the implementation strategy used by engineering practitioners to solve engineering changes seems ill-defined, these research questions aim to discover the methods used by engineers, filling the research gap and identifying pitfalls. The first two research questions frame the ad hoc teams’ work, i.e. the context in, and which types of engineering changes they solve. The third and final question focuses on developing an actionable process to improve engineering change management performance.
1. Which project organisational structures are relevant to the ad hoc teams in solving engineering changes?

As ad hoc teams utilise both formal and informal organisational structures, the first research question aims to establish which structures are relevant and in what way teams interact with those structures. The polar cases of product development and engineering projects are used to differentiate in what way they influence the ad hoc team’s modus operandi for solving engineering changes and how these project features can be understood.

2. How are initiated and emergent engineering changes treated by ad hoc teams in projects?

The second research question juxtaposes the differences in handling routines by ad hoc teams when dealing with emergent or initiated changes. The question aims to gain a better understanding of the ad hoc teams’ ways of approaching two inherently different design issues.

3. Which elements are required in an adapted and continuous process, developed for ad hoc teams, to facilitate more effective and efficient engineering-change management?

Given what is known about ad hoc teams’ ways of addressing changes, the third and final question aims to achieve the research objective of developing a process for ad hoc teams’ engineering-change management. As has been argued in the Introduction, this research emphasises that the practices of ad hoc teams often are reactive. In this, effective (i.e. how impactful they are) and efficient (i.e. how much resources that are required) handling are two means of assessing reactive engineering-change management.

Together, the three research questions aim at developing knowledge of how practitioners work with engineering changes in a broader sense when accounting for factors of the immediate (project organisation) and outer environment (project type and line organisation) as well as how the type of engineering change (emergent or initiated) affects handling.

1.5 Limitations and delineation of the research

While this research examines engineering-change management, it does not pursue the objective of prescribing guidance on engineering-change-management software systems, nor their relation to impact analyses. Acknowledging that engineering-change-management processes are not detached from these software systems. Moreover, this research does not focus on engineering changes in the context of operations management but project-based tasks. Moreover, based on the five coping strategies of engineering changes proposed by Fricke et al. (2000), this research focuses on three effective, efficient, and learning (less and earlier being the other two), as well as the opportunity detection (Hutanu et al., 2016) strategies during the “pre-change”, “in-change” and “post-change” phases.
Furthermore, the research primarily focuses on one case company and industry, achieving verification of results by alternating the investigated cases and projects as well as using follow-up interviews. As the project groups were mostly different for each project, it was possible to triangulate the results. From a change point of view, the focus is directed towards the project-execution process, i.e. not early project planning, or later maintenance in already commissioned projects.

Outside of interview data, the empirical data is limited to minutes of meetings, contracts, formal mail correspondences and change carriers, e.g. change orders, variation orders, and non-conformance reports. All empirical data was collected from the case company’s databases, except for Study B (see section 3.2.4 for a detailed description). From an originator point of view, the project management and ad hoc teams are the primary creators of the empirical data that has been analysed.

In this research, a learning organisation approach is expected to, over time, improve the engineering-change-management performance of ad hoc teams. However, the research field of organisational learning is vast, and this research only scratches its surface. The sub-category of organisational learning, a learning organisation, is used in an applied manner in this research to support the implementation of the engineering-change learning process.

From a research-area perspective, the areas covered in this work are products and processes regarding the design aspects of product-development projects and engineering projects. However, the research focuses on the processual and organisational aspects of engineering changes that concern the product, but not on the product itself (see Figure 1). Product details have not been considered unless required to investigate aspects of the process or organisation.

Finally, engineering-change management is not to be confused with the concept of change management. Change management is, as Sirkin, Keenan, and Jackson (2005) put it, more broadly the knowledge of how to coordinate and implement change in an organisation. This research is limited to the technical changes in engineering efforts while acknowledging that to implement the suggested learning process, change management in the broader sense is relevant.

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**Figure 1**: The research focus in relation to product, organisation, and process.
1.6 Outline of the dissertation

Chapter 1: An introduction to both the subject and the research project. In this chapter, the subsections cover the research background, the problem statement, the research objective and questions, the limitations and delineation of the research, and, herein, the outline of the dissertation.

Chapter 2: Contains the theoretical background or frame of reference of the dissertation, covering engineering changes, processes, projects, and strategies, as well as positioning research regarding its contributions.

Chapter 3: The research approach, scientific approach, and research process (data collection, data processing, and analysis), as well as sections associated with the conducted studies and quality of the research, are all presented in this chapter.

Chapter 4: Provides the empirical findings for each study. In this chapter, the progression of the accumulation of results throughout the project is made visible. This chapter is concluded with a synthesis of the findings and the theoretical framework.

Chapter 5: This chapter connects the empirical findings to the overall aim of the research work. It provides a full description of the proposed engineering-change-learning process. This chapter is aimed at practitioners and process-owners to enable them in implementing their engineering-change-learning process.

Chapter 6: A discussion of the developed process in relation to prior research, its logical foundation, and its expected efficacy in use.

Chapter 7: Summarizes the research work and includes general, methodological, and research-quality discussions, along with contributions, both theoretical and practical, as well as suggesting avenues for further research.
2 Frame of reference

This chapter treats changes as part of the product development process in general and their effects on projects in particular. Furthermore, the different project settings for product development and engineering projects are presented. Subsequently, adapted engineering-change-management models are reviewed, and the differences both between emergent and initiated and formal and informal change processes are contrasted. Finally, the project-management concept of ad hoc teams is described and its association with engineering changes.

2.1 Engineering changes in project environments

The Empire State Building (completed in 1931) was first designed as an 80-story building. However, as it became known that the Chrysler Building was to stand 77 stories tall, but with a taller spire, the architects of the Empire State Building revised their plans and added 22 stories. Engineering changes abounded, but the Empire State Building surpassed the Chrysler Building to become the world’s tallest building at the time (Willis & Friedman, 1998). Some changes are unavoidable (Dvir & Lechler, 2004), other can elevate project value (Lechler et al., 2012) and late changes are most often costly (Fricke et al., 2000). As a rule of thumb, raising engineering changes after production has started can be ten times as costly as a change raised in the conceptual-design stage (Huang & Mak, 1999).

Riley, Diller, and Kerr (2005) found that engineering changes account for 5–15% of a project budget. This percentage range is only related to the process of change management itself, not the incurred cost of a given change. As with most costly project stages and entities, research has focused on how to reduce and mitigate the change in a proactive manner. Langer et al. (2012) also found that engineering changes consumed upwards of 30% of all work effort, following a survey of 90 engineering companies. Furthermore, Deubzer et al. (2006) found that 22% of changes in the automotive industry could be avoidable with better management processes. Such statistics have motivated research on improving engineering-change management, which is reflected in the growing interest in this area of research.

Wright (1997) published the first literature review of research into engineering-change management. The literature on engineering-change management at the time was scarce, and Wright (1997) divided 24 retrieved references into two broad categories: tools; and methods. At that point, the tools category was small, comprising only one-quarter of the papers reviewed. Today, the tools of engineering-change management are mostly studied in the area of project-lifecycle management (PLM) and software for a systematic approach to engineering change management. Engineering-change methods were found to be less industry-specific than tools and primarily concerned with correcting product development mistakes so that they would not interfere with the fabrication process (Wright, 1997).
Only 15 years later, Hamraz et al. (2013) published a literature review that analysed the then-current research body of over 400 publications covering engineering-change management, 384 of which were journal articles and conference papers. In conjunction with their literature review, they developed a holistic categorisation framework (see Figure 2). Hamraz et al. (2013) constructed their ideal definition of what engineering-change management should cover. Their definition was based on the product lifecycle developed by (Pahl & Beitz, 1984; Ulrich & Eppinger, 1995). Their ideal definition covered the entire project envelope, except for planning, and emphasised the iterative nature of the engineering-change-management process.

Jarratt et al. (2005, p. 268) suggested one of the broader definitions of engineering changes as “…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.”

Over the years, scholars have suggested and mapped change processes as they have been conceived or observed. One of the most cited is the generic engineering-change processes suggested by Jarratt et al. (2005) that has broad applicability. Other researchers have reported on more specific, but less generalizable, processes (Table 1). These processes differ in their focus and resolution. Engineering change management is often used in complex products and systems due to its inherent benefits in this type of development work. These kinds of projects were studied by Rouibah and Caskey (2003), who found that, in projects involving many stakeholders and where concurrent engineering was needed, the use of IT support for these processes was low. Other than the official approval process, IT support was seldom used to cooperate with colleagues and sub-suppliers to manage changes and deviations.

Moreover, Rowell, Duffy, Boyle, and Masson (2009) analysed the engineering-change-management process in the development of aircraft carriers. Rowell et al. (2009) were interested in the effects of the impact-analysis phase, how long it took for a given change to be resolved, and how many new changes for an original change were generated (propagation). Their study provided rich data analysis of over 100 change requests.

![Figure 2: A holistic categorisation framework of engineering-change management, adapted from Hamraz et al. (2013) (relevant fields to this research are lightly shaded).](image-url)
Rowell et al. (2009) also reported on the formal process used in the studied aircraft-carrier project to effectuate changes (Table 1). Kissel and Lindemann (2013) prescribed an engineering-change-management process developed to be used in the system-architecture design with decision-supporting guidelines (Table 1). Both Jarratt et al. (2005) and Kissel and Lindemann (2013) suggested that there should be alternative solution generation before a solutions evaluation and decision were made. Furthermore, they suggested that the decision and selected solution (to be implemented) be reviewed.

Rowell et al. (2009) and Rouibah and Caskey (2003) did not include these steps in their processes. Rowell et al. (2009) reported on the processes that were observed, and Rouibah and Caskey (2003) study focused first and foremost on product parameters. When considering engineering-change design processes, in general, the emphasis is often put on the generation of solution alternatives (Eckert, Pulm, & Jarratt, 2003) and the importance of learning through past mistakes by reviewing previous decisions, as in Jarratt et al. (2005) and Kissel and Lindemann (2013). Ahmad et al. (2011), however, asserted that the body of research connected to engineering change management was still rather young and would benefit from more case studies than were currently available. These studies followed in the tradition of the sub-fields of engineering-change management as defined by (Hamraz, 2013), i.e. strategic guidelines, organisational issues, people-oriented, and people-, process- and product-oriented (see Figure 2).

Table 1: Comparison of suggested engineering-change process models, adapted from Wickel, Chucholowski, Behncke, and Lindemann (2015).

<table>
<thead>
<tr>
<th>Generic process (Jarratt et al., 2005)</th>
<th>Many stakeholders (Rouibah &amp; Caskey, 2003)</th>
<th>Complex product (Rowell et al., 2009)</th>
<th>System architecture (Kissel &amp; Lindemann, 2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change trigger</td>
<td>Emergence of need to change</td>
<td>Experience stimulating factor</td>
<td>-</td>
</tr>
<tr>
<td>Request raised</td>
<td>Request for change</td>
<td>Raise formal query</td>
<td>-</td>
</tr>
<tr>
<td>Identification of possible solution(s)</td>
<td>Management approval of change</td>
<td>Describe reason for change</td>
<td>Clarification of change case</td>
</tr>
<tr>
<td>Risk/impact assessment of solution(s)</td>
<td>Implementation of change</td>
<td>Establish affected attributes</td>
<td>Selection of change mechanism(s)</td>
</tr>
<tr>
<td>Selection and approval of solution</td>
<td>Document of all impacted product data</td>
<td>Establish affected departments</td>
<td>Evaluation of alternative change options</td>
</tr>
<tr>
<td>Implement solution</td>
<td>Categorise change</td>
<td>Actual decision-making and approval of options</td>
<td></td>
</tr>
<tr>
<td>Review of change process</td>
<td>Describe proposed solution</td>
<td>Implementation</td>
<td>Review</td>
</tr>
<tr>
<td></td>
<td>Identify cost and schedule impact</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Raise change notification</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Implement</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Historically, engineering-change management has been a field of research concerned with issues encountered in a manufacturing setting (Wright, 1997), e.g. products that are rolled out of development and enter production but their designs are deemed unfit for manufacture by production standards and require changes. However, more recently, the field has expanded to encompass the entire product realisation (product development to product phase-out), except for early ideation phases where the process contains more changes than it does fix plans (Hamraz et al., 2013) and very innovative projects (Fricke et al., 2000).

In their study of change drivers, sources, and approaches, Eckert, De Weck, Keller, and Clarkson (2009) compiled causes of change from seminar sessions with project managers from a selection of industries. According to Eckert et al. (2009), all project managers could recognise the existence of changes in all categories. However, those that were checked were the most important for each industry. The authors concluded that the difference naturally came from the wide selection of participating industries but also noted that the approaches to handling change varied among industries.

Dvir and Lechler (2004) asserted in the title of their article: “Plans are nothing, changing plans is everything”. Their study was based on 448 projects and found that almost all of them suffered from changing goals during the project execution. In their paper, they argued that the static state of a “plan” is useless in the dynamic environment of a project; the project manager has to be aware of the changing plan and adapt to deviations (i.e. active planning). As deviations and their characteristics have been explained in the research literature, so have the methods and concepts been developed to deal with deviations. Planning could be one of these.

Table 2: Causes of change in different industries, adapted from Eckert et al. (2009).

<table>
<thead>
<tr>
<th>Industry / Changes to:</th>
<th>Cars (US)</th>
<th>Cars (EU)</th>
<th>Auto parts</th>
<th>Aero engine</th>
<th>Defence aero</th>
<th>Defence vehicle</th>
<th>Fire engines</th>
<th>Printers</th>
<th>Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirements</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Regulations</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Market opportunities</td>
<td>●</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Technology</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Quality, cost, and capability</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Sustainability</td>
<td>●</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Errors/problems/system integration</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Project management</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Changes to use of product</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Design for service/upgrades</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>
The notion of deviations is typically used in the project-management literature to describe changes that are of a more general nature than engineering changes. Deviations in project execution are a common theme in research and industry since they are so demanding to manage. Deviations hinder project managers from planning the development of a project from point A to point B. Deviations will require the project organisation to take detours and re-work and revisit previously valid designs, methods, and processes. In this research, Hallgren and Maaninen-Olsson (2009) definition of deviations simply as “unexpected events” is used. Within that definition, one could fit other similar concepts, e.g. disturbances and changes. Furthermore, deviations can typically lead to engineering changes being raised. Conversely, engineering changes might lead to project deviations.

2.1.1 Product development vs engineering projects

Not all projects are created equal, and researchers have long argued that different project types need different management styles (Pinto & Covin, 1989; Prabhakar, 2009; Shenhar, Dvir, Morris, & Pinto, 2004). Project size, project complexity, customer (external or internal), and level of project risk all define the project type (Prabhakar, 2009).

Product-development projects are associated with a high level of uncertainty and an unstable solution path. Project management in product-development projects must consider both current costs and future incomes in its decision making (Pons, 2008). Product-development projects often have a degree of novelty and experience a high rate of change, market turbulence, and subsequent changes in customer requirements; and these are all factors that increase project uncertainty (Olausson and Berggren, 2010), nevertheless, these changes need managing. Stockstrom and Herstatt (2008) found, through a regression analysis of 475 cases, that changes in new-product-development projects negatively influenced project goals, a finding in line with Dvir and Lechler (2004)’s results, which looked at projects in general, including engineering projects.

Engineering projects, as opposed to product-development projects, often have the following characteristics (Pinto & Covin, 1989):

- They treat the realisation and construction of more significant, often one-off, engineering-to-order-type products (e.g. plants, heavy transport kinds, infrastructural).
- Their content is mainly physical in delivery and is traditionally managed by EPC contractors (engineering, procurements and commissioning).
- They require many sub-suppliers and their coordination to reach completion.
- They usually answer to an order placed by an immediate client in a business-to-business industry relationship. The business-to-business contracts associated with engineering projects lead to extra demand deadlines due to fines that can, contractually, be imposed by the client on the company executing the project.

Using the UCP (uncertainty, complexity, and pace) model developed by Shenhar et al. (2004), differences between product-development and engineering projects can be visualised (see Figure 3).
Uncertainty denotes the level at the outset of a project. In product-development projects, the uncertainty is more significant regarding outcomes than in engineering projects. Complexity in the UCP model refers to the size, number of product elements, variety, and interconnectedness of the project. Regarding complexity, engineering and product-development projects may be similar. Finally, pace refers to the available time frame of the project. As engineering projects, in general, have more external stakeholders and may be subject to fines in the event of broken deadlines, the pace is considered a more severe factor than in product-development projects.

2.2 Categories of engineering changes

There are several ways of characterising engineering changes. According to Eckert et al. (2004), initiated changes are planned changes aimed at correcting or improving a known factor of the design. Emergent changes are responses to a weakness in a product’s design (Eckert et al., 2004). The categories of emergent and initiated changes are valid both for project-development and engineering projects. In Figure 4, Eckert et al.’s (2004) table is combined with Hamraz et al.’s (2013) engineering-change-management envelope. The figure shows the common origins of initiated vs emergent changes. Deubzer et al. (2006) used the two categories of optional and mandatory changes that are similar to, but not the same, as initiated and emergent changes. Mandatory changes are changes that need to be implemented to fulfil basic project requirements (i.e. safety and contractual) and optional changes fulfil project wishes. In this however, all emergent changes may not be mandatory and all initiated changes are not always optional.

Langer et al. (2012) categorise changes as critical vs average changes: a change that threatens a project’s critical path is considered a critical change. They compared the properties of critical changes to those of average changes (i.e. those that were not observed to have an impact in the project’s critical path). Critical changes had a longer processing time than average changes, with a mean processing time of 80.2 and 60.6 working days, respectively (Langer et al., 2012). Although it was not part of Langer et al.’s (2012) analysis, it is notable that both critical and average changes are more often emergent rather than initiated in nature.
One would think that the types of changes to be handled affect the chosen method used to handle them. However, Alblas and Wortmann (2012) found that incremental and radical (small- and large-extent changes) were both handled with methods and tools developed for incremental changes.

When change management needs to react faster, and to more complex issues (i.e. critical changes), the typical symptom is the breakdown of formal processes and procedures (Hällgren & Maaninen-Olsson, 2009). In some instances, project managers would decline radical and discontinuous changes due to the lack of processes to handle them professionally, ultimately affecting the quality of the product. For these types of changes, Weick, Sutcliffe, and Obstfeld (2005) even went as far as saying that processes are useless in dealing with emergent changes in a dynamic project environment.

