ICED13
INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED13
19-22 AUGUST 2013, SUNGKYUNKWAN UNIVERSITY, SEOUL, KOREA

DEVELOPMENT OF AN ENGINEERING CHANGE MANAGEMENT CAPABILITY FRAMEWORK FOR ENTERPRISE TRANSFORMATION

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ABSTRACT

With the current financial crisis focus of product development in industry has centred on efficient variant development and increasing the utilisation of existing products and platforms. Together with this change in focus the handling of engineering changes has grown in importance. Several studies however document a slow and inefficient handling of engineering changes, indicating a general low maturity of this area in industry, e.g. (Sharafi et al., 2012), (Huang, Yee & Mak, 2003). Although a noticeable amount of work has been published on engineering change, the literature, as highlighted by Jarratt et al. (2011) in a recent extensive literature review, overwhelmingly points to the need for more comprehensive guidance in how engineering changes can be handled more efficiently. This paper seeks to address this gap using a capability perspective. Based on literature review and a case study, the process areas especially important to develop capabilities within to ensure an efficient change handling are identified, and an ECM capability framework is proposed. This paper thus enables further research to focus on clarifying ECM capabilities, maturity levels and levers.

Keywords: new product development, design management, engineering Change, capability framework

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1 INTRODUCTION

Global competition, shortening product lifecycles and the current economic crisis has increased the demand for more efficient product development. After years of academic research, e.g. (Cross, 1989) pointing at variant development and reuse of existing solutions, been acknowledged by industry which now focus more extensively on design of new products based on adaptions from existing products. This change in focus is highlighted in a study by Aberdeen Group of 135 enterprises from different industries, which concludes that although change management always has been a crucial process, it has elevated in importance in today's fast-paced market (Brown and Boucher, 2007). At the same time there has been a shift in research of engineering design. Publications for several years have reported on the challenges in the industry of ECM, e.g. (Watts, 1984), (Loch and Terwiesch, 1999), (Huang, Yee & Mak, 2003), (Hölttä et al., 2010) etc. research has for a long period focused on design of new product platforms and families, e.g. (Pahl and Beitz, 1988), (Otto and Wood, 2000). Only recently has the configuration of existing platforms and handling of engineering changes gained increased attention. One of the earliest contributions having engineering change as the primary topic is by some, e.g. Huang and Mak (1999) noted to be (Dale, 1982). Since his study several other contributions have been given, and the research on engineering change has expanded into several different focus areas. The definition in literature of engineering change coming closest to the authors experience is brought by Jarratt et al. (2011): "An engineering change is an alteration made to parts, drawings or software that has already been released during the product design process, regardless of the scale of the change." This paper takes an even broader perspective, engineering change is thus defined as; 'an alteration made to the technical system and/or its related value chain processes and documentation, that have already been released during the product and process design process'. This paper supports the perspective that engineering changes occur throughout the entire product life cycle (Shankar, Morkos & Summers, 2012), and can range from minor changes to more complex changes affecting several modules and systems (Jarratt et al., 2011).

Jarratt et al. (2011) argue that the three main perspectives of ECM are a process perspective, a product perspective and a tool perspective. Building on these perspectives Jarratt et al. (2011) introduces a classification of literature on engineering change in the five categories; (1) General characterisation of engineering change, (2) Nature of change Processes, (3) Product focused research, (4) Tools addressing the needs in change processes, (5) General strategies and methods to cope with engineering changes. Several contributions in literature can be found within the categories (1) to (4), addressing more isolated topics as e.g. reasons for triggering engineering change (Ahmed and Kanike, 2007), effects of change propagation (Koh, Caldwell & Clarkson, 2012), impact assessment (Shankar, Morkos & Summers, 2012), etc. Only very few contributions are however given on more general strategies and comprehensive guidelines in how to cope with engineering change. On this topic (Huang and Mak, 1999), (Fricke et al., 2000) and (Brown and Boucher, 2007) are apparently the only contributions. Even less is published on how a company can transform from an immature and inefficient ECM to a more mature and efficient ECM. The study of Brown and Boucher (2007) seems to be the only describing steps in improving ECM and the industry is thus only offered limited guidance from academia on what to focus on in order to ensure an efficient ECM.

Whereas little is to be found within the engineering change literature on how to transform an organisation in relation to ECM, useful and more general theory on improving technical process systems and handling enterprise transformation has however been established in other research areas within academia. One of the growing perspectives or streams in literature addressing enterprise transformation is the organisational capability-perspective. In this stream of literature organisational capabilities are most often described as imbedded organisational assets or stocks of resources that have been developed and accumulated in the firm over time through learning e.g. (Boer et al., 2001) and (Bessant and Francis, 1999). The study of Boer et al. (2001) has brought one of the most comprehensive definitions on organisational capabilities, defined as: "the integrated stocks of resources that are accumulated over time through learning, or established through deliberate decisions. These stocks of resources include internalised behaviours, technical skills, organisational routines, and corporate assets such as information systems, databases, libraries, tools, and handbooks." Central defining aspects of capabilities are thus that they only are developed and accumulated in the firm over time through learning and thus that needs to be institutionalised, which makes the capability perspective highly relevant in relation to describing organisational transformation. The capability perspective has today gained ground in many different domains, among others Quality Management where the Software Engineering Institute (SEI) at Carnegie Mellon University has developed a multi-level maturity ranking process which is also known as the Capability Maturity Model (CMM) (Paulk et al., 1993). Similar work on multi-level capability models is published within other domains, e.g. Lean where the Lean Aerospace Initiative (LAI) at MIT has contributed with a multi-level capability maturity model for lean enterprise transformation (Nightingale and Mize, 2002). Generally speaking the capability maturity models supports three overall goals, 1) to provide guidance for applying best practice in improvement initiatives 2) enable appraisal of a process, an organisational area or improvement initiative, 3) to enable certification based on assessments (Chrissis, Konrad & Shrum, 2003). As the CMMI focus on product development in general and LESAT focus on organizations in general, no specific guidance is given in developing capabilities within ECM.