Regarding the management process of engineering changes, Eckert et al. (2004) categorised change-handling processes into formal and informal change processes. Formal processes are the established ways of working, i.e. in processes and documented minutes of meetings. Informal handling refers to undocumented communication and tacit routines (Eckert et al., 2004), the kind of information that hierarchical and centralised project management has problems addressing (Lindemann et al., 1998). Informal processes are the processes that exist between functional divides and are often used to handle smaller changes, outside any formal process (Eckert et al., 2004). In general, radical, critical, emergent changes are signified by their extent and, often, tight deadlines, circumstances under which formal processes often break down (Hällgren & Maaninen-Olsson, 2009), this is indicated in Figure 5 but the darker shading. Conversely, optional, initiated and incremental changes have the luxury of being processed formally and in a structured way (lighter shade in Figure 5), with the exception that Eckert et al. (2004) mention, changes so small they do not register in a formal process (Figure 5).
Holmström, Hameri, Nielsen, Pankakoshi, and Slotte (1997) looked at how incremental (smaller) changes add up during operations until they reach a critical point and significantly disrupt the given process. Similarly, Rauniar and Rawski (2012) argued that it is often the smaller changes that end up causing the most problems as they fly under management’s radar, while more radical (substantial) changes immediately attract attention and are dealt with accordingly. Holmström et al. (1997) suggested the causes of this accumulation of changes were the lack of control systems (e.g., product data management, PDM) and the reliability of information communicated through the organisation. Another valuable finding by Holmström et al. (1997) is the way in which incremental emergent changes may seem unpredictable but, as they claim, this is often an effect of the time scope through which one sees the changes. Widening the scope one can often reveal seasonal, periodical, or even daily fluctuations as patterns formed by incremental changes in operations.

2.3 Proactive and reactive strategies

Fricke et al. (2000) categorised change strategies as having five attributes: less; earlier; effective; efficient; and learning.

Less refers to preventing the occurrence of changes; this strategy is sound given the many subsequent change propagation following a first change and the possible re-work incurred. However, as Fricke et al. (2000) themselves acknowledged, change is also a tool to introduce innovative solutions in products and can be a source of opportunities. Thus, prevention will only get us so far.

Earlier refers to front-loading and is also a sound engineering-change strategy given the increase in cost associated with “late-changes” in projects. It has been found that Japanese companies that engage in this strategy experience half the number of late changes than their American counterparts who front-load to a lesser extent (Hölttä, Mahlamäki, Eisto, & Ström, 2010). Less and earlier strategies are proactive in their approach. The later effective and efficient strategies are reactive, while learning can be viewed as reactive in the short run and proactive in the long run and aimed at increasing effective and efficient practices (Fricke et al., 2000).
Effective strategies aim to assess the ratio of effort expended to benefits gained for each change (Fricke et al., 2000). Change as an action can be generated from three stages of conscious action by practitioners: impact; decision-making; and observation. Observation is the most informed stage, followed by decision-making and impact as the most effective and intentional (Ross, Rhodes, & Hastings, 2008) (see Figure 6). According to Fricke et al. (2000), only 40–60% of analysed technical changes were necessary, results which the authors attribute to poorly informed decisions. To achieve more effective change management, Fricke et al. (2000) suggested that changes be categorised, that the reason of the change is well-established, that alternatives be evaluated, and that changes from past projects be reused as a form of lessons learned. They also pointed to the fact that changes may harbour innovative opportunities and that an effective strategy would seek to discover these opportunities. The emerged change is subject to both opportunities and risks. In a redesign, specific parameters and requirements are set due to the existing design and this is often viewed as a delimiting factor. Pena-Mora and Park (2001) noted that not only is there the question of what to do instead of the previous solution; often there is already a structure in place that needs to be removed. Conversely, the existing design also represents knowledge about an otherwise uncertain terrain, conditions that are known and that can be used in the planning of the change execution.

In this, opportunity discovery can be considered a subset of efficient change practices (i.e., the practice of discovering and exploiting opportunities associated with initiated changes) (Hutanu et al., 2016). With this extended meaning of opportunity, the definition of Krane et al. (2014, p. 617) is used in this investigation: “opportunities are factors, variations, and events that may lead to changes that make the project able to deliver the same quality in less time or to lower price than was agreed upon in the beginning of the project.”

The risk-averse mindset focuses on solutions in the design process, often the one that first comes to mind (Yilmaz, Daly, Seifert, & Gonzalez, 2015). The engineering-change process is similar to the design process (Wickel et al., 2015), in which similar one-solution assessments have been observed in the past (Eckert et al., 2004; Wickel et al., 2015). The iterative and reflective parts of the design process are essential in design thinking; there is seldom an optimum solution and, instead, one should seek to find a good solution for a given situation. Brown (2008) called this learning by doing, a culture of “building to think” instead of thinking about what to build. In engineering changes, there is no contradiction to the prototyping mindset proposed by (Brown, 2008) but engineering-change processes should, and do, focus more on an existing design and its limitations (Wickel et al., 2015).

![Figure 6: Stages of intelligent change management for a given change agent, based on Ross et al. (2008).](image-url)
Efficient strategies are what follow the efficient handling of changes. Given that a change is considered meaningful and worthwhile, optimal use of resources in implementing that change ought to follow (Fricke et al., 2000). Factors that are important in expediting change efficiently are spatial distance; communication media; quality of information; and practitioners’ willingness to communicate. These factors can be enhanced by integrated product teams (Fricke et al., 2000). Furthermore, Fricke et al. (2000) acknowledged the need for a standard engineering-change process but also emphasised that some changes need a more ad hoc way of being resolved as efficiently as possible. They also advocate introducing “changeability” (Ross et al., 2008) into product designs and not concentrate solely on organisational matters and processes.

Learning, the last strategy found by Fricke et al. (2000), aims to increase the quality of the project and engineering change processes. Changes, if meaningful, should be implemented to improve the product and the organisation should learn from that change, not only for the sake of the product but the overall product-development process (Fricke et al., 2000). Learning as it relates to engineering changes, is more closely examined in the following section.

2.4 Organisational-learning and engineering-change processes

Engineering-change-management processes can be adapted to suit specific needs and, since the concept of engineering changes is broad, customisation is essential (Becerril et al., 2017). Adapted engineering-change models also seek to encompass organisational aspects of the problems faced by management due to changes (Wilberg, Tommelein, Elezi, & Lindemann, 2015). Developed models ought to answer the criticism that engineering-change-management tools are too intricate to be adopted by new organisations and start-up companies (Becerril et al., 2017; Wilberg et al., 2015). Furthermore, engineering changes are not only instrumental in correcting past wrongs and introducing new innovative solutions, but they are also essential in the continual improvements of companies (Lindemann et al., 1998). Furthermore, it has been suggested that continuous improvements are applied to the process of engineering-change management to increase its efficiency and effectiveness (Hölttä et al., 2010).

In a case study by Hölttä et al. (2010), lean principles were applied to four engineering companies to increase the engineering-change processes’ efficiency. Related to the discovered waste in the process and organisation, they observed, among other things, “poor process discipline” and “the physical transport of paper documents”. Nor did the companies employ any continuous improvement strategies for their engineering-change processes. Training of personnel and implementing a scheme of continuous improvement was suggested to remedy these issues (Hölttä et al., 2010). Learning from past engineering changes has been suggested by several scholars in the past (e.g. Fricke et al., 2000; Hutanu et al., 2016; Wickel & Lindemann, 2014). These publications primarily concerned the changes themselves (i.e. given knowledge of past changes, which improvements could be performed in the product domain). However, (Hollauer, Wickel, & Lindemann, 2014) suggested an organisational-learning approach that not only aimed to improve product-specific aspects but the engineering-change-management process as a whole. Missing the holistic point of view in this
approach fails to acknowledge that the engineering-change process itself can be improved upon (Hollauer et al., 2014). Furthermore, Hollauer et al. (2014) made the distinction between “organisational learning” as a process- and theory-oriented concept and the concept of “the learning organisation” as a process- and practice-oriented. In their suggested framework, Hollauer et al. (2014) emphasised the importance of “people” by being the creators of knowledge that, in turn, is supported by “technology” (i.e. software and communication tools).

This research uses the definition of learning provided by Buckler (1998, p. 16): “a process that results in changed behaviour in ways that lead to improved performance”. Performance is measured over a range of organisation-specific key performance indicators (KPIs) and, as conceptualised in this research, leads to more effective and efficient engineering-change management. However, the research on KPIs for engineering-change management is undeveloped and needs more focus in the future (Kattner & Lindemann, 2017). Furthermore, Buckler (1998), differentiated between two styles of learning: “taught” (i.e. teacher-centred, controlled, behaviourist, and low risk to outcomes); and “discovery” (i.e. practitioner-centred, empowering, following in the Gestalt school, with higher risk to outcomes). Buckler (1998) asserted that to become a learning organisation, as Hollauer et al. (2014) also suggested, “discovery” is the better style of learning. In turn, workshops as tools of discovery were promoted by Buckler (1998) to attain an increased performance in a business setting.

2.5 Ad hoc teams

A distinction can be made between engineering-focused system research (what should be done, e.g. optimisation of a system) and practice-focused social science research (what is done in practice) (Blomquist et al., 2010). The dichotomy illustrated by Blomquist et al. (2010) also applies to the two research concepts of engineering changes and project deviations. The two both address adjacent issues; however, the former stems from product development and the latter is developed from the field of project management (hard vs soft).

Formal process breakdown has been observed in the management of engineering changes (Hällgren & Maaninen-Olsson, 2009). This is, in part, due to errors made in practitioners’ practices (e.g. communicating changes in project teams, recalling information, and documenting changes) (Busby & Hughes, 2004). Fricke et al. (2000) argued that integrated product teams overcome those factors. Decision-making in changes is difficult for individual engineers due to the often multi-domain nature of changes and subsequent propagation. Therefore, teamwork and change-request meetings are essential to any engineering-change-management process (Hölttä et al., 2010). Furthermore, traditional forms of project management with a hierarchical and centralised form of management are unable to take advantage of the dynamic and agile ability of autonomous engineering teams (Lindemann et al., 1998).

Ultimately, however, the breakdown of formal processes in the event of changes is due to time limitations. A change often represents extra work being performed in the project by those already tasked with pre-defined responsibilities in the current project (Hällgren & Maaninen-Olsson, 2009). The time constraint hinders individual and collective reflection (informal) and makes structured reflections (formal) even more challenging to achieve (Hällgren & Maaninen-Olsson, 2009).
Ad hoc teams, as studied in this research, are formed to handle changes as they emerge (Engwall & Svensson, 2004). As opposed to “ongoing project teams” that are existing teams with relatively stable membership during the project lifecycle, ad hoc project teams exist for a finite period to solve problems, make plans or decisions, or interact with clients or customers. Ad hoc project teams are, however, formed from “ongoing project teams” (Devine et al., 1999). In this, the ad hoc team require resources from the ongoing project teams as a change is raised which leads to resource management problems that increases the project risk (Lindemann et al., 1998).

Ad hoc teams often lack established procedures in handling engineering changes and, as the name of the teams implies, the resolution is often ad hoc in nature and, as Häggren (2007) described, highly dependent on the competence of the members of the team. Ad hoc teams in the project are “loosely-coupled” (Eriksson & Brannemo, 2011) parts of regular project teams whose members are often, but not always, part of the regular teams (Engwall & Svensson, 2004). Ad hoc teams are deployed to resolve an issue in a project that requires work outside, alongside, or in addition to the initially planned project activities (Engwall & Svensson, 2004). Their task is typically to resolve deviations or a perceived project crisis (Hällgren & Wilson, 2008). Similar concepts have been studied in the case of engineering-change management by Lindemann et al. (1998) in the context of concurrent engineering teams. They used the term “matrix team”, which is almost the same as an ad hoc team. A matrix team bridges product-functional divisions of concurrent engineering teams in projects to solve problems across component interfaces (Lindemann et al., 1998). However, compared to an ad hoc team, Lindemann et al. (1998) emphasised that the matrix team’s position in the project must be formalised to gain authority. Furthermore, matrix teams are expected to work more effectively and efficiently if the information flow in the team is moderated interactively, bi-directionally, and evenly distributed within the team. The team leader of a team working to deal with the moderation of change has a supporting role in the overall team whereas, in a classical hierarchical team structure, the team leader has a leading and controlling role (Figure 7).

The concept of dual structures is used to describe the duality or ambidexterity of many organisational or system structures. Dual structures, as a concept, serve to explain how a system or organisation utilises two for one. As Häggren and Maaninen-Olsson (2009) noted, whenever a change emerges in a project, an ad hoc team is set up for the given change. The ad hoc team usually consists of engineers, planners, a project manager, and on-site personnel from the project in what Häggren and Wilson (2008) called a “dual structure”, i.e. on-site vs in-house personnel.

![Figure 7: Control of change information flow vs moderation, adapted from Lindemann et al. (1998).](image-url)
The dual structure of organisations applies to ad hoc teams but is used to describe the normal workings of a project team as well. On-site personnel and in-house engineers are organised in a mirrored structure, i.e. the in-house structural designer in a construction project has a structural engineer on-site to discuss the physical reality of the fabrication processes with and, *vice versa*, the on-site engineer can receive calculation and design updates from his/her in-house engineering counterpart (Hällgren & Wilson, 2008).

The organisation of a project in a dual structure is an efficient way of increasing communication pathways in projects without increasing bureaucracy (Hällgren & Maaninen-Olsson, 2009). This way of organising is standard practice in construction projects but is applicable in other project formats as well, e.g. development projects where a development team might hand over their work progressively to a sales, testing, or project-execution team.

### 2.6 Positioning this research

Figure 8 depicts the research areas covered in this chapter. The research-contribution diagram, modelled using the method proposed by Blessing and Chakrabarti (2009), indicates the dissertation’s overall theme, which research areas are essential or useful, and the expected contributions of the research. Essential areas are fundamental to the conceptualisation of this research, while useful areas represent topics that are of a higher level of abstraction or from where general assumptions are drawn. The expected contributions of the research are shown; however, second-order effects and contributions are more difficult to predict.
3 Research approach

This chapter describes the scientific approach, followed by a description of the research process and the applied methodologies. Subsequently, methods of data collection and data analysis are described. This chapter also provides a summary of all the conducted studies. The chapter concludes with a discussion regarding the quality of the research and the role of the researcher in the conducted studies.

3.1 Scientific approach

Following Arnbor and Bjerke (2008), the scientific paradigms were considered on a spectrum ranging from the positivist, objectivist, and rationalistic (analytical and explanatory) to the hermeneutic, subjectivist, relativistic (understanding of knowledge), including the systems approach (Figure 9). The methodologies followed, and the methods used to answer the research questions were motivated by the problem described in the problem statement. The research environment and the role of the researcher also influenced the appropriate scientific paradigm. To answer questions of how case studies are a suitable mode of investigation (Miles, Huberman, & Saldana, 2013; Yin, 2011). In this research, case studies that consider both systems and an actor’s view were favoured over deterministic, quantifiable data methods. However, earlier studies (A-C) aimed more towards explanatory knowledge creation than later studies (D and E) that aimed more toward an understanding of knowledge. The research problem, therefore, determined the method of inquiry. Methodologies appropriate for handling qualitative data were chosen to determine the practices of practitioners associated with their management of engineering changes.

Figure 9: Positivistic and hermeneutic spectrum of research approaches, adapted from Arnbor and Bjerke (2008).
The project management-research perspective used was based on the projects-as-practice approach (Blomquist et al., 2010). At the core of the projects-as-practice perspective lie project practitioners and their practices. However, as this research concludes with a suggested process of learning, the actor’s view is central to its implementation.

Furthermore, the scientific method and general approach were based primarily on Miles et al. (2013) *Qualitative Data Analysis: A Methods Sourcebook* and its proposed compilation of practical methods of data collection, structure, and analysis. Qualitative data-analysis methods are the standard used to study in-depth and complicated research data. Qualitative data analysis represents a broad and relatively new set of methods born from the needs of the social sciences (Miles et al., 2013). More specifically, the means of analysis incorporates the lens of soft systems methodology (SSM) (Checkland & Scholes, 1999).

Considering the aim of the research question, the selected methodologies are suitable for acquiring rich and descriptive data to analyse the “how” and “why” questions whereas the “what” questions can be tested by statistical models, e.g. regression analyses (Miles et al., 2013), i.e. analytical approaches (Arnbor & Bjerke, 2008). Furthermore, it has been stated by Coghlan and Brannick (2014) that, to obtain rich information and produce research that is of value to those being studied, the researcher should submerge him/herself in the unit of analysis.

Coghlan and Brannick (2014) argued that doing action research in one’s organisation ought to be the gold standard of management research, and not fear the old positivist adage of being influenced by the object under study. Throughout the conducted research, the author has been employed by the case company, which supplies electric transmission solutions to the world’s grid operators. Given that the author was employed by the company, the amount of data collected was ample and in-depth. The data was also often unstructured as the case-company branch in question had been recently established as an organisation with subsequent effects on its process development. This role of the researcher within the case company has enabled submersion in the words of Coghlan and Brannick (2014), as an “insider”. However, as further elaborated in section 3.5.2, an action-research project (i.e. to study an initiated change within an organisation) was not possible for this research project. Still, the concepts and tenets of research quality are considered valid for the conducted research and are used to evaluate this research and to suggest future research projects.

### 3.1.1 Research process

The overall research process has, since the outset, been based on Blessing and Chakrabarti (2009) *DRM: A Design Research Methodology*. The framework developed by Blessing and Chakrabarti (2009) was used to guide the overall research process. DRM was developed to support the research process in engineering design. Engineering design as the overarching research domain of engineering-change management makes DRM an appropriate research process methodology. Their framework’s main stages and primary methods are “research clarification”, followed by a “descriptive study” that, in turn, yields further insights. From there, one can either refine the “research clarification”, commence the “prescriptive studies” stage, or both. Closing the circle as a “prescriptive study” can be evaluated and then described as “descriptive study II” (Figure 10).
### Design Research Methodology, Education and Progression

<table>
<thead>
<tr>
<th>Basic Method</th>
<th>Stages</th>
<th>Methodological Results</th>
<th>Studies</th>
<th>Ed. Progression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Literature and Analysis</td>
<td>Research Clarification</td>
<td>Goals</td>
<td>Study A</td>
<td>PhD</td>
</tr>
<tr>
<td>Empirical Data and Analysis</td>
<td>Descriptive Study I</td>
<td>Understanding</td>
<td>Study B</td>
<td></td>
</tr>
<tr>
<td>Assumption, Experience and Synthesis</td>
<td>Prescriptive Study</td>
<td>Support</td>
<td>Study C</td>
<td></td>
</tr>
<tr>
<td>Emperical Data and Analysis</td>
<td>Descriptive Study II</td>
<td>Evaluation</td>
<td>Study D</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Study E</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Study ?</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 10: Research stages, based on the framework of Blessing and Chakrabarti (2009).**

The first two research questions formed in this research are descriptive; their outcomes, however, have prescriptive elements, while the third question is mostly prescriptive. As there is no final evaluating study, this approach corresponds to what Blessing and Chakrabarti (2009) defined as research type 2 (see Table 3). This is also part of the qualitative data-processing process; making an initial assumption is necessary (Miles et al., 2013) letting the data speak to the researcher, and not the other way around. This exploratory approach was used initially in this research, which revealed phenomena worthy of pursuing further. All the discovered phenomena, however, were not suitable to pursue as part of this research, due to either a lack of resources or difficulty in obtaining valid data. In omitting some phenomena, the role of the researcher and his interest should not be neglected. Initially, this research aimed to investigate offshore platform projects and what made them reliable and, from there, to interpret the current situation. Later, it was found that some aspects of the same projects were malfunctioning despite the project organisation’s efforts. This finding led the research to critically study the current practices within the project organisation, related both to the reliance on design as a warrant of reliability (see Sjögren, Bellgran, Fagerström, & Sandeberg, 2014b) and how engineering changes were handled. Other phenomena that were observed but not pursued further included contractual technicalities and supplier–client relations.
Table 3: Types of research-project designs, adapted from Blessing and Chakrabarti (2009). Research type 2, lightly shaded, is representative of the work performed in this research.

<table>
<thead>
<tr>
<th>Type</th>
<th>Research Clarification</th>
<th>Descriptive Study I</th>
<th>Prescriptive Study</th>
<th>Descriptive Study II</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Review based →</td>
<td>Comprehensive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Review based →</td>
<td>Comprehensive →</td>
<td>Initial</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Review based →</td>
<td>Review based →</td>
<td>Comprehensive →</td>
<td>Initial</td>
</tr>
<tr>
<td>4</td>
<td>Review based →</td>
<td>Review based →</td>
<td>Review based →</td>
<td>Comprehensive ←</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Initial/Comprehen-</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>sive</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Review based →</td>
<td>Comprehensive →</td>
<td>Comprehensive →</td>
<td>Initial</td>
</tr>
<tr>
<td>6</td>
<td>Review based →</td>
<td>Review based →</td>
<td>Comprehensive →</td>
<td>Comprehensive</td>
</tr>
<tr>
<td>7</td>
<td>Review based →</td>
<td>Comprehensive →</td>
<td></td>
<td>Comprehensive</td>
</tr>
</tbody>
</table>

3.1.2 Qualitative analysis and SSM

This research is based on five case studies. Early on, the issues in the studied project’s organisations directed the research towards frustrations over how engineering changes were handled. While processes and software/technical tools were often in place, they seemed not to be utilised fully, leading to the questioning of how engineers went about solving the many engineering changes that arose during the execution of the projects.

SSM was used to map the actual/observed process, not necessarily conforming to the established/theoretical process, to reveal successful implementation strategies, bottlenecks, and malpractices both in the actual as well as the theoretical approach.

According to Locke (2001), the theories, in this case, should not be limited to those based on academic sources but should include the personal experience of the researcher as well as others involved in the research project. The idea is that problems as complex as humans’ interaction with other human beings and the organisations they work in are far too multifaceted to be captured by the constraints of any quantifiable phenomena, and this is where SSM proves apt.

SSM is based on the work of Checkland and Scholes (1999) that was an attempt, in a scientific way, to capture complex and organic phenomena based on systems thinking holistically. Checkland and Scholes (1999) developed a methodology that did not claim to be discrete in a positivist fashion. Instead, it made use of the power of description from mathematical systems and applied it to modelling reality. Hence, the soft vs hard separation, similar to the “harder” engineering change management approach vs the “softer” deviations-management approach of dealing with virtually the same issue. Checkland and Scholes (1999) acknowledges that the models purpose is not to be an exact representation of reality but a tool of change aimed at improving a given situation. In this, the model forms the basis for discussion in development work.
The development, through analysis, of the soft system model is part of establishing a common view of the current situation. The six axioms of SSM are:

1. problems do not exist independent of humans;
2. problems are interrelated and do not exist in isolation to one another;
3. the *weltanschauung* (worldview of an individual) is equally important as that of each individual;
4. solutions do not exist in isolation;
5. sharing perceptions, persuasion, and debates improve the system; and
6. analysts cannot be separated from the problem.

SSM can be applied at three levels: SSM as a process of inquiry; SSM as an action-oriented methodology; and the hybrid use of SSM (Hanafizadeh & Mehrabioun, 2017). In this research, SSM was primarily used as a process of inquiry. However, in the suggested engineering-change learning-organisation process (Chapter 5), SSM ought to be applied as a tool of action.

As a methodology, SSM has been used successfully by engineering-management scholars in the past to develop concepts related to their studied fields (Colombo & Cascini, 2014; Fagerström & Jackson, 2002; Page, 2008). The studies of both Staadt (2012) and Small and Walker (2010) applied SSM to the study of the organisational and social aspects of projects in particular.

Central to SSM is defining the root definitions of the intended soft system, i.e. what foundations the system rests on, what the systems’ intended use is, and whom and what the system includes. To this end, part of the work on SSM is to establish an accessible entry point to the root definitions for users. CATWOE [customers, actors, transformations process, *weltanschauung* (worldview), ownership, and environmental] constraints are the six essential aspects to consider (Basden & Wood-Harper, 2006). CATWOE is summarised in Table 4.
<table>
<thead>
<tr>
<th>Aspect</th>
<th>Research definition</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customers (C)</td>
<td>The actual customers of the projects that both initiate and experience the emergent changes that need resolving. In this case, the product owner is the internal customer, and the customer is the external customer and final recipient of the project. For both the internal and external customer, it is essential that costs are minimised, quality is maximised, and the project is completed on or before the estimated delivery date in an as safe a way as possible.</td>
<td>In product-development projects, the customer is often only internal.</td>
</tr>
<tr>
<td>Actors (A)</td>
<td>The practitioners in the ad hoc teams. In this research, actors primarily hold the roles of engineers from different technical disciplines, part-project managers, project manager, and members of the project steering committee. Practitioners who, in this case, perform T, defined below.</td>
<td>T is the core of each system. Activities to achieve T are sub-systems, and T’s situation on the broader system is defined by W and E, defined below.</td>
</tr>
<tr>
<td>Transformation process (T)</td>
<td>Transforming a requirement from one state to another to meet the goal of the initiated or emergent change</td>
<td></td>
</tr>
<tr>
<td>Weltanschauung (W)</td>
<td>Central to the studied case is that initiated and emergent changes need management in order to comply with new requirements and circumstances in a project. Furthermore, it is assumed and that the current management can be improved. In a broader view, this research assumes that processes influence, and are influenced by, practitioners as they perform their practices. Weltanschauung describes the world-view, which makes the transformation meaningful.</td>
<td></td>
</tr>
<tr>
<td>Owner (O)</td>
<td>The raison d’être of line organisation’s managers, as well as project and quality management, is to implement changes, organisationally, to the system, officially; thus, management is the principal owner. However, in another sense, the As (i.e. the practitioners) are also owners: if the As do not handle the emergent changes in an improved way, there will be no change. Owner stands for the person/persons who can permanently stop the transformation.</td>
<td></td>
</tr>
<tr>
<td>Environmental constraints (E)</td>
<td>External constraints and limitations that affect the success of changes to the system, including time frame, management, and economic support from O.</td>
<td>Given elements outside the system.</td>
</tr>
</tbody>
</table>
Based on CATWOE, the root definition used in this research is formulated as follows:

“Engineering changes, initiated and emergent, are handled by ad hoc teams, turning changed requirements into requirements met. Performance requirements need to be met in order to maintain or improve parameters such as cost, quality, time, and safety for the project stakeholders. The ad hoc team operates under the influence of the company-wide policies as well as established quality processes. Other projects in the company portfolio affect the current project and the ad hoc team as well as the line organisation. In turn, the ad hoc team affect other projects and the line organisation and reports to the project manager in a system that always has to respond to changes.”

According to Miles (1979), qualitative data offer a range of benefits, e.g. it is easily collected without advanced instruments, it preserves chronological flow, and it lends itself to multiple data-collection instances in an iterative process. Qualitative data also has its allure to researchers over quantitative data; as Miles (1979, p. 590) described it, “they lend themselves to the production of serendipitous findings and adumbration of unforeseen theoretical leaps…”. However receptive they were to the possibilities of qualitative data, Miles (1979) critique lay in how most qualitative data was treated in the analysis phase of research work. In essence, Miles (1979) asserted that analysis was often described in theoretical ways, not disclosing the actual method used by researchers to reach their conclusions. To that end, Miles (1979) urges researchers to make their internal process visible and transparent. As the aim of SSM is to construct a system from the empirical data through analysis as a basis for discussion and further development, this approach was chosen to finalise the research work.

3.1.3 Project-as-practice

The project-management research approach of projects-as-practice is a response to the critics who hold that contemporary management research not only has difficulty in making sense of current management practices but also produces irrelevant research unable to guide actual management practices (Blomquist et al., 2010). Project-as-practice aims to examine work performed and understand why it is performed in a particular manner. Projects-as-practice research focuses on what people do in projects (praxis) rather than on the confirmation of best-practice models of project management (Blomquist et al., 2010). Regarding definitions, praxis is the work performed to “get the job done”, and practice is what governs praxis. Moreover, practices are built from praxis (Hällgren & Söderholm, 2011).

Within project-as-practice, there are “bigger-picture” questions of project management that are lost, i.e. better handled by other, often more quantitative methods. Posing questions typically about project success factors or the utilisation of methods (including proposing different methods) is what Blomquist et al. (2010) referred to as traditional project-management research. Projects-as-practice, as an approach, does not shun empirical evidence, rather the questions posed are more suitably answered by focused qualitative data sets.
As stated by Blomquist et al. (2010, p. 7) in their review of the field, project-as-practice is subject to the first two critiques of contemporary project management research:

1. “Process studies are mostly concerned with processes defined by the structure, which results in a focus on projects as defined by these organizational structures. As a consequence, a more fine-grained analysis of the microactivities upon which the processes are built is sacrificed.

2. Following the first point, process studies focus on people in charge, thus sacrificing a bottom-up analysis of what individual actors do when they work on projects.”

For outside practitioners’ practice and praxis, the “site” is a central concept of the project-as-practice approach. The “site” is not a physical site – although it could encompass it – it is rather the site at which social phenomena that can be analysed occur, i.e. where human interaction occurs (Hällgren & Söderholm, 2011). In this research, however, this is not a central concept; the ad hoc team and the spaces (physical, digital, and ether) they reside in are considered synonymous with a “site”.

3.2 Methods of data collection

Interviews were the primary method chosen as the means of collecting empirical data in all studies. The interviews were semi-structured and performed following the guidelines proposed by Kvale and Brinkmann (2009). Interview is a suitable tool to acquire rich qualitative data (Yin, 2011). Apart from interviews, observations and archival studies were also used to gather data. Archival data included emails and organisational and project documentation, including plans, contracts, and minutes of meetings and are according to Yin (2011) a suitable companion data format to interviews as they can be used to confirm findings from interviews as well as representing precise and steady data over time.

3.2.1 Qualitative content studies

Qualitative content analysis has a similar modus operandi to that of general qualitative data collection and analysis (Schreier, 2012). What is straightforward about content collection and analysis is often, however, what makes it difficult. The data is not collected actively for interviews performed by the same research, so it saves some effort. However, the effort saved is often needed both to acquaint oneself with the data and later confidently analyse it (Schreier, 2012). Qualitative content analysis is a sub-category of qualitative analysis that sprung from the need to interpret complex data-sets, which could not be compiled quantitatively or could complement quantitative content analysis.
Qualitative content analysis lends itself to:

- verbal data;
- visual data;
- data sampled from secondary sources (documents, databases, and Internet sources); and
- data collected by the researcher (interviews and workshops).

Miles et al. (2013) described the processes of qualitative data collection and analysis in a detailed manner, and these were applicable to studies A, B, D, and E in the current research. However, in studies D and E, extensive database content was analysed, and in these cases, the lessons from Schreier (2012) proved valuable. As with the coding of interview material, only so much can be coded in a deductive manner, i.e. a priori coding. In studies D and E, change-request databases were studied for two different projects; a change request is a document (change carrier) that is documented in a template document and stored with meta-data in a database. However, meta-data is not mandatory to submit a request, nor is the template of the request locked from author “meddling”. This led to data that often was incomplete or difficult to interpret. Often, tertiary sources had to be consulted to complement and complete sets and, often, a qualitative judgement had to be made. However, the main reason for using qualitative content-analysis methodology is the interpretation that is made as part of operationalising the concepts that are to be analysed. Again, this requires an iterative coding approach as data can reveal new codes and themes that supersede previous ones (Schreier, 2012).

3.2.2 Interview studies

Semi-structured interviews were held for studies A, D, and E. Some interviews were carried out by the author alone and some with a fellow researcher for the validation and joint utilisation of results. The interview as a tool to gather qualitative research data was described by Kvale and Brinkmann (2009) as a method for gathering research data and as a basis for analysis. Those who claim interviews are too biased have a valid point, but the benefits of qualitative enquiry outweigh the downsides. Easton, McComish, and Greenberg (2000) identified the three most common pitfalls of interview studies as equipment failure, environmental disruptors, and transcription errors. Equipment failure was avoided by having two recording devices used in parallel and environmental disruptors were avoided by always conducting interviews in secluded meeting rooms. Transcription errors were possibly harder to guard against but, as almost all interviews were held in the native tongue of both the interviewer and interviewees, the room for misunderstanding was estimated to have been negligible.

Interview guides were used for each interview along with original deductive codes. No pilot interviews were held for the first interviews of study A. Since study A was of a general character and the researcher had a similar background to those to be interviewed, the nomenclature and background information discrepancies were low between interviewer and interviewees. However, as the research area was refined with specific concepts from academia, a pilot interview and a more precise interview introduction were needed in the second half of interviews of study A (A2).
All interviews were recorded then transcribed and notes were taken during the interviews. The interviewees were told the purpose of the interviews and assured before the interviews that their identity would not be revealed. All interviews were concluded by asking if the interviewee had something he or she wanted to add to the record. Regarding data handling of the interview data, both audio and transcriptions were anonymised by coding interviewee pseudonyms. Also, access to mail correspondences had been granted to the researcher and, in accessing them, they were never published nor stored in their entirety. The role of the interviewees, the date of interviews, and the relevant study are provided in Table 5.

Table 5: Role of interviewees, date of interviews, and relevant study.

<table>
<thead>
<tr>
<th>Engineering project (studies A, A2, and E)</th>
<th>Product-development project (study D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Consultant</td>
<td></td>
</tr>
<tr>
<td>Systems Engineer</td>
<td>131024 A</td>
</tr>
<tr>
<td>Supply Manager</td>
<td>130218 A</td>
</tr>
<tr>
<td>Commissioning Manager</td>
<td>130508 A</td>
</tr>
<tr>
<td>Commissioning Engineer</td>
<td>131024 A 140509 A2</td>
</tr>
<tr>
<td>1st Project Manager*</td>
<td>130220 A 140224 A2</td>
</tr>
<tr>
<td>Naval Architect</td>
<td>130802 A 140509 A2 170126 E</td>
</tr>
<tr>
<td>2nd Project Manager*</td>
<td>130826 A 151116 A2 170119 E</td>
</tr>
<tr>
<td>Transport &amp; Installation Manager</td>
<td>130809 A 140516 A2 170126 E</td>
</tr>
<tr>
<td>Electrical &amp; IT Lead Engineer</td>
<td>130820 A 140410 A2 170120 E</td>
</tr>
<tr>
<td>Permit Manager</td>
<td>130822 A 170120 E</td>
</tr>
<tr>
<td>Contract Manager*</td>
<td>140224 A 170126 E</td>
</tr>
<tr>
<td>Health Safety Environment Manager</td>
<td>140430 A 170120 E</td>
</tr>
<tr>
<td>Maintenance &amp; Operability Manager</td>
<td>140408 A 170119 E</td>
</tr>
<tr>
<td>Contract Manager 2*</td>
<td>151201 A2 170127 E</td>
</tr>
<tr>
<td>Health Safety Environment Engineer</td>
<td>170316</td>
</tr>
<tr>
<td></td>
<td>Product Manager</td>
</tr>
<tr>
<td></td>
<td>Specialist Main</td>
</tr>
</tbody>
</table>

Notes: The 1st and 2nd project and contract managers interviewed were four different individuals. PM = project manager.
3.2.3 Literature studies

Prior research and a theoretical background were established in all studies (A through E). The theoretical background formed the base from which each study would be performed. Based on the initial research questions of each study, both random-search and chain-search methodologies were used to establish a preliminary research landscape. As subcategories and prominent researchers emerged, the search adopted what Rienecker, Jørgensen, Hedelund, and Nordli (2002) called a chain-search methodology (Figure 11).

A systematic search should, according to Rienecker et al. (2002), approach the search data in a planned, ordered, and documented manner. This form of search was used toward the end of each study to assure that no relevant research had been omitted. On occasion, the systematic approach did yield new results and insights that could be incorporated either in the theoretical background or the discussion points in subsequent publications. The systematic search method used was adapted from Hunt, Nguyen, and Rodgers (2007). Their method stems from patent search strategies, but the approach is transferable to scientific research as well. While the term “classification” is not applicable to this research, this stage can be seen as equivalent to the research field (Figure 11).

Google Scholar was used for the initial effort in most of the searches; it was also used to determine a particular search string’s impact on the returned results to establish relevant keywords. During this process, keywords were generated from subject-matter words, e.g. by creating synonyms and acronyms. Boolean search criteria were necessary for all academic research and were therefore used both spontaneously and in an ordered fashion later in the literature-search process. As results from Google Scholar searches often featured recurrent publication databases, these were then searched individually with the same or a similar search string. Science Direct, IEEE Xplore, EmeraldInsight, SpringerLink, Taylor & Francis Online, The Design Societies repository of conference publications, and Wiley Online Library were among the more commonly searched databases, with Science Direct being used most frequently. Regarding citation databases, Scopus was used both in analysing search results and for generating search strings. Chalmers University of Technology’s library database (CHANS) and Mälardalen University’s library database (OPAC) were used to find physical publications and books, together with the national library database (LIBRIS).

*Figure 11: Description of the search methodology used in this research.*
3.2.4 Case-company presentation and case selection

All cases treated in this dissertation, except for study B, originated from the case company, presented in this section. Study B used another setting for its investigation that is presented in the detailed method section for study B. Studies A, C, D, and E were conducted at the case company’s business unit for power transmission and grid integration. The case company is one of the world’s largest engineering companies, present in roughly 100 countries, and operates in the industry of power grids, among other sectors. The case company’s power-grid division delivers large engineering solutions to their customers. A recent broadening of their offering into the offshore-wind energy sector increased their need for operational excellence in the area of project management, particularly for offshore engineering projects. The venture into a new business opportunity coincided in a timely manner the initiation of this research and proved to be a dynamic environment in which to develop the ideas that are at the foundation of this work.

Projects studied in this research were selected to enable a cross-case analysis of engineering-change-management practices. Specifically, the focus was on contrasting initiated and emergent change as well as the extreme cases of production/product development and engineering projects. Altogether, three engineering projects, one production-development project (change scenario), and one product-development project were selected. The selected cases of engineering projects also enabled improving reliability through the projects’ similarities.
### 3.3 Conducted studies

Five different studies form the basis of the research presented in this dissertation (A–E). The studies are described according to their research characteristics in Table 6. In Figure 13, the types and stages of engineering changes are depicted. The figure can also be used to differentiate the focus of each study. All studies utilised the previously presented methodologies to different extents, these have been mapped in Figure 14.

**Table 6: Relationship between research questions and methodology, a model adapted from Arbnor and Bjerke (2008)**

<table>
<thead>
<tr>
<th>Study method(s)</th>
<th>Study A (1&amp;2)</th>
<th>Study B</th>
<th>Study C</th>
<th>Study D</th>
<th>Study E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit of analysis</td>
<td>Case study</td>
<td>Empirical study</td>
<td>Case study, participatory research</td>
<td>Case study</td>
<td>Case study</td>
</tr>
<tr>
<td>Investigated RQ</td>
<td>Internal process: the engineering-change-management process in two projects and its effect on the fabrication.</td>
<td>The process of changing the production method of the component in the automotive industry.</td>
<td>Planning and documentation of one emergent change in a construction project.</td>
<td>Steps 2 and 5 (Figure 13) of the emergent change process for development projects.</td>
<td>Ad hoc teams opportunity detection in engineering changes.</td>
</tr>
<tr>
<td>Empirical evidence</td>
<td>Archival data, literature study, and interviews.</td>
<td>Archival data and observations of practice.</td>
<td>Based on detailed empirical data from study A.</td>
<td>Archival data, interviews, and continuation of study A.</td>
<td>Archival data, interviews, and workshop.</td>
</tr>
<tr>
<td>Expected outcome</td>
<td>Influence of engineering-change management on the fabrication of platforms.</td>
<td>How the engineering-change process should be conducted: a generic model for engineering projects.</td>
<td>How planning and documentation of emergent changes are handled.</td>
<td>How steps 2 and 5 (Figure 13) are handled by engineers in development projects.</td>
<td>Practices and praxis used by ad hoc teams to detect opportunities.</td>
</tr>
<tr>
<td>Time of study</td>
<td>2013.02 to 2014.03</td>
<td>2014.05 to 2015.09</td>
<td>2014.05 to 2015.05</td>
<td>2016.01 to 2017.02</td>
<td>2016.01 to 2017.06</td>
</tr>
</tbody>
</table>
Figure 13 can be used to differentiate the focus of each study.

- Study A was a broader investigation of engineering changes in two engineering projects.
- Study B focused on following a specific initiated change and how it was executed in the context of a production-development effort.
- Study C reported on an emergent change and how it was planned for and documented in a third engineering project similar to those in study A.
- Study D, based on a case study of a development project, specifically studied how step 2 (“possible solutions identification”) was handled in practice and how the fifth step (“implementation of the solution”) was integrated into both the risk assessments in step 3 and the review of solutions in step 2.
- Study E explored how ad hoc teams identify and exploit opportunities in engineering changes of an engineering project (one of the two in study A).

Figure 13: Overview of engineering-change types and stages of the generic engineering-change process (Jarratt et al., 2005).
Qualitative analysis methods, as suggested by Miles et al. (2013), and case study research, following Yin (2011), were used to guide the work in all studies. In study A, the initial study, the two methods were sufficient for establishing a problem statement. However, as investigations proceeded, and the researcher’s analysis needs grew, other approaches were included. Value-stream mapping (VSM) (Rother & Shook, 2003) and discrete event simulations (DES) (Detty & Yingling, 2000) were used to compare the two change alternatives in study B. In study D, both SSM and project-as-practice were used to analyse the results. In the last study, study E, projects-as-practice was the primary tool of analysis.

3.3.1 Study A: Environment and structures of engineering changes

Study A was divided into two parts: A1; and A2. Its purpose was to investigate issues in two different engineering projects that had led to problematic project execution (a background to these project endeavours is provided in the introductory problem statement, section 1.2). The first part was exploratory and descriptive in its approach, while the second part involved prescriptive measures. Study A1 looked both at the product design of two offshore platforms and the project execution of these two projects. Study A2 was the continuation was study A1 and aimed to investigate the engineering-change-management process in the same two engineering projects. Specifically, study A2 aimed to investigate the hierarchyc structures and phases of a project that was relevant to the treatment of engineering changes. Furthermore, its purpose was to map the different ways in which changes could be issued in the project, which was later conceptualised as engineering-change carriers. In engineering projects, there are various ways of initiating and tracking changes to the expected delivery of the project; the concept of change carriers was the framework that was developed to contextualise this issue.

Qualitative data from initial interviews were used in thematic conceptualisation, i.e. in-vivo coding, theme-building, and conceptualisation of the data (Miles et al., 2013). Interviews were held in two rounds (i.e. one for study A1 and another for study A2) (see Table 5). The studied department at the case company had the function of project management of the two projects, reviewing documentation, and performing quality control of the delivery from the offshore platform designer and fabricator (sub-suppliers) (see the shaded areas in Figure 15).
3.3.2 Study B: Initiated engineering-change strategy

The case study examined two initiated change alternatives to a production system as they relate to the lean principles of kaizen (continuous improvement) in scenario A; and kaikaku (radical change) in scenario B. The case study was performed at a company that produces components for the automotive industry. The study followed the introduction of a new lightweight component into the existing production line. The change alternatives are analysed in terms of the generic engineering-change processes proposed by (Jarratt, Eckert, Caldwell, & Clarkson, 2011).

Study B was the only of the studies performed outside of what is otherwise referred to as “the case company”. In study B, engineering change was related to a production system as the technical “product” under consideration had to be altered. The principles of engineering-change management were used, in a structured way, to evaluate alternatives, implement a solution, and review results. VSM (Rother & Shook, 2003), environmental value stream mapping (E-VSM) (Kurdve et al., 2011), and DES (Detty & Yingling, 2000) was used to compare the two alternatives.

The process of analysing the two scenarios followed the engineering-change-management process suggested by (Jarratt et al., 2011) with actions explicitly taken for the initiated change (0-7):

0. The current state is analysed by VSM and line walk.
1. Engineering-change request raised: challenges of weight and productivity improvement.
2. Possible solutions identification: solutions for scenario A (CI, using SMED and autonomous maintenance) and scenario B (redesign of component and process) were identified and the results calculated.
3. Risk assessment: analysis of the solutions by VSM and potential gains and risks were assessed.
4. Selection of solution: made from match-making of steps 1 and 3.
5. Implementation of the solution: a simulation of the current line and each of the scenarios was built to simulate and review solutions.
6. Reviews of the solution: the results of the simulations were evaluated.

3.3.3 Study C: Emergent engineering-change implementation

Study C aimed to show how project managers and engineers work to implement an emergent change in an engineering project. The study focused on the implementation and physical completion of the change. The studied project was a third offshore platform project outside of the two studied in study A. Both the planning and documentation aspects of the emergent change were investigated.

The case of study C involved four primary stakeholders: the company (the stakeholder from whose perspective this case was studied); the customer (the client of the project and the initiator of the emergent change in this case); the sub-suppliers (different specialised firms that were subcontracted by the company to execute tasks to realise the emergent change); and the competitor (a company in the same industry as the company and remotely involved in the studied change).

The selected case was a variation order (emergent change) issued by the customer of the company to accommodate a bridge between the offshore platform being built by the company and a sister offshore platform being built by the competitor. However, the bridge design was not set before constructing the bridge landings. This led to a redesign to accommodate the bridge on both platforms.

The case-study design is built on a single-case-study methodology with an established unit of analysis (Yin, 2011). The unit of analysis was the documentation of construction planning for an emergent change. Data collection and analysis was performed concurrently as the intertwining of the two is inevitable while analysing qualitative data (Sieber, 1976). The research-problem statement was taken primarily from study A. Data were collected from the company plant’s design-management system and by access to project-specific e-mail database. The author also worked on the project and observed the process as part project manager, responsible for the ad hoc team and the case company’s delivery of a complete bridge landing.

3.3.4 Study D: Ad hoc teams in development projects

The tactics of ad hoc teams working on a large development project (200+ engineers engaged at its peak) was the focus of study D. Two research questions were posed: how engineers assessed the implementation in the solution-assessment stage and how the ideation and solution assessments were carried out; and how the implementation, considered already in step 2 [represented by the added feedback loop and a question mark in Figure 16, to the process initially proposed by Jarratt et al. (2005)]. As found in study A, even if all these steps were carried out by the practitioners, in between steps 2 and 5, there seemed to be no feedback or anticipation of the implementation outcome in the studied projects. Making matters worse in step 2 (“identifying possible solution(s)”, the generation of alternative solutions was often neglected. The *modus operandi* it seems is: that the first feasible solution conceived of is later implemented. Having a one-solution idea without evaluation against others is not a decision point, and thus the involvement and critical review of colleagues and management are bypassed.
At the time of the study, the studied business unit consisted of four technical areas. For the purpose of this research, the technical areas are denoted as:

- **M**: the (M)ain product of focus, employing the most engineers in the business unit.
- **C**: handling the (C)ontrol of M (commercially, C is sold as a product in and of itself).
- **S**: the (S)ystem integrator (S also conducts system analysis as consultants to other companies).
- **P**: responsible for the (P)lant architecture of the physical installation, and the point of contact for construction contractors.

The company, as well as the product development department and, subsequently, the studied project, had a functional split that corresponds to the four technical areas. The product development department and delivery projects in the business unit had historically shared resources, but the product development department got its own set of permanent staff in 2015, to increase the reliability of personnel availability.

The studied product development project was initiated in 2012 to develop an improved product generation to maintain a competitive edge over their competitors regarding technological advancements, and aggressive; long-term targets were set. Furthermore, the product development project was initiated to assure future quality and incorporate the lessons learned from the previous product version.

Study D used SSM as a means to answer the research question and map the system that enables the practitioners to act. Also, the projects-as-practice approach was used in the theoretical background and as a discussion point, rather than an analysis tool. Interviews were held with members of the steering committee, the project manager, part project managers, and lead engineers of the case project (Table 5). All analysed documents, including the change request log, change request descriptions, risk assessment log, and change request template, were retrieved from the company’s document-
management system. All formal processes, including the change request formal process and stage-gate process, were retrieved from the case company’s management system. Data generated between 2011 and the beginning of 2017 were collected. The project’s change-request database was used to quantify aspects of the changes such as the amount of emergent compared to initiated changes, their resolution time, and opportunities seized in changes.

3.3.5 Study E: Opportunities in changes of engineering projects

Study E focused on the opportunity identification and exploitation of emergent and initiated changes in an engineering project, one of the offshore projects studied in study A. Similar to study D, interviews with project managers and engineers working in the case project were combined with content analysis of the projects change-request database. The interviews were used to explore how the project practitioners identified opportunities and then exploited them. Data from the project’s change-request database was used to quantify aspects of opportunity management in the subject changes.

The project-as-practice research approach was used as an analysis tool more extensively than in study D. For study E, a round of interviews was performed to explore the case-research question; also, interviews from study A were revisited and re-analysed in light of the current research question. Study E was analysed in its entirety first and, while results were satisfying, the added examples that could be yielded from more interviews motivated the inclusion of study A. This was possible due to the general nature of the questions posed during the research clarification in study A and that all of the interviewees had worked on the project in question. No discrimination between studies A and E was used after the conceptualisation phase of the analysis. The quantitative data retrieved from the project database’s change-request log accompanied the interviews as they both dated back to the beginning of the project.

The analysed change requests for the project were examined for opportunities both identified and exploited. Over 200 change requests (of which 87 were engineering-related) were collected from the project-management database, registered from 2010 to 2015. Change requests stemmed from deviations from the contract. In this definition, some situations that could trigger and be affected by a change request, were, for example, technical, organisational, regulatory, or purely contractual. Study E’s analysis was limited to change requests that had a technical consequence, even though the trigger might have been something different.

The analysed change requests for the project were searched for opportunities both identified and exploited according to the definition in the frame of reference, i.e. the opportunity had to be explicitly stated in the change requests or implicitly detectable to be reported. If change requests contained ambiguous or incomplete information, accompanying documentation and contacts were used to supplement the data collection.
3.4 Data analysis

Like any process that involves qualitative information, what is essential in data analysis is that there is a method, following a methodology, and that it is documented. The methodology channels the processing of ideas much like any Post-it-fuelled brainstorming session. Ideas are there, but they need vessels and a structure through which to be conveyed. Dye, Schatz, Rosenberg, and Coleman (2000) kaleidoscope analysis metaphor elegantly describes the phases in building concepts from what initially is fragmented data (see Figure 17). Their metaphor was relevant in all performed studies and the methodology described below was used in studies A, D and E. From the fragmented data, categories were found. These categories were then used to form themes that could be combined to form a complete constellation of a concept.

The list below explains the categories in Figure 17 for this research by dividing the data analysis into the categories proposed by Dye et al. (2000):

- **Fragmented data**: observations (notebook notations), interviews and their transcripts, as well as archival documents (processes, guidelines, and memos), are compiled in a case study database.

- **Category formation**: building themes and cross-referencing between fragmented data. Interviews and other data were analysed based on the methods described by Miles et al. (2013) to identify units of meaning relevant to the given research from the material. In this phase of the analysis, data were quantified to search for commonalities between respondents. For this task, separate spreadsheets were used so that both the qualitative and quantitative aspects of the data could be captured for similar phenomena. The encountered problems, phenomena, and experiences were categorised and assigned keywords.

- **Refinement**: discarding “loose ends” and aggregating keywords into themes and ideas. In this phase, the fragmented data were revisited to enrich the ideas if observations had been lost early in the process. The thematic-analysis method has been likened by Fereday and Muir-Cochrane (2008) to the translation of a language, as what has been said in interviews is interpreted to add meaning in a new context.

- **Final constellation**: in this phase, the main conclusions and results were presented and packaged in a communicable way. In this research, this phase corresponded to the results presented in section 5. However, study-by-study results are also provided in sections 4.2 - 4.4.2.
The steps proposed by Dye et al. (2000) are an incremental approach to achieving the conceptualisation of data. However, Schreier (2012) explains its iterative nature in more detail in her eight-step approach:

1. research question to analyse;
2. material/data selection;
3. develop a coding frame (deductive and inductive approach);
4. divide material into units of coding;
5. test coding frame;
6. evaluate the coding frame;
7. main analysis; and
8. present findings.

In steps three and four, the research is advised to let the data drive the coding. This happens as deductive codes are complemented by, or replaced by, inductive codes (in-vivo). Step three tends to generate a plethora of codes, step four divides and refines codes based on their compliance with the research questions. Following this, step five then tests the refined frame on the same data again to further increase the resolution, similar to the kaleidoscope strategy of Dye et al. (2000). In this, one way to test one’s conclusions is through what Miles (1979) called “validity through practitioner reviews”. In this research, this was primarily performed through the presentation of preliminary research results to practitioners and, if possible, including their objections, additions, and reflections on the results.

Figure 17: A kaleidoscope of data, adapted from Dye et al. (2000).
3.5 Quality of the research

It has been argued for the last 30 years that validity and reliability need to be complemented with additional aspects to advance the theories of quality in research, particularly when dealing with qualitative data analysis (Morse, Barrett, Mayan, Olson, & Spiers, 2008). Instead, Morse et al. (2008) chose to focus on the overall significance, relevance, impact, and utility of the performed research. This is also a collective view of qualitative data analysis shared in the action research community (Coghlan & Brannick, 2014). Given that this research merely aspires to action research, in performing research in an industrial setting, the research ought to consider the tenets of action research as conducting research on both academic, and industry terms (as in this research) entails many of the quality requirements of action research.

The tenets that supplement the conventional concepts of reliability and validity have been described by Creswell (2012) as shared responsibility/critical dialogue, collective reflection, mutually beneficial, and alliance building.

As Lindhult (2001) pointed out, there are quality aspects of action research that can be achieved by benefiting multiple interest groups in the same research. Lindhult (2001) divided the concept of quality in action research into two categories: value/relevance; and credibility. As part of an industry–university collaborative project, this research fulfils this criterion at a higher level of abstraction while, at a more applied level, both employees and the company stand to benefit through reduced frustration and increased process efficiency while the dissemination of this research stands to benefit the broader academic community.

Nevertheless, validity and reliability are conceptual cornerstones of research quality, according to Yin (2011), who categorised validity into construct validity, internal validity, external validity, and reliability. The test proposed by Yin (2011) in Table 7 proved useful in determining the level of validity and reliability in all studies and appended papers.

<table>
<thead>
<tr>
<th>Tests</th>
<th>Case-study tactic</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Construct validity</strong></td>
<td>Use of multiple sources of evidence</td>
<td>Collection</td>
</tr>
<tr>
<td></td>
<td>Establish a chain of evidence</td>
<td>Collection</td>
</tr>
<tr>
<td></td>
<td>Key informants review case study report</td>
<td>Composition</td>
</tr>
<tr>
<td><strong>Internal validity</strong></td>
<td>Pattern matching</td>
<td>Analysis</td>
</tr>
<tr>
<td></td>
<td>Explanation building</td>
<td>Analysis</td>
</tr>
<tr>
<td></td>
<td>Address rival explanations</td>
<td>Analysis</td>
</tr>
<tr>
<td></td>
<td>Logic models</td>
<td>Analysis</td>
</tr>
<tr>
<td><strong>External validity</strong></td>
<td>Theory in single-case studies</td>
<td>Design</td>
</tr>
<tr>
<td></td>
<td>Replication logic in multi-case studies</td>
<td>Design</td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td>Use a case study protocol</td>
<td>Collection</td>
</tr>
<tr>
<td></td>
<td>Case study database</td>
<td>Collection</td>
</tr>
</tbody>
</table>

Table 7: Test of validity and reliability, adapted from Yin (2011).
Construct validity was warranted through multiple-source data collection, both regarding multiple interviewees being interviewed on the same subject and through the several studied projects. Respondents, after their interviews, participated in discussions of the results, as well as the analysis of the results. From an academic point of view, there were no restrictions in accessing published material. The databases most frequently used have been licensed by the university library and, in the case of restricted access, this has been solved satisfactorily.

By conducting research interviews in Swedish and then publishing the results in English, there is a risk of distorting the original findings. Therefore, statement translations have been verified with the providing source when in doubt. Published statements and identified factors were freely translated into English from the interviews held in Swedish. The guidelines on how to translate native languages into English from Day and Gastel (2012) were adopted in this work. Furthermore, nomenclature and described phenomena have, in some instances, been translated by the researcher from a general or company-specific meaning to research-community-specific nomenclature or phenomena.

Pattern matching, primarily between interview data and archival data, was used to ensure internal validity. Alternate explanations were discussed on multiple occasions throughout the process, but not as part of systematic practice. However, the researcher maintained the practice of noting competing explanations for continued reflection throughout the research project. As part of the internal validity of research, the importance of replication logic to researchers using the case-study method cannot be understated. As Flyvbjerg (2006) noted, the replication of results is a false promise of case-study research. Instead, the tests of validity are used to ensure a transparent scientific approach to developing knowledge so that, if another researcher would like to replicate the method used, standing on the same “giant’s shoulders”, it would be possible. However, to expect the same outcome would be foolish; a case study researcher’s strength lies in his/her ability to be aware of biases of validity and disclose them, rather than hiding behind statistics (Flyvbjerg, 2006).

External validity is difficult to prove for any case study, beyond the constructs of this dissertation. In discussions with interviewees, having worked otherwise primarily in the oil and gas industry and civil works, it can be said, with some degree of certainty, that this research is valid also for this industry. Reliability has primarily been achieved by using study protocols for each study, interview protocols for the semi-structured interviews, and structuring collected data in case-study databases.

Finally, reliability was built into the triangulation of different projects and different cases, both within and between projects. Furthermore, the saturation principle states that, when the data material starts to yield the same results, information saturation has been reached and the need for new samples begins to diminish with each similar finding. Naturally, the very idea of a saturation principle in the broader sense of knowledge acquisition is flawed as disruptive data might be “right around the corner”, as elaborately explained by Taleb (2007) in *The Black Swan*. However, for this research, one assumes that the saturation principle is valid.

### 3.5.1 Role of the researcher

The company, employing the researcher/author, has its liabilities in the research project in the form of trade secrets (inventions, processes, methods, and ways of working).
For the researcher not to infringe or otherwise besmirch the company, Lundin (2011) suggested that company representatives read the material to be published and provide written consent before publication. As of this time, case company representatives have read and, in some instances, co-written publications in the current research. Furthermore, written consent has been given in cases when warranted.

The question of data storage was raised by Hermerén (2011). In this respect, the research project in question was treated as any other R&D project regarding documentation, budgeting, and storage: data will be accessible until the deadline stipulated. The results of the research project are meant to be used in guiding practitioners in their work in handling engineering changes in projects, and the process developed as part of the research results are intended to be continuous, i.e. they will be added to and refined in the future.

The researcher as an industrial PhD student is in a position of dependence on the company, which dictates the researcher’s salary, working environment, and future career within the company. If the employing company can be regarded as the client of the research project, then the informants/interviewees are the suppliers of empirical data. In the role of an industrial PhD student, informants are often colleagues with whom the researcher sometimes has a personal relationship. From a positivistic point of view, this is an unfavourable situation that could cloud the researcher’s judgement but, according to Coghlan and Brannick (2014), it is a prerequisite to capturing the depth and multiplicity of factors of cases that quantitative data and survey studies lack. As the researcher has had varying roles in the company during the conducted studies, a short description of these roles is provided in Table 8.

Table 8: Roles of the researcher at the time of the conducted studies.

<table>
<thead>
<tr>
<th>Study</th>
<th>Role of the researcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>The researcher had the role of a traditional case-study researcher, i.e. a passive observer and collector of qualitative data. As an industrial research student, the researcher was employed by the case company (and also for the subsequent studies).</td>
</tr>
<tr>
<td>B</td>
<td>The researcher aided in the introduction of the theoretical model for analysis and aided in the analysis. In this case, the researcher was a passive observer of pre-collected empirical data as the data were collected from another organisation outside the case company (see section 3.2.4).</td>
</tr>
<tr>
<td>C</td>
<td>The researcher worked as a part project manager (of the studied change request) and was responsible for coordination with the client and sub-suppliers as well as performing structural calculations. The study was a retroactive account of the events as they unfolded. In this case, the researcher affected the project as an active part; that role was not, however, as a researcher.</td>
</tr>
<tr>
<td>D</td>
<td>The researcher had the role of a traditional case-study researcher, i.e. a passive observer and collector of qualitative data. The site of data collection was within the case company but geographically distant from the researcher, requiring travel for interviews and other forms of data retrieval.</td>
</tr>
<tr>
<td>E</td>
<td>The researcher had the role of a traditional case-study researcher, i.e. a passive observer and collector of qualitative data. In this study, the researcher was an insider as all research time was spent at the location of the studied department.</td>
</tr>
</tbody>
</table>
3.5.2 Co-production in the research project

The research environment in which the current research is a part, the research school Innofacture, is a collaboration between Mälardalen University and several multinational companies in Sweden, with additional funding from the Swedish Knowledge Foundation.

Mälardalen University (MDH) is known for its close industry collaborations, and the case company is a natural and acknowledged industry. MDH’s specialisation in innovation and product realisation was identified early as a suitable research environment for this project, given their expertise in project management as part of the project-realisation focus area. The consensus, in this case, is that co-production of research is something constructive and worthwhile. Co-creative and co-productive research are, together with innovation, the research pillars promoted by the Knowledge Foundation.

The results and first- and second-order effects of co-production initiatives have been studied by the Swedish research funding organisation Vinnova to measure the time to anticipated effects of previously conducted co-production projects (Åström et al., 2015). Results and effects in *italics* are the areas in which this research has contributed:

- **Results (0−5 years):** *scientific publications*, patents, *education of PhD students*, and thesis work.
- **First-order effects (2−10 years):** *development of processes*, software, *training of personnel*, raising the competence of specialists, access to laboratory equipment, *strengthened company and employee networks*, and *multidisciplinary research environments*.
- **Second-order effects (5−20 years):** new ways of working, strengthened competitiveness of companies and universities involved, technological spread outside the immediate co-producing environment, strengthening Sweden’s research infrastructure, and new companies.

The enablers of co-production in this research project include: that the benefits of this research are evident to those who participate; and that there is a transparent organisation open to probing. The most substantial obstacle to co-production in this research project was matching the research- and company-operation pace. Often, research is a slow and thorough process, while those involved in project execution operate at a faster pace. This obstacle was bypassed by analysing historical cases using archival data for more detailed and quantifiable data. However, as has been argued previously, the research could be of even more significant benefit if the issues of pace could be addressed and an action-research project initiated. In an industrial research school where industry and academia come together to pool competences to solve relevant problems, co-production is a central concept (Figure 18). Co-production, as mentioned in the Swedish Higher Education Act (1992:1434 §2), is freely translated as:

“It is part of the universities’ responsibilities to cooperate and work together with society at large.”
The research environment of an industrial research school enables much of the co-production potential that the KK-foundation, as well as the Education Act, emphasises. Enablers specific to the author’s situation of co-production include that the benefits of the conducted research are evident to those who participated. Moreover, the case company has a transparent organisation that was open to probing. Probing is of course enabled by the fact that the researcher has “infiltrated” the organisation as an insider. Coghlan and Brannick (2014) mentioned the difficulty a pure academic researcher could have accessing data and the somewhat skewed and sanitised picture painted by employees and managers as they do not want to lose face.

3.5.3 Innovation and design in the research project

The focus on design in this dissertation in relatively evident as engineering change is central to the design process and, in the broader sense, more so for the entire product lifecycle. The dissertation is written to meet the aims and requirements of Mälardalen University’s goals of Innovation and Design (Mälardalen University, 2018) to broaden the understanding of central concepts and theories in innovation and design as well as developing innovation processes for service and product development that are relevant to international projects, spanning the humanities, the social sciences, engineering, and the health and welfare sector.

Moreover, the case company regards innovation as essential, acting as a driver of sustainable design and profitable growth. An obstacle to research innovation is the sheer size of the case company; larger companies move slower and have more bureaucracy that hinders innovation (Ahmad et al., 2011). The expected result of guidelines and teaching material should incorporate and make use of process-innovation techniques to support innovation rather than hinder it (Ahmad et al., 2011). According to (Frankelius, 2009, p. 49):

“...Innovation really means something 1) new with high-level of originality, 2) in whatever area, 3) that also breaks in to (or obtains a foothold in) society, often via the market, and 4) means something revolutionary for people. An innovative process has not been fulfilled until customers or others for whom it may be of benefit have acknowledged and accepted a new thing.”
To that end, the learning engineering-change process suggested in this research can both be used to lessen the strain that inventive engineers feel when trying to work creatively as well as sparking novel ideas within the process of change handling. Thus, there are two tiers of innovation embedded in the suggested process.
4 Research findings

Five case studies were carried out as part of this research project. This chapter summarizes the results of the case studies performed. Their study designs and details are presented in chapter 3 and the appended papers (I–VI). This chapter emphasizes the studies’ contribution to the studied concepts and the outcome of this dissertation.

4.1 Studies and outcomes

As concepts and phenomena were developed and refined iteratively throughout the entire research project, studies A–E have treated these concepts to different degrees. Starting from the concepts, rather than the studies, the sections of this chapter treat the individual research findings associated with each concept. Table 9 indicates to which degree concepts were treated in each study.

Table 9: Studies contribution to concepts.

<table>
<thead>
<tr>
<th>Concepts</th>
<th>Study A (paper I &amp; II)</th>
<th>Study B (paper III)</th>
<th>Study C (paper IV)</th>
<th>Study D (paper V)</th>
<th>Study E (paper VI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change carriers</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Hierarchies</td>
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<td></td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Project phases</td>
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<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Initiated changes</td>
<td>●</td>
<td>○</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Emergent changes</td>
<td>○</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Formal vs informal</td>
<td></td>
<td>○</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Ad hoc teams</td>
<td>○</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Product development</td>
<td></td>
<td>○</td>
<td></td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Engineering projects</td>
<td>○</td>
<td>○</td>
<td></td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>Opportunities</td>
<td></td>
<td></td>
<td>○</td>
<td>●</td>
<td></td>
</tr>
</tbody>
</table>

Note: “○” and “●” indicate low and high correlations, respectively.
4.2 Change carriers, hierarchies, and project phases

Study A comprised two parts: a research clarification phase (A1) that set the stage for all subsequent studies; and a later descriptive and prescriptive phase (A2). It was concluded in study A1 that sub-supplier scope control is needed to deliver projects on time and within budget. One suggested way of controlling project scope is by using methods of engineering-change management. Furthermore, it was found that the design has an impact on the project outcome, but that project execution is of equal importance. The results pointed in two different directions: project-organisational issues on the one hand; and product-design issues on the other (to read more about the product-design issues encountered in study A1, the reader is referred to (Sjögren et al., 2014b).

In study A1, the importance of a well-documented “front-end engineering design” study together with an established scope split was suggested by interviewees to avoid complications due to responsibility issues in the project downstream. As one interviewee reasoned, in redesigning, the time needed to agree on the scope between stakeholders was often more time-consuming than the redesign itself:

“One main concern during the FEED [front-end engineering design] phase is to have the competence and capacity that is expected in project organisation as a whole. Otherwise, there will be imbalances of influence over the FEED and customer requirements probably will not be fulfilled in the end.” (Systems Engineer 131024 A; see Table 5).

Interviews with on-site engineers and observations during site visits revealed an air of frustration. On-site engineers had the tools at their disposal to manage problems but, due to slow decision-making processes, their hands were often tied. Software compatibility and project management’s understanding of the on-site problems were suggested reasons for delayed change implementation.

Furthermore, study A1 illustrated the decoupling of the digital engineering-change process and the physical engineering-change process, i.e. the review process as opposed to the quality-control process. This was found as part of the project documentation and described by interviewees. As the digital space has infinite possibilities to revise drawings using fast 3D-modelling software, a manual weld today is as time-consuming as it was ten years ago. This difference in capabilities on-site and in-office (i.e. dual structure) is exemplified in this case. Engineering changes should be part of the fabrication process, used to manage emergent changes. The frequency of change possibilities during the product development phase must be controlled to reduce postponed decision-making. In this respect, the dual structure of ad hoc teams is of importance as their communication dictates the quality of these dependent processes. As depicted in Figure 19, the engineering review (digital phase) and the quality control (physical phase) are, to some extent, handled concurrently. The effect of uncontrolled changes during the project-development phase is that deadlines are postponed (in the digital space) while the contractual final (and physical) deadline is fixed, which strains the project organisation and leads to a staccato project process.
Results from study A1 (interviews and project documentation) led to the conceptualisation of change carriers, prescribed in study A2. Change carriers can be categorised depending on where and at what level they are active in the project. A change carrier, as defined in study A2, is the vehicle of a particular change within the project, also recognising that both formal and informal carriers exist. Formal carriers, e.g. design-revision requests and change requests or punch items (non-conformities in the fabricated and installed component or system), are those determined and recognised by the project organisations. Formal carriers are predetermined and used in the project to evoke, control, and follow changes. Informal carriers, however, are those that may evoke, control, and be used to follow changes but are not contractually valid if a dispute in the project arises. Furthermore, informal carriers are difficult to track and follow up.

In one of the studied offshore platform projects, 18 formal change carriers were identified, primarily due to a large number of stakeholders and their respective PLM systems. In such a large project, performing a change-carrier categorisation supports the identification and definition of at which hierarchical level the carrier is used and in which phase. Such categorisation of the formal and informal change carriers is needed to understand where change originates, and in which phases they are active.

Apart from hierarchy and phase, change carriers possess other properties that are of interest, e.g. to which part of the project organisation they belong and by which parts of the organisation they are used. The databases that are going be used to store the carrier information and the programs or media used to communicate carriers should be established early in a project and continuously monitored. In introducing new carriers during a project, they ought to be categorised before introduction, as part of any sound engineering-change-management process. The change categorisation aims to go from the less ordered situation of Figure 20 to the more ordered situation in Figure 21, in which carriers are defined and distinct.

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**Figure 19:** Offshore project phases, established in the case study, compared to traditional manufacturing in an engineering-change-management context [adapted from Hamraz et al. (2013) and presented in Sjögren, Bellgran, Fagerström, and Sandeberg (2014a)].
Study A2 recognised that change carriers seemed to decrease in quality the further the project proceeded (e.g. in one of the studied projects notification of changes on-site was scribbled on post-it notes and then manager types these into an excel-spread sheet without follow-up). Information entropy increased over time as the methods employed became more and more primitive: documentation, tools, and feedback became cruder as the project progressed. From a managerial point of view, this does not make sense as later changes are more expensive than early ones; if anything, engineering-change management should become more advanced and precise the more the project proceeds. In general, there was a focus on upstream activate rather than downstream in the projects. If the engineering-change strategy is a proactive one, this makes sense, but from a reactive-strategy point of view, the focus has to be on improving the quality of the engineering-change process quality in the later project phases.

Figure 20: Illustration showing undefined and unstructured change carriers in a process-hierarchy grid.

Figure 21: Illustration showing defined and structured change carriers in a process-hierarchy grid.
The six categories of change-carrier properties following the two studied projects of study A2 were the principal finding and an initial attempt at structuring the engineering-change-management process (Figure 22):

1. **Hierarchy**: At what management level is the carrier functional? Can it be handled engineer-to-engineer or does it have to involve project management?

2. **Media**: What media is the carrier using (PLM systems, e-mail, face-to-face meetings)? Different company cultures might have various ways of conveying information, e.g. drawing formats, nomenclature, and standards, which in turn creates issues in terms of interpretation. If the media is not appropriately handled, e.g. taking minutes of meetings, then there is no way of conveying lessons learned in a convincing manner for future projects.

3. **Storage**: Where is the carrier stored and recorded? Storage is a crucial part of handling lessons learned.

4. **Organisation**: Who in the project owns the carrier? Who has the right to issue the change carrier? The question is often associated with the “storage” category.

5. **Influence**: In what phase can the carrier have the right of implementation? This is important to empower engineers to judge the validity of an ordered change.

6. **Time**: During what project phases is the carrier active? A vital question to pose to avoid working on carriers that are no longer valid. Long lead times inevitably lead to diffusion of information, thus defining the intervals in which carriers are to be active is needed.

![Figure 22: Categorisation of change-carrier properties.](image-url)
In Figure 23, the hierarchy of the change carriers is divided into three levels: project negotiations; change requests; and design revision. Design-revision changes can aggregate in the form of change requests, which can be split, functionally, into several design revisions after their issuance. This behaviour is also noted in the project negotiations about a change request. Conversely, design revisions, change requests, and project negotiations can all be treated in isolation.

Regarding the product domain and project-organisation domain, the change carriers follow the hierarchy in the formal processes. Informally, the ad hoc team is organised around the topic of the change request (indicated by the grey cloud form in Figure 23), here lacking hierarchical structure. Furthermore, the ad hoc team communicate by informal change carriers (e.g. by phone, informal meetings and e-mail correspondence) However, this managing behaviour is valid from the point of raising the change request until the first formal decision point, at which point the line of decision is vertically oriented, as in the formal case. The informal structure of the ad hoc team in the change-resolution phases of “possible solution(s)” and “risk/impact assessments” bridges hierarchical barriers, i.e. when communication has informally enabled the silos of engineering disciplines to cooperate horizontally. These findings, which complement the findings from study A, are conclusions drawn from studies D and E.

Furthermore, Study D mapped the system of the ad hoc teams in handling engineering changes, using SSM in the analysis phase of interviews and archival records. By this, identifying the following project structures relevant: meeting structures other than change request meetings (risk assessment and project management meetings), pre-project (pre-studies), post-project (follow-up and spin-off projects), the project management organisation and other affected line organisational structures, the overarching management strategy (represented in study D by the quality and operational excellence department) (see Figure 30). Where the line organisation is the functional division of competences (i.e. product development, engineering, purchasing, management, sales etc.) that assigns resources to projects. In this, the project management office (PMO), is the line organisation responsible for the operations of the projects (i.e. project process owners and resources responsible for project managers).

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**Organisational Structures**

<table>
<thead>
<tr>
<th></th>
<th>Formal</th>
<th>Informal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product Domain</strong></td>
<td><strong>Organisation Domain</strong></td>
<td><strong>Change Carriers</strong></td>
</tr>
<tr>
<td>Portfolio</td>
<td>Steering Committee</td>
<td>Project Negotiations</td>
</tr>
<tr>
<td>System</td>
<td>Project Manager</td>
<td>Change Requests</td>
</tr>
<tr>
<td>Sub-systems</td>
<td>Part Project Managers</td>
<td>Design Revisions</td>
</tr>
<tr>
<td>Components</td>
<td>Engineering Disciplines</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 23: Hierarchical structures that are influencing the ad hoc teams’ work.**
4.3 Differences in practices between initiated and emergent changes

Study B exemplifies the way in which initiated changes can be treated in a more structured and less urgent way than emergent changes. In the study, the case contains two alternatives. The example in study B allowed two alternatives to be evaluated, whereas study A, C, D and E often found that only one-way solution was pursued. Furthermore, as the study examined the two different change strategies, i.e. continuous improvement as opposed to a radical change to the production system, it explored the differences in the need for a structured engineering-change process. The continuous-improvement strategy was believed to be less reliant on a structured change approach as this strategy capitalises on the steady state that is already present in the production system process and is thus less risky. However, while risk assessments are an essential part of the engineering-change-management process, so is overall documentation and initial assessment of alternatives, not to mention the final step of reviewing the solution implemented.

In study B, it was also shown that changes generated by customer demand led to an initiated change at the company. The project team saw the imminent change as an opportunity to evaluate two different approaches. The more conventional route would have been the continuous-improvement alternative. However, this was shown to be less competitive than the radical-change strategy. This conclusion would not have been possible without an evaluation and a review. Finally, the case strategically structured the *kaizen* (continuous improvements) and *kaikaku* (radical changes) efforts based on engineering-change principles.

Study C, contrary to study B, followed the implementation of an emergent engineering change in the form of a variation order (change order) from the customer to the case company. The change aimed at accommodating a bridge between an offshore converter platform (the case company’s) and its twin (commission by a competitor). The study mainly focused on the planning and documentation aspects of the construction of the bridge landing as work unfolded of an ad hoc team in a dual structure setup with on-site and in-house engineering personnel.

From the records of the emergent change in question, it was found that no formal construction planning was performed. Scheduling was related to the overall emergent-change realisation with a subsection for the installation procedure, but there was no mention of how to perform each action; this was left to engineers on site.

Study C showed that documentation associated with the construction planning of emergent changes was mostly related to safety planning and that no formal construction planning was conducted for the studied case. Furthermore, as safety was prioritised in the following order (safety, quality, delivery, cost), study C suggested that construction planning was based on the overall safety-planning activity for emergent changes as a way to increase priority by proxy, i.e. to be better included in the work by ad hoc teams and their dual structure in this case. In study C, therefore, it is argued that risk assessments *were* construction planning. However, that pragmatic approach fails to acknowledge crucial components in construction planning, i.e. action succession and buffer times. Additionally, risk assessments and work cards (work-description plans and reports) were often issued on-site close to the installation time itself, thereby reducing the possibility of correcting faults in the design or construction process.
Studying the implementation of an emergent engineering change in detail yields insights into the differences in the handling strategies that are needed compared to those, for example, for initiated changes. The urgency created both by new and existing deadlines in the project can be detrimental to planning and documentation efforts, as was the case for the emergent change in study C. Further organisational complexity was added as there were more stakeholders involved that did not share company culture, processes, and software, which in turn increased the need for formal structure.

The results of study C also allow further investigation of safety documentation as a means of establishing ways of working in other ad hoc teams. Furthermore, study C furthers knowledge of the concept of ad hoc teams, their dual structure, and their capabilities. The study also reports on a case from an industrial setting that covers the issues and problems that are to be expected in an industry setting, thereby bridging the academic–industry gap.

The results of study D were threefold, as they related to practitioners’ practices, providing insights into: the process of handling emergent changes in a product-development project for the sub-project-manager level “as-is”; how change request meetings are conducted; and how risk in such projects is handled compared to emergent changes and safety risk, concepts that are often confused with each other. It was found that fabrication (and implementation) was not a technical area included in the change handling. The finding was surprising given the cost associated with correcting designs in the fabrication phase of subsequent engineering projects. One interviewee attributed this to company culture and tradition:

“The technical area of Plant has traditionally been viewed as a non-core focus area, and much of this work is outsourced to construction designers. There are, however, initiatives to better incorporate them earlier in the design process” (R&D Project Manager 170214 D; see Table 5).

Out of the four technical areas involved in the project, three (control, system, and main [hardware]) perceived difficulty in understanding each other’s requirements while praising the cooperation of engineers within each technical area. In a similar vein, it was attested by interviewees that interfaces between technical areas were the most difficult to handle from a change perspective as they involved cooperation between engineers with different competencies. One of the interviewees, a systems specialist, referred to the three technical areas as:

“... the Bermuda triangle” (Specialist Control 170213 D; see Table 5).

Regarding generating alternative solutions for a given emergent change in the project, the most common approach was that one solution was evaluated in an iterative loop between engineers and, depending on size, technical areas, project management, and, finally, the project-steering committee. The implication of this is that as emergent changes are discovered by a single engineer, he/she must raise the issue (in the form of a change request) for it to gain traction and attention. The technical area “M” used weekly “sit-downs” to discuss current issues as a way of making problems visible. It was also noted that, for a solution to be as reliable as possible, it was critical that as many persons in the project as possible had seen and evaluated the suggested solution. Moreover, Figure 24 depicts a soft-system representation of the engineering-change process in the studied product-development project.
The figures was the result of employing SSM in the analysis phase of interviews and archival records and shows how ad hoc teams work both within formal processes (with change escalations and requesting further information from individual engineers) and informal processes (where the team is not hierarchically bound). Recalling the technical areas M, C, S and P from section 3.3.4. Furthermore, it was noted that the change type discussed in paper III from study C (see Figure 13), the detached emergent change, was used twice in study D as market demands had challenged the project goals. Aside from training and extending the knowledge base of the engineers, other relevant suggestions for improvement were: to make sure that all documentation was stored and organised collectively for the project so everyone could access the information they needed, which generates more cross-discipline discussions; and to assign cross-discipline experts or “ambassadors” that can bridge department divisions. These “bridging” individuals often already existed, e.g. someone who had worked in Plant before and now sat within the System-technology-area, but giving them a formal role can further help facilitate communication.

In the final study, study E, practices and praxis in exploiting opportunities in initiated changes and discovering, as well as exploiting, them in emergent changes was the focus. Following interview- and change request content analysis, in total, three practices and six praxes where associated with opportunity identification and exploitation in emergent and initiated changes.

The practices and praxes are listed below (a more substantial account of each is provided in paper VI):

- **Establish the root cause**: What is the actual cause of a change? What motivated the change request? Asking these questions was rarely encountered in the studied project, but some observed instances sparked discussions that redefine the contents of a change request to identify opportunities better.
- **Proven experience**: The proven experience that a member of the steering committee possessed was typically broad knowledge and the ability to see opportunities in the surrounding environment (customers and...
adjacent projects). Conversely, individual engineers observed opportunities associated with details and combinations with other engineering disciplines and sub-suppliers (see Figure 25).

- **Ad hoc meetings**: In one of the emergent-change-request cases, an entire design was found to be reusable from a sister project, based on discussions in ad hoc meetings. The meetings were held between the ad hoc team of the company and the customer. Moreover, meetings were one of the primary modes of communication by ad hoc team members as a practical method of promoting discussion and thereby identifying opportunities.

- **Revisiting**: When a change request was raised, a praxis involved revisiting the requirements of the original solution. This praxis could lead to identifying a better design because more knowledge was available. Alternatively, another practitioner might have reviewed the issue in a new way. A third possibility could involve the utilisation of a new technology to approach an issue differently from when original plans were developed. Finally, the physical conditions may have changed to a more favourable situation than that before the change request was raised.

- **Floating**: This praxis was observed when practitioners intentionally tried to avoid a single solution by exploring novel ideas and methods. This approach was partly implemented by establishing a “true deadline”, which is the opposite of an as-soon-as-possible mentality. Instead, practitioners asked for more time, re-evaluated, and assessed how much time was needed. In this way, practitioners knew when it was time to settle on a solution and, in the meantime, they were free to explore alternatives.

- **Win–win solutions**: Initiated changes were often driven by a win–win situation, e.g. if the customer allowed the company to make exceptions from the requirements, the company could increase the quality of the outcome or shorten the lead time.

- **Inter-change prioritisation**: This praxis involved the prioritisation of some requests over others and was used to save time on urgent requests by de-prioritising specific requests, strategically withdrawing requests with extensive requirements that were considered difficult to achieve. Thus, although requests were withdrawn, an opportunity was discovered in not pursuing the request.

- **Design conditions**: In the implementation phase, there was a need to reconnect with the decision makers to ensure that the right task was being performed. In some of the analysed cases, the time from decision to implementation was so long that the change might not have been relevant. In a way, this praxis is similar to the revisiting praxis in the discovery phase, but for the on-site rather than in-house part of the ad hoc team, taking the lead.
- **Retroactive request**: The typical procedure of raising change requests involves a physical need that must be changed; however, in eleven cases, a change request was issued to establish a new contractual or regulatory agreement based on a differently designed or installed component. The most common reasons for such changes were a shortage or lead time issues related to the previously specified components, stringent adherence to the contract, or the implementation of regulations. This practice has two benefits. The request, if approved, is a documented decision of a pre-existing change. Second, the request is used to demand payment for additional services outside the contract.

Aside from the process-based aspects of the practices and praxes, the hierarchal structure of the project was a formal barrier to most ad hoc teams in their pursuit of discovering opportunities. The finding adds knowledge to the discussion on hierarchies from study A. Moreover, the change resolution focused on the person informally responsible for the change request. The same person often had the most knowledge of the topic and was the informal leader of the ad hoc team (i.e. ‘change responsible’ see Figure 24) Thus; the ad hoc team might bypass certain hierarchal levels (Figure 25) in their discovery process. To be able to draw on as much proven experience and information as possible, ad hoc teams often crossed hierarchal project boundaries.

These studies add to the overall results of this research as they can be to compare and contrast both the relative stability of a development project (study D) and the structured process of initiated-change handling (study B) to the lack of stability and structure experienced in the projects of studies A, C, and E and their emergent changes.

![Figure 25: Ad hoc team formation based on formal project hierarchy.](image-url)
4.4 Product development vs engineering projects

Product development projects (study D) and engineering projects (studies A, C and E) were different in terms of uncertainty, complexity, and pace, as described in section 2.1.1. The difference was reflected in the observed ratios of initiated to emergent changes that were raised during the two studied project types. This difference required the ad hoc teams to focus and prioritise differently depending on the project type (Table 10).

In study D, for the studied product-development project, one result was the importance of creating a sense of urgency, usually by having more deadlines. Moreover, in study D, practitioners were sheltered, due to fewer and internal stakeholders, than the practitioners of study E’s engineering projects. Therefore, proposed solution alternatives to changes could only be tested within the organisation, and sometimes not even that, as the confidentiality of the project hindered discussions with those outside the project. As such, fewer contacts could be the reason for the faster “mean solution time” of the product-development project (Table 10). Furthermore, documentation needs and processes could be, and were, respected as deadlines that were often set by the project organisation itself. However, market need initially drove the need for deadlines. The level of ingenuity was high, and the initiated changes that followed were welcomed, as reflected in the high number of exploited opportunities (Table 10).

Conversely, the studied engineering project (study E), operated under a sense of urgency. Stakeholders were many and worked in close cooperation. Deadlines forced the projects forward, and emergent changes were more common than initiated changes (Table 10). The engineering project, also, saw fewer opportunities for emergent changes than the product-development project.

That the “technical change trigger” was more common in the engineering project, could be explained by the more substantial physical content of an engineering project. While the analysed change requests are contrasted in Table 10, a more comprehensive presentation is given in the following two sub-sections.

Based on the analysed change requests, in studies D and E, it was not possible to quantify the number of engineering changes that were directly and secondarily (propagation) generated for each change request, nor was it possible to track the changes’ implementation.

Table 10: Change requests analysed in study D (product-development project) compared to study E (engineering project).

<table>
<thead>
<tr>
<th></th>
<th>Product development (study D)</th>
<th>Engineering (study E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change requests analysed [n]</td>
<td>49</td>
<td>87</td>
</tr>
<tr>
<td>Ratio emergent/initiated [%]</td>
<td>55/45</td>
<td>76/24</td>
</tr>
<tr>
<td>Technical change trigger [%]</td>
<td>56</td>
<td>70</td>
</tr>
<tr>
<td>Mean solution time (emergent) [days]</td>
<td>103</td>
<td>170</td>
</tr>
<tr>
<td>Median time (emergent) [days]</td>
<td>48</td>
<td>104</td>
</tr>
<tr>
<td>Mean solution time (initiated) [days]</td>
<td>56</td>
<td>154</td>
</tr>
<tr>
<td>Median time (initiated) [days]</td>
<td>26</td>
<td>97</td>
</tr>
<tr>
<td>Identified opportunities in emergent changes [%]</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>Exploited opportunities in initiated changes [%]</td>
<td>68</td>
<td>62</td>
</tr>
</tbody>
</table>
4.4.1 Quantifying changes in a product development project

Of all the analysed changes in study D ($n=49$), 55% were emergent, and 45% were initiated. Of all the initiated changes, only 5% (1) had an external trigger, while the corresponding number for the emergent changes was 33% (9), for which the market was the primary driver. As an example, one of the emergent-change requests involved a change in market requirements for the guarantee period, which led to changes to various technical aspects. One of the initiated changes was a suggested change of material to increase component reliability. That request, however, was rejected. The mean solution time (i.e. from raised request until a decision was reached) for the emergent changes was 103 days, compared to 56 days for initiated changes. The solution time for each change is presented in Figure 26; changes that carried over from one gate to another had not accumulated enough information for a decision to be made at that time. In cases where the decision was to accept the change, the implementation phase was absorbed into the regular project plan. Another difference between initiated and emergent changes was that initiated changes saw a higher rejection ratio than emergent changes (32% compared to 15%).

Figure 26: Time from when a change was raised to when a decision was reached for emergent and initiated changes, with indicated gates (study D).
4.4.2 Quantifying changes in an engineering project

In all, 87 change requests with a technical impact were analysed, issued between December 2010 and July 2014. A change request, in the context of the studied project, was not only concerned with engineering changes to the technical solution, but also with other categories of changes identified. These were often project-specific in that they concerned scheduling, project-organisation, or contractual issues that did not impact the technical solution. Here were 118 change requests of this type and these changes were omitted from further analysis. Of those 87 with technical impact, 66 were emergent changes, and 21 were initiated. The rejection rate of the initiated changes was 38%, while the corresponding rejection rate for the emergent changes was 15%. Initiated changes concerned added functionality or components (29%) as opposed to changing existing designs (71%) than did emergent changes (18% and 82%, respectively).

Four out of 21 initiated changes were triggered by contractual questions, while the remaining 17 were of a technical nature. The corresponding rate for emergent changes were four for unknown reasons, 44 technically-driven, three project-driven, 9 for regulatory reasons, and six raised due to issues with the contract.

Regarding the number of opportunities associated with initiated changes that were exploited, i.e. they were not rejected, there were 13. Eight initiated changes were rejected. In the studied sample, there was no one reason for all rejections. Similar to those initiated changes that were exploited, rejected changes also related to increasing the quality of the end product by, for example, increasing system reliability, adding functionality, or facilitating operability. There were, however, two general differences. The initiated changes that were accepted were either a clear win–win solution for the company and the customer, or they increased system safety, a quality highly prioritised in projects of this kind. The mean and median resolution times from when a change was raised to when a decision was reached for initiated changes were 154 and 104 days, respectively; and the corresponding resolution times for emergent changes were 170 and 96.5 days (Figure 27). For emergent changes, each time an opportunity was identified in change requests, it was exploited. However, this was only found to be the case in four of the emergent changes that were identified from the analysed change requests.
4.5 Synthesis of research findings and prior research

This section presents the synthesis of research findings from studies A-E and describe these in the context of the frame of reference. This section also warrants the suggested learning process of chapter 5 through its final discussion points. Study A formed the research clarification and set the stage for the subsequent studies (Figure 10). Studies B and C are polar cases, in that study B studied an initiated change that was well-evaluated, well-documented, performed with few stakeholders and, to a large extent, defined by formal processes, while in study C, it was precisely these factors that were deficient at the heart of the emergent change, with problems arising from poor planning and difficulties regarding the documentation, informal management, and a large number of stakeholders. Studies D and E studied both initiated and emergent changes, but in two different project settings. The overarching concepts (project development vs engineering / initiated vs emergent) that were cross-case analysed are depicted in Figure 28.
In study A, it was argued that the informal change carriers were unwanted as they made follow up, lessons learned, and use in post-project negotiations impossible. As previously shown in paper II (study A), change carriers can be both formal and informal. Furthermore, in the hierarchical structure for the change carriers, what is often referred to as engineering changes in the field of engineering-change-management is the design revisions. In this research, the aggregation of these changes, in the form of change requests, has been studied. It should be noted that, ideally, design revisions (individual engineering changes to drawings and components) should be handled discretely and analytically in an engineering-change-management system, well before they uncontrollably propagate and aggregate into change requests and, in the worst case, start to “snowball” (Nichols, 1990). Change requests, however, as an aggregate of changes, may involve more complex change propagations where a more ad hoc solution strategy is warranted (Fricke et al., 2000). Compared to change carriers, however, for ad hoc teams, it was found in study D that the informal procedures of the ad hoc team allowed it to permeate hierarchical boundaries (e.g. between steering committee, project manager, part project manager, and engineering). The hierarchical structure (Figure 23) was similar to the hierarchical organisation for changes observed in the past by Eckert et al. (2004) as well as Fan and Zhang (2013), who categorised hierarchies as “strategic-level”, “method-level” (department organisation, contract management, and information communication) and “means-level” (virtual construction technology and change management). In study D, the drawbacks that Eckert, Clarkson, and Stacey (2001) found in the degradation of information in hierarchical communication paths, was observed as well.

As discussed in study A, engineering-change-management software is not always able, due either to the functionality or project structure, to span across project phases, e.g. product development, engineering, and commissioning (paper I). The project’s phase-to-phase information distortion was what Eckert et al. (2001) termed a lack of awareness of information history. An ad hoc team can informally bridge this phase gap and transfer the information from one project phase to another; clear examples of this were the dual structures discussed in studies C and E. Studies A and C, regarding another form of project phases, also highlighted the difficulties in bridging the digital (e.g. drawings) and physical (e.g. structures and installations) phases (see Figure 19). Uncoupled punch lists and design-revision requests were also found by Fan and Zhang (2013), caused by what they called the “backwardness” of project change management information, when describing the phenomena of paper documents having to be re-typed into the engineering-change-management or PLM software, rather than being
directly transferred. The effect of this is that deadlines in the engineering projects are postponed continuously (in the digital space), while the contractual final (and physical) deadline is fixed. This observation is also tied to the phenomena described by Eckert et al. (2004) of “change effort and system behaviour”. In their conceptualisation, they defined three distinct behaviours of engineering changes: ripple; blossom; and avalanche. A ripple, as it sounds, is the accumulation of changes that are systematically incorporated, thus neutralised. Blossom concerns a more dramatic increase in change propagations that requires a more extensive engineering effort for it not to turn into an avalanche, in which changes propagate uncontrollably through the system, causing havoc [what Nichols (1990) called “snowball”].

As study B treated a case from the manufacturing industry and changes to a production system, the case contributed through its meta-perspective of what is considered a part of the engineering-change area of application. Traditionally, engineering changes have been considered for products or projects. This case viewed the production system as the product. The results showed that products affect the production system, and vice versa, and that this synergistic relationship needs to be considered in the analysis phase of the engineering-change implementation of changes to production systems in production-development efforts.

Moreover, one of the technical areas in study D, on its own initiative, used weekly “sit-downs” to discuss current issues as a way of making problems visible, much like the sought-after structured group reflection proposed by (Hällgren & Maaninen-Olsson, 2009). This meeting practice by the technical area is semi-formal, while the two contrasting process depictions in Figure 24 (formal vs informal) and can be compared to the control vs moderation of information suggested by Lindemann et al. (1998) in Figure 7.

Two emergent changes were detached in the project studied in study D due to new market demands; the shift in project goals was too significant to support their pursuit in the original project. Ad hoc teams do operate loosely coupled to the original project (Eriksson & Brannemo, 2011) but detaching a change request to form a new project altogether is more akin to true decoupling, i.e. ridding all dependencies, as discussed by Engwall and Svensson (2004) in their concept of “cheetah teams”. Decoupling in these cases is a practice that is supported by Dvir and Lechler’s (2004) findings that changing project goals may have detrimental effects on project outcomes. Contrary to active planning, as it was observed in study A and C that plans were often a post-project artefact that showed what had happened (i.e. a historical report rather than a tool for reducing risks and increasing decision reliability). Dvir and Lechler (2004) argued that active planning, as opposed to static plans, forms the basis of successful project management, in this post-project plan reports can be regarded as static.

When contrasting studies D and E, these product-development and engineering projects were similar in many project-related aspects, but their drivers were different. In an engineering project, deadlines force the project forward, while, in a product-development project, the goal fulfilment required to pass to the next gate is more critical. Pinto and Covin’s (1989) work on the difference between product-development and engineering projects, not only are there projects different, but the degree to which they are different varies with the project phase. Pinto and Covin (1989) found that urgency was a success factor in product-development projects. However, and counter to the premise of this research, “troubleshooting” (i.e. handling changes in the projects) was only found relevant in the termination stage of engineering projects by sur-
vey respondents and did not register in any project phase of product-development projects (Pinto & Covin, 1989). The suggestion is that there are other factors for projects that are also important besides engineering changes.

The distinction between initiated change and emergent change is quite similar for product-development projects and engineering projects. However, the distinction is more directly applicable to change handling within these two types of project. Study B can be used to examine how engineering-change management should be used in an ideal way by using the process prescribed by Jarratt et al. (2011) and exploring each of the stages of this generic engineering-change process as it relates to the case’s stages. It is interesting that, in study B, change alternatives were evaluated (by VSM, E-VSM, and DES) prior to a change being implemented as this is was seldom the case in the other studies. Additionally, as argued in the frame of reference section 2.2, all emergent changes may not be mandatory and all initiated changes are not always optional. But the findings from study D and E support that there is a tendency towards this pairing. As reflected in the number of rejected initiated compared to emergent changes in studies D (32% compared to 15%) and E (38% compared to 15%), thus initiated changes can be said to have a higher degree of optionality attached to them.

The principal difference between the view of Eckert et al. (2004) and this research in terms of how this research regards emergent compared to initiated changes is that, from the viewpoint of the company, “new customer requirements” appeared as emergent (see Figure 4). The reason this research makes this assumption is the project- and ad-hoc-team-centric view. As Eckert et al.’s (2004) view were primarily product-centric, their categorisation is to be expected. Even so, customers might impose new requirements based on input that responds to a new-found weakness in the product (e.g., new market requirements making systems inadequate). Initiated changes are often similar to an organic form of continuous improvement in a project concerning the product or service as it is treated within the project and, as such, they should be valued and managed accordingly.

In study C, a more active planning strategy in the event of an emergent change is predicted to decrease the risk associated with the change propagation. This would enable a more elaborate thought process by the ad hoc teams that realise the change. Moreover, it was suggested that not actively planning might be a mindset problem of the engineers working in the ad hoc teams and the suggested remedy is to teach, through education, ad hoc team members about the importance and craft of active planning.

Finally, a recurrent theme in studies A and C was the abandonment or lack of structured groups and individual reflection, which led to fast and informal, but unevaluated, solutions strategies, similar to past observations by, for example, Hällgren and Maaninen-Olsson (2009). Study E, therefore, investigated the practices and praxes of practitioners that significantly lacked support from formal processes and how they managed to turn some emergent changes into opportunities and exploited the opportunities in initiated changes. At the other end of the spectrum, studies B and D treated production and product-development projects that did use formal processes to their advantage and, through the evaluations made, informed decisions on changes. Even though structure and formal processes had a place in engineering-change management, faced with tight deadlines and critical changes, practitioners resorted to ad hoc practice and praxes. To make practitioners aware of, and utilise, their practices to the best of their abilities, the following section proposes a learning-organisational approach to engineering-change management as it relates to ad hoc teams.
5 Engineering-change learning-organisation process

This chapter presents the developed process that captures the ad hoc team practices in projects and recycles them through the line organisation in a learning-organisation approach. The proposed process phases are presented and discussed further in the following chapter.

Based on the research findings and synthesis, an engineering-change learning-organisation process has been developed. The purpose of the developed process is to support the needs of project managers and engineers that formally or informally manage ad hoc teams or are expected to be part of any ad hoc teams in projects. The process is to serve as a basis for discussion in project organisations as a means to inspire structured individual and collective reflection. It can also be used as a part of a project management office’s process-quality incentive or program, aiming to bridge the project and line organisation. As ad hoc teams and their practices, to a large extent, are informal, the dissemination of knowledge based on this process is best directed towards those expected to be, or already working, in ad hoc teams, as directed in this chapter.

The engineering-change learning-organisation process uses a nested approach in which the line organisation acts as the stable arm of the project hub (Figure 29). Depending on the company organisation in which the process is to be implemented, the line organisation could be the one implementing quality incentives or project-management office might hold this responsibility themselves. In smaller organisations, an individual process owner might bear the overall responsibility of the framework implementation and maintenance.

Figure 29: The engineering-change learning-organisation process.
In larger companies, the project organisation acts as the hub of all ongoing projects managed under a project management office, as depicted in Figure 29. The principal rationale in the development of the process is that practitioners will use certain practices and praxes in a specific environment, i.e. there is an adaptation to the environment given its set of demands and constraints. However, these adaptations can become predominant to achieve short-term gains to the detriment of long-term success. As shown in the research findings, ad hoc teams under stress by the next deadline might skip uncomfortable process steps to resolve a change. This might correct the problem in the short run but, since the change was not thought through, change-propagation problems and re-work might ensue. Furthermore, opportunities could be lost in a rushed approach. Conversely, too relaxed deadlines and a lack of accountability, as found primarily in study D, could stall project progress and lead to unwanted slack in the project execution.

Based on the concepts developed in studies A−E, the proposed process centres on the ad hoc team and the organisational structures that are relevant to them to resolve engineering changes in a project efficiently and effectively. In this, the aim of the suggested process is to maintain and develop the practitioner’s practices as they relate to engineering changes.

5.1 Pre-project: Prepare

Depending on the division of responsibility or the availability of a project management office, compared to a line organisation, the following pre-project initiatives could be initiated. In smaller organisations, individual processes owners would be responsible for the pre-project preparations. First, the workshop format (Table 11) should be deployed to raise practitioners’ awareness of the concepts of ad hoc teams and the established formal process of engineering change management in the intended project. The fundamental difference initiated compared to emergent changes should be reviewed and discussed, particularly how opportunities can be identified and exploited. Second, the project management office, pre-project, ought to establish change-carrier usage. Based on the analysis of how changes are handled in the studied projects, recalling specifically from study A, the following steps are suggested to structure the change carriers:

1. identify the project's official and unofficial change carriers;
2. limit the use of unofficial change carriers;
3. monitor and emphasise change identification in the early stages of the engineering phase;
4. maintain controllability and traceability of engineering-change management during the fabrication phase and do not allow for data degradation as the project progresses;
5. reduce the number of change carriers and eliminate overlapping pathways; and
6. communicate official change carriers to the project organisation (could be discussed in the initial workshop).
Insights can also be used from the below-described workshop to include a discussion on change carriers, including notions of formal and informal carriers. Also, before initiating the suggested workshop format, intended participants ought to read about the engineering-change-management processes and practices, to establish a common understanding of engineering changes and their characteristics (suggested reading, sections 2.2, 2.3, 2.5, 4.2, and 4.3 of this dissertation).

Table 11: Suggested workshop format of the engineering-change leaning-organisation process.

<table>
<thead>
<tr>
<th>Workshop step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>Moderator presents engineering change based on the suggested reading in sections 2.2, 2.3, 2.5, 4.2, and 4.3 to refresh the participants’ memory.</td>
</tr>
<tr>
<td>Group work I</td>
<td>Have participants discuss the sections:</td>
</tr>
<tr>
<td>Divide partici-pants into groups of 3–5 individuals.</td>
<td>Cue participants with:</td>
</tr>
<tr>
<td></td>
<td>i. What was obvious?</td>
</tr>
<tr>
<td></td>
<td>ii. What was odd?</td>
</tr>
<tr>
<td></td>
<td>iii. What was interesting?</td>
</tr>
<tr>
<td></td>
<td>iv. Was something wrong?</td>
</tr>
<tr>
<td>Discussion I</td>
<td>Discuss the group’s reflections among the whole group. Moderator takes notes of the discussion for documentation and follow-up.</td>
</tr>
<tr>
<td>Group work II</td>
<td>Cue a discussion about the formal process: if the company or organisation has a formal engineering-change process, the following discussion points are discussed concerning that process. However, if no processes are or have been established, the steps of the generic engineering change-management process (Figure 16) can be used as a starting point. A variation to this step is presented in section 5.1.1 (Installation based on soft-systems session).</td>
</tr>
<tr>
<td>Divide partici-pants into groups of 3–5 individuals (preferably different groups than for the first session).</td>
<td>Ask of the participants to map trigger words in the process: e.g. where does the following occur: reflection; discussion; most mistakes; and isolated/individual work? Where in the process are alternative solution sets generated and assessed? Which phases and practices are informal?</td>
</tr>
<tr>
<td></td>
<td>Ask participants to answer how they differentiate between initiated and emergent changes and is there room for innovation and identifying as well as exploiting opportunities in this process?</td>
</tr>
<tr>
<td></td>
<td>Relationship to PDM/engineering change-management tools regarding the tools in relation to possible ad hoc teams and their practices.</td>
</tr>
<tr>
<td>Discussion II</td>
<td>Discuss the group’s reflections among the whole group. Moderator takes notes of the discussion for documentation and follow-up.</td>
</tr>
<tr>
<td></td>
<td>Does the established formal change process need to be updated given the group work? Are there difficulties and steps that should be reflected upon in the formal process given the discussed informal process?</td>
</tr>
<tr>
<td>End workshop</td>
<td>End the workshop by reiterating the purpose (practitioners’ thought processes) and assign responsibility in case the formal process is to be updated (usually the responsibility of a process-owner in the line organisation).</td>
</tr>
</tbody>
</table>
If this is a post-project workshop (Figure 29), impressions about the engineering-change process from previous workshops might also be provided ahead of time, as well as KPIs to be discussed. The workshop could then follow the suggested structure presented below (expected duration: 1.5−2h).

5.1.1 Additional workshop initiatives

Derived from the research findings of this research, four additional workshop variations or alternatives are given below to raise awareness of the engineering-change process further as it relates to handling ad hoc teams:

1. **Installation based on a soft-systems session to discover the current project organisations that own the engineering-change-management praxes and practices.** Use either the SSM process described in Figure 30 as an inspiration or develop an SSM description of the organisation’s system from scratch based on the process described in section 3.1.2. Ask the groups to map the engineering change processes as they see them in their organisation. If there is a formal, organisation-specific engineering-change-management process, that process can be discussed in the formed groups in terms of the process they mapped themselves and what the differences are.

2. **Installation and follow-up on “opportunity detection”.** Based on the same workshop format suggested above, the process model for opportunity detection in emergent changes, based on results from study E (paper VI), can be used to raise awareness of praxes and practices relevant to discovering opportunities in projects’ engineering changes. This workshop format could also incorporate a practical case that emphasises the value of developing and evaluating alternative solutions.

3. **Co-creation session between practitioners in development and engineering projects.** It is partly assumed in the original workshop format that practitioners have experience both of product-development and engineering projects. In a larger organisation, however, the two might be separated to the degree that the two practitioner groups never experience both types of projects. In this case, it can be rewarding to have a session where practitioners from both project types reflect on their practises and praxes in the presence of their respective counterparts from another project type.

4. **Dual structure.** Finally, it may also be worth considering that the ad hoc teams as loosely-coupled to the ongoing project team. Furthermore, the on-site and in-house parts of the ad hoc team are loosely coupled to the ad hoc team as a whole. This relationship can also be explored in a session that focuses on the dual structure.
5.2 Project execution: Pre-, in-, and post-change

In a project’s execution-phase, changes occur and are handled in due course by the ad hoc teams. As an example of a generalised engineering-change-management process of the ad hoc teams, the observed and discussed process in study D is depicted in Figure 30. The following sections refer to Figure 30 regarding how the ad hoc teams should progress through pre-change, in-change, and post-change.

Figure 30: Adapted and generalised version of the observed ad hoc team’s engineering-change process in study D.
**Pre-change: Request.** The request should be enabled by the meeting structure of change-request meetings that are supported by risk assessments (pre-change) and project-management meetings (planning) as well as the change-request template (carrier). The change request template as a change carrier ought to include the question of which alternative solutions were evaluated and a differentiation between initiated and emergent changes as well as a visual or textual cue for opportunity discovery. These cues were missing in the studied projects in studies D and E. In this process, changes are formally raised by a change request, using a template, an improved generic suggestion for which is provided in Table 12.

**In-change: Collaborate.** In the in-change phase, the ad hoc teams should enact the practices developed and discussed in the workshop (pre-project). Changes, as they are raised, should be handled in the change-request meetings, in which structured, collective reflection about solution alternatives are discussed and evaluated (Figure 30).

<table>
<thead>
<tr>
<th>Change Request</th>
<th>Description</th>
</tr>
</thead>
</table>
| **Reason, description and category** | • This change request is raised due to...
• The problem or initiative initially originated from...
• Is the change emergent or initiated?
• Is the change critical? |
| **Alternatives** | • Except for rejecting the change, the solution alternatives are... |
| **Opportunity** | • By initiating the change-solution alternatives above, there is an opportunity in... |
| **Consequences** | • The change alternatives have the following consequences...
  ○ The change will propagate to...
  ○ The following disciplines will be affected...
• The project risk profile is affected...
• The health, safety and environment (HSE) risk profile is affected... |
| **Applicant** | • Applicant name and department/organisation. |
| **Decision** | • Motivation behind the decision...
• Decision: Go/Reject or Further investigation needed. |
| **Decision Consequence** | • Updated implementation plan |
Ad hoc teams should acquire knowledge about the change case informally (see detailed depiction from study D; Figure 24) and formalise their findings in the change-request template as well as in the change-request database. The ad hoc teams can use practices of opportunity discovery as discussed in pre-project workshops.

**Post-change: Review.** As a change request is closed, either by acceptance or rejection of the proposed and evaluated solution, it should be the responsibility of the initiator of the change requestor and the project manager (in case there is an assigned change-request manager, it would be that individual’s responsibility) to finalise documentation for processing post-project (i.e. include all relevant and pre-determined data for follow up (KPIs). Also, the basis of the decision reached for each request has to be collected in the change-request database.

5.3 Post-project: Reflect

Post-project, it should be the line organisation’s (quality department or project-management office) or process owner’s responsibility to collect the generated data and store it in a change-request database or similar repository. From that repository, KPIs can be retrieved post-project. Suggested KPIs to be recorded are based on:

- **Efficient change management:** measure the speed in decision making and, if possible, the speed of implementation.
- **Effective change management:** demonstrate that there were fewer changes as the project progressed; show that a number of alternative solutions were evaluated; measure the ratio of emergent vs initiated changes; record how many opportunities were identified and exploited in the emergent changes; and record how many opportunities were exploited in the initiated changes.

In addition to efficient and effective, **learning** can be an included part of the KPIs by recording, which department that raised the most requests, what their causes were and which department they affected as exemplified in sections 4.4.1 and 4.4.2. Post-project, a follow-up workshop is advisable to reflect on lessons learned by ad hoc team members, convey KPIs, and update formal processes, if needed, based on insights from the follow-up workshop.

Finally, an evaluation of the proposed engineering-change learning process and its workshops is advisable to update the workshop structure and process based on ad hoc team participants’ impressions.
6 Discussion

In this chapter, the concepts presented in the research findings are discussed in terms of their relationship to the developed process proposed in the previous chapter. The suggested process use and utilisation are discussed along with the quality of this research.

6.1 The suggested process

Learning from previous engineering changes has been identified by researchers in the past as a success factor in handling engineering changes. Unfortunately, its use has not been reported to a corresponding extent (Fricke et al., 2000; Hutanu et al., 2016; Wickel et al., 2015). Furthermore, given that a project can be described as a temporary organisation within an organisation (Shenhar et al., 2004) and that the ad hoc team is a temporary organisation in and of itself (Engwall & Svensson, 2004) within an already temporary organisation, the difficulties in establishing formal procedures for these practitioners’ work is understandable. As argued in this research, the practitioners that make up the ad hoc teams to manage changes are central to the performance of the change resolution.

The engineering-change-learning process is front-loaded and back-loaded. The reason for this is that the practices that practitioners then use are expected to be enhanced by the awareness-raising activity of the workshop that should, in turn, increase ad hoc teams’ performance. As concluded by Häggren and Maaninen-Olsson (2009), informal processes and practices increase with time constraints on change resolution. In any project, the in-change phase practitioners will act outside formal processes if time pressure is high enough. Therefore, it makes more sense to front-load training to raise awareness of practices pre-project. Learning is one of Fricke et al.’s (2000) five strategies for coping with engineering changes, and the suggested process uses this strategy through organisational learning for the prospective ad hoc teams. In learning, both from past mistakes and successes, reflection need to be practiced (Buckler, 1998). Therefore the suggested processes is said to also be back-loaded, as reflection through follow-up workshops and analysis of KPIs is proposed to cement knowledge gained, post-project.

As projects-as-practice aim at a bottom-up perspective that centres on practitioners and their practices, rather than suggesting best practice (Blomquist et al., 2010), this research suggests an organisational-learning approach that involves and makes use of the practitioners’ experiences. Hollauer et al. (2014) made the distinction between “organisational learning” as a process and a theory-oriented concept and “the learning organisation” as a process and a practice-oriented concept. In this, a systematic approach is, therefore, a prerequisite to becoming a learning organisation (Buckler, 1998). The suggested process provides a systematic and continuous approach to learning for ad hoc teams.

The steps of the proposed engineering-change organisational-learning process follow the integration categories of engineering design of project planning, project exe-
cution, and project development as they have been proposed by Browning and Ramasesh (2007) and discussed by Eckert et al. (2017), then in its relation to the corresponding product development stages. Relevant to the proposed learning process is the planning and execution categories of “structuring the process” and “assessing progress”, as well as the development categories of “organisational learning” and “training”. Browning and Ramasesh (2007), as well as Eckert et al. (2017), also discuss “project visualisations”, (i.e. visualisations of actions, interaction, and commitments). In this category, the suggested change request template (Table 12) and SSM representation on the ad hoc teams process (Figure 30) are relevant contributions.

The suggested workshop format is designed based on the learning-organisation recommendations of Buckler (1998): each workshop’s content needs to be limited so that it can be reasonably absorbed; a “taught” learning strategy is needed to introduce concepts, but discovery is to form the lion’s share of a workshop’s content; the workshop outcome is actionable; reflections on former workshops and actions in later installations; continuity is needed to sustain learning over time; and managers should attend workshops as equals to other attending practitioners. The process requires a process owner or responsible organisation that can moderate workshops and follow up on KPIs post-project.

As Hollauer et al. (2014) noted, ad hoc teams disband after an engineering change is resolved, so post-change documentation is essential both to secure lessons learned as well as to enable post-project analysis of KPIs. Furthermore, Hollauer et al. (2014) suggested a “learning lab”, in which engineering change and its management can be discussed with a focus on learning and development. This is enabled in the processes suggested in this research by the re-occurring workshops and the function of the line organisation and process owner.

As argued in the frame of reference, post-project KPIs ought to be measured to establish the efficacy of the continuous-improvement framework in terms of effectiveness (e.g. opportunities discovered) and efficiency (e.g. time to resolution). In the field of engineering-change management, the research focus on KPIs is new, and Kattner and Lindemann (2017) have suggested a framework to guide the implementation of KPI measurements of engineering changes based on five steps:

1. Decide the level of concretisation, i.e. the hierarchal levels that the KPIs should target.
2. Choose change classification (e.g. initiated or emergent change).
3. Identify context-specific analysis criteria. In this research, for example, resolution time, opportunities, and causes, among other metrics, were suggested.
4. Develop company-specific analysis criteria based on iterative practice; the criteria should be updated to fit the goals of the organisation.
5. Retrospective analysis or future-driven data collection. If available, the case data can be analysed but, if data currently generated does not support future analysis, this ought to be included in future projects to be recorded.

The fifth and last step much resembles the situation in studies D and E, in which initiated and emergent changes had to be determined from qualitative data rather than stated by the person raising the request. As suggested in the change-request template of Table 12 practitioners ought to indicate this themselves.
In study E, proven experience was identified as an enabler of opportunity identification and exploitation. The finer, narrower proven experience and subsequent opportunity discovery in sub-change request levels will be difficult to detect as these day-to-day discoveries are not reflected in change requests.

Thus, the metrics suggested in this research ought to be viewed as a point of departure. To that end, this research suggests measuring effective change management in terms of opportunities, initiated and emergent changes, and proof that the rate of engineering changes raised is reduced as the project progresses. However, if advanced software is available, change propagation can also be measured more quantitatively following (Eckert et al., 2004), who discussed how the changed components of products can act as constants, absorbers, carriers, and multiplier, and are relevant data to analyse. However, it ought to be noted that the concept of “carriers”, in the framework of this research (i.e. carriers of information about the change), is more of a meta-concept related to the project organisation, than the product component based carrier concept that Eckert et al. (2004) describes.

Lastly, the purposed process is a starting point of implementing an organisational-learning approach to engineering changes. However, further evaluation and studied is needed to determine its efficacy. Moreover, the process, as Kattner and Lindemann (2017) suggest, focuses on a particular set of changes, in this case, change requests, as these are reasoned to be of most relevance and magnitude for ad hoc teams. More detailed changes are more suitably handled in a structured PDM software approach.

6.2 Expected outcome of the proposed process

Those roles that have the most potential to make use of the model for the benefit of the practitioners and, ultimately, the company are the practitioners themselves; as argued in the CATWOE of SSM (Checkland & Scholes, 1999), the practitioners are the not only the actors but also, to an extent, the owners. However, the suggested workshop format can be moderated by a project, general, or quality manager. Practitioners as members of ad hoc teams are often, though not always, part of a project (internal environment) and project organisation (outer environment). Furthermore, they can have experience from working in both development and engineering projects, with both initiated and emergent changes. In this way, those practitioners can easily be briefed on the general process premise and reap the benefit of its content in a workshop initiative.

Hällgren and Söderholm (2011) pointed to two significant challenges in the projects-as-practice approach: the pattern challenge; and the relevance challenge. The pattern challenge concerns the “situatedness” of the studied practitioners’ practices and praxes, i.e. to what context the observed actions are situated and how these practices and praxes can be tied to those surroundings. The relevance challenge regards the usefulness of the performed research to the domain that has been studied, which follows the “giving-back” tradition of action research (Coghlan & Brannick, 2014).

The model, as used in the workshop format, is practical in its use and aims to disclose subtle parts of the engineering-change-handling organisation and processes, issues that are read between the lines. By studying the proposed model, practitioners, e.g. engineers, part project managers, and project managers may better guide their work with engineering changes regarding formal and informal structures that are pre-
sent in their organisation. They might identify that there are harmful formal hierarchical structures in place that hinder collective reflection across hierarchical glass ceilings. As previously discussed, engineering-change-management software is not always able, due either to the functionality or project structure, to span project phases, e.g. engineering and commissioning (study A and paper II). The ad hoc team, however, informally bridges this gap and carries the information from one project phase to another. Thus, the ad hoc team’s strength lies in its ability to work across disciplines, hierarchies, and project phases; they are loosely coupled to the current project (Hällgren, 2009). As ad hoc teams’ strength lies in their agility, this agility, in turn, rests on the practitioners’ own abilities (Hällgren & Maaninen-Olsson, 2009). Thus, the workshop format can be used to build on the practitioners’ knowledge of their processes and make them aware of their practices and praxes.

Although it is not the primary purpose of the suggested process, it can also be used to supplement the often-discrete process descriptions of engineering companies and their project-management systems. However, the primary goal is that practitioners, in the form of project engineers, project managers, and project-management offices, should use the framework as a way of learning from, and guiding, their day-to-day activities.

At the time of writing, one pilot project has been initiated at the case company in the product-development department. Using the KPIs from the studies E and D from this research, ad hoc team members have been briefed about the outcome of these studies and also taken part in a post-project workshop based on the format suggested in this research. An evaluation of the performed workshop format has also been initiated with preliminary results received.

6.3 The quality of this research

This section is the continuation of section 3.5 and discusses the quality of the completed research. This research and, in particular, the proposed learning process, emphasise the quality aspects suggested by Creswell (2012):

- **Shared responsibility/critical dialogue**: achieved through the active participation of engineers and project managers.
- **Collective reflection**: achieved mainly during the suggested workshop format.
- **Mutually-beneficial research**: as suggested, the continuation of this research should be action-research-oriented in implementing the learning process and, therefore, stands to benefit the researchers, practitioners, and, perhaps, society in the second-order effects.
- **Alliance-building**: this research project and its research school, Innofacture, has been an alliance-building activity that has involved not only the case-company and the university, but also other companies and actors also involved in the Innofacture research school. These alliances and their first-and second-order effects have been discussed in section 3.5.2.

Yin (2011) claimed that gaining access to data and information can pose a significant challenge in case studies. As an industrial research student, the access to data was not an issue; the problem lay instead in the categorisation, quality, and selection
of data from the vast amount of data available. Processes and design aspects were studied as the researcher, through his employment with the case company, had access to databases, mail correspondence, drawings, internal documentation, and, in the social arena, encountered informants on a daily basis. Much of the business- and industry-related research was also dependent on the contribution to, and direct financing of, academia. The factors described above no doubt lead to biases in the researcher; this it is inevitable. However, as Merriam (2014) explained, separating the data collection from the analysis, in qualitative research, is not only complicated, it negatively influences the outcome of one’s research by creating a barrier between what would otherwise be rewarding iterative loops.

In studies D and E, quantification of the change requests was used to assess the management of the studied projects. Given the number of studied changes and the qualitative data they contained (that was later analysed), little can be said about statistical reliability of the results. Rather, the many change requests that were analysed served not only as a source in and of themselves but were also part of the triangulation in the performed analysis. The change requests, therefore, aided the researcher in achieving the standards of research quality proposed by Yin (2011) (Table 7). Construct validity was confirmed as the change requests were complemented by interviews and other archival data (processes, guidelines, and minutes of meetings). Internal validity and external validity were also confirmed as two project types were studied, both of which contained initiated and emergent changes, so pattern matching was enabled. Finally, as Yin (2011) asserted, archival data (as change requests) increases the reliability of overall results as it is a stable, exact, and usually quantifiable type of data.

Moreover, it should be noted that this research was conducted during a confined time window and, as such, was influenced both by external environmental circumstances and internal (to the research project) academic and industrial events. Given the nature of the performed studies, this ought not to cause alarm. Case studies provide a record of studied phenomena in a defined context. Hence, a commonly held critique is that they lack being of general interest. However, as Flyvbjerg (2006) argued, we as humans learn based on experience. That experience is an aggregate of the cases we encounter. Therefore, cases might not always be fit for generalisation, but they serve as building blocks and, through enough anecdotal evidence, close to empirical certainty can be drawn from their conclusions. In the projects-as-practice approach to project-management research, it is just such situated, case-specific details that are interesting (Hällgren & Söderholm, 2011).

By using the projects-as-practice approach, this research has utilised the building blocks of the approach’s concepts. Unfortunately, this research is guilty of mixing a purely project-as-practice approach and a more traditional process view of projects. Moreover, the author agrees that observations are more apt than interviews for studying practices and praxes and the focus should be less on existing processes and more on actual performed day-to-day activities (Hällgren & Söderholm, 2011). The author humbly acknowledges this deficiency and views this as a lesson learned for future research projects.
7 Conclusions

This chapter revisits the research questions to discuss their promise and fulfilment. The outcome of this research is also discussed regarding its impact on the scientific community as well as industry practice. Finally, suggestions are made regarding further research avenues to advance, broaden, and verify the results of this work.

7.1 Summary of conclusions

This research has studied the practices of ad hoc teams in their management of engineering changes. In this, practices have been discovered and presented as they relate to initiated and emergent changes. Practices and change-request quantification have also been presented as they relate to the two project types of product development and engineering. It has been found that to best support both the formal processes and informal practices of ad hoc teams, a learning-organisational approach is advisable. This approach capitalises on the practitioners’ own experiences and develops their capabilities, based on structured collective reflections gathered through a workshop method. Furthermore, the suggested process includes guidance on performance measurements for the engineering-change process in general and the ad hoc team’s involvement in particular.

7.2 Revisiting the research questions

By recalling the research questions from the first chapter, a brief discussion follows regarding to what extent they have been answered.

1. Which project organisational structures are relevant to the ad hoc teams in solving engineering changes?

Primarily through studies A and C, the hierarchical structures have been studied, while the organisational structures of change-request meetings and their relevance to ad hoc teams has been explored in studies D and E. As previously discussed in section 4.2 meeting structures other than change request meetings (risk assessment and project management meetings), pre-project (pre-studies), post-project (follow-up and spin-off projects), the project management organisation and other affected line organisational structures, the overarching management strategy (represented in study D by the quality and operational excellence department) (see Figure 30), are all project organisational structures identified in this research to be relevant to ad hoc teams in solving engineering changes.
Suggested connections to engineering-change aspects that have not been treated in this work but are still considered essential to research in engineering changes include: impact analysis; authorisation (decision-making); technology and product interfaces to teams work; and costs analysis (Hamraz et al., 2013). Hamraz et al.’s (2013) framework present those aspects of engineering change (structures) that are relevant but not touched upon in this research. However, all engineering-change aspects and structures might not be directly associated with the practices of ad hoc teams.

2. **How are initiated and emergent engineering changes treated by ad hoc teams in projects?**

This research has both quantified differences in how initiated and emergent changes are different and shown, based on qualitative data, how they are handled by ad hoc teams. This research also revealed that initiated and emergent changes are different in terms of opportunity discovery (primarily through study E). Moreover, this research has investigated the difference between engineering-change management in product-development and engineering projects, as well as the extent to which initiated and emergent changes are treated differently in these project types.

3. **Which elements are required in an adapted and continuous process, developed for ad hoc teams, to facilitate more effective and efficient engineering-change management?**

The learning process suggested in this research is based on the findings of studies A–E, combined with relevant prior research (Fricke et al., 2000; Hollauer et al., 2014; Hölttä et al., 2010). This research suggested a learning-organisational approach to the improvement of engineering-change-management performance that centres on the ad hoc teams and their change tasks. The suggested essential elements for the learning-organisation process uses a workshop initiation followed by in-change and post-change tracking of results, concluding with a follow-up and implementation of improvements relating back to the process itself and the change processes and tools it concerns. The responsibility for the process and its implementation should preferably lie with a process owner of a project-management office or a process-quality engineer. These are all initiatives that have been identified previously to increase engineering-change efficiency and effectiveness (Fricke et al., 2000; Hölttä et al., 2010).

7.3 **Scientific contribution**

This research contributes to further understanding of how emergent and initiated engineering changes are treated differently in product-development and engineering projects. The two has not to the authors knowledge been compared from this perspective in the past, but separately in (Eckert et al., 2004) (initiated vs emergent) and (Pinto & Covin, 1989) (product development vs engineering). Furthermore, it contributes to advanced knowledge of how engineering changes are treated from a hierarchical perspective in project organisations as they relate to ad hoc teams. In its investigations, this research has also contributed to the idea that opportunities, in the context of
changes (Acar et al., 1998; Hutanu et al., 2016), ought to be viewed as exploit or discovery situations, depending on whether the change was initiated and emergent. Furthermore, this research ties opportunities to the engineering change strategy of _effective_ practices, developed by (Fricke et al., 2000). Moreover, the applicability of the generic engineering-change process (Jarratt et al., 2005), particularly in study B, has also been studied.

Although engineering change management, in the context of lean product development, has been studied in the past (e.g. (Hölttä et al., 2010; Mahlamäki, Ström, Eisto, & Hölttä, 2009), the focus on _kaikaku_ is a novel contribution. This research has also established the concept of change carriers, i.e. there are many different ways of evoking change in a project and both the hierarchal and phase dependencies in which the carrier is used at any particular time are essential for understanding the structures that are used by practitioners in solving changes.

Furthermore, this research contributes with several case studies (three engineering projects, one production development and one product development case) as had been requested by Ahmad et al. (2011) and Ullah et al. (2016) in the context of engineering changes.

Lastly, project-as-practice Blomquist et al. (2010) and SSM Checkland and Scholes (1999) has been used as analysis tools in this research and thus broadening the proven applicability of these methodologies.

### 7.4 Industry contribution

Most engineering companies that handle both product-development and engineering projects are expected to experience similar problems in their business to those described in this research. Companies not only of this kind but also those that deal only with product development or engineering projects can also experience such problems, which further increases the contribution to the industry of these research results. The format of this work, based on case studies, constitutes an accessible format of knowledge to representatives form industry that can quickly find commonalities between the results presented in this work and their own situations.

The very idea of formalised processes is contradictory to the premise of the research questions. Formalised processes are often bypassed in what Hälgren and Maaninen-Olsson (2009) called project-“martial laws” when handling engineering changes. Thus, it is argued that the results yielded and insights gained from this research have to be implemented in a tacit process of discovery by practitioners themselves. To that end, the engineering-change learning-organisation process (Figure 29) was developed, based on a workshop structure that aids practitioners in exploring their practices and praxes. It is also preferable that the process is adapted to the organisation, built in part by those that use it.
The process can be utilised in the following instances:
- by individual project members (practitioners);
- guiding the discussions in change-request and change-progression meetings, emphasising solution alternatives and evaluation practices;
- establishing ways in which change-request forms can be enhanced by introducing prompts such as opportunity identification and solution alternatives; and
- adding to the quality and operational-excellence procedures of a company.

Lastly, the first- and second-order effects generated by this research, as discussed in section 3.5.2 can also be perceived in terms of development of processes, training of personnel, and raising the competence of specialists, with the hope of achieving new ways of working, all contributions to industry.

7.5 Further research

An action-research approach would be the natural progression of research following this dissertation. Given the suggested process, its implementation would be a suitable action-research project. An action-research project could study both the introduction and subsequent implementation of the suggested framework. Both the suggested KPIs and practitioner reactions could be studied to evaluate the efficacy of the framework.

For practitioners working on projects and handling engineering changes, there seems to be a need for less rigid software and processes that allow for several media (change carriers) to be documented in the same system. Copying-and-pasting is how most of us work and, in a project-as-practice spirit, systems ought to be developed for such work. There is a strong need to define product architectures to work like clockwork, but there is also a need to be able to independently document changes, regardless of change carriers (i.e. facilitating the formalisation of informal change carriers). Thus, this is a call to developers of PDM and engineering-change-management systems to design software that capitalises on both divergent and convergent ways of solving and documenting problems.

As suggested in study A, but not further pursued, there are benefits to utilising lessons learned or generating lessons learned from engineering changes themselves. This research is more concerned with the process of managing change rather than with individual changes. However, while individual changes are relatively detailed, change requests might, through their aggregation, paint a more comprehensive picture of which areas to focus on regarding lessons to be learned. This would complement and extend the work of Hollauer et al. (2014); Hutanu et al. (2016); Wickel and Lindemann (2014), which was the starting point for this research.

Finally, as the opposite of opportunity discovery and exploitation of changes, the concept of engineering-change resistance deserves broader recognition. As has been argued in this work, engineering changes are reliant on the practitioners that execute them and, in this, the resistance to act needs to be better understood. Fricke et al. (2000) noted three reasons for this: delaying raising a change as it is seen as unpleasant; waiting for someone to change something else to shift responsibility; and waiting until change becomes critical to gain maximal management attention. However, these can be further explored using some of the methods employed in this research.
References


Towards a Learning Process for Ad hoc Engineering Change Teams

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