This paper contributes to the research on engineering design and ECM in particular. The research is based on a case study in Vestas Wind Systems A/S, a global industrial manufacturer of wind turbines that are huge and complex mechatronic products, with approximately 20.000 employees. Vestas, hereafter referred to as the case company is currently undergoing an economic crisis and has as the majority of the players on the wind market a general low maturity level of its operations. The case company of this paper is thus in an emergent need for enterprise transformation, especially in the handling of engineering changes. As a result the handling of changes, which in the case company formalised in an ECM-process, has gained increased management attention and led to initiation of a company-wide improvement project summer 2012. The research behind this paper is conducted as a part of a larger research project in collaboration with the case company. The overall research-theme is how to ensure an efficient product variant development and as a part of this how changes to existing platforms can be handled more efficiently. The research question for this paper is: *What are the areas that an organization need to develop its capabilities within in order to ensure an efficient handling of changes?* The purpose of the paper is based on this to propose an ECM capability framework and by this build the foundation for developing theory on enterprise transformation regarding ECM. The following section presents the research design. In section 3 ECM capability areas are clarified and a capability-framework proposed. This is in section 4 utilized to analyse the case material.

2 RESEARCH METHODOLOGY

Based on the research question and purpose it is as research design of this study chosen to conduct a literature review and analysis to clarify capability areas for efficient ECM, and a single case study to assess the relevance of the capability areas proposed as well as identifying areas not covered.

The literature review is done based on an extensive search primarily using The Web of Science database together with forward and backward search methods. Due to the scarcity of literature on engineering change, also referred to by other scholars, e.g. (Jarratt et al., 2011), a broad literature search have been conducted including books, conference papers and journals papers. Using engineering change as search string approximately 500 results have been found and by narrowing down to literature addressing the following three topics, 62 papers have been selected for further analysis:

- Practices, methods tools or strategies for managing engineering changes
- Studies on re-engineering or accelerating the engineering change process
- Overview of issues, current practices and best practices within engineering change handling

This broad basis for the literature analysis has been chosen as both challenges and best practice tools methods etc. have been found relevant in pointing out areas with significant impact on ECM efficiency. By more detailed review against the topics above, the point of departure for the literature analysis has been narrowed down to 12 papers presented in Table 1 in section 3.4 of the paper. Analysing the literature the following approach have been followed: (1) identification of overall process areas indicated as significant for ECM, (2) identification of practices and related more generic areas within each overall process area for ECM, (3) classification of areas and proposal of framework.

The case study has been conducted based on a larger improvement initiative on ECM in the case company initiated June 2012. The aim of this improvement initiative was to reduce the engineering change lead time, and in scope was to ensure simplified workflows and increased control of the process without major changes of IT systems and data bases. The improvement initiative also encompasses aspects not relevant for this case study, and hence only the first part of the improvement initiative is as depicted on Figure 1 in-scope of this paper.

Based on the input from eight semi-structured interviews conducted as brown-paper value stream mapping exercises, an initial list of issues regarding ECM was generated. This list was used as point of departure for a survey distributed to 42 key-stakeholders within the case company representing the entire company internal value chain in the handling of engineering changes. The respondents were asked to give input on the greatest barriers for efficient ECM, and to validate and prioritize the other respondent inputs. Response was given by 27 acceptable in term of ensuring a sufficient broad response, if the distribution of respondents depicted at Figure 2 is taken into consideration.

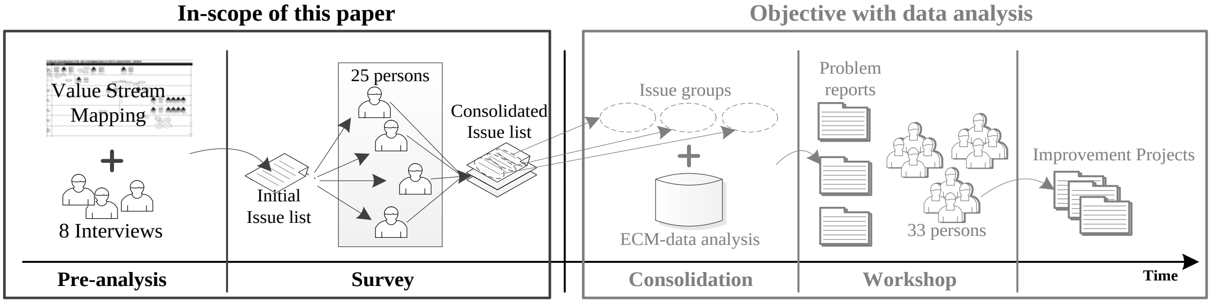

Figure 1 - Improvement initiative and scope of the focal case study.

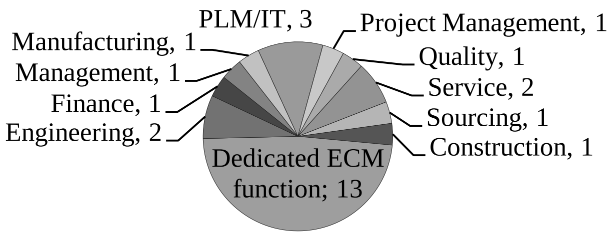

Figure 2 – Survey respondent distribution in proportion to function or department.

All respondents have been asked to validate the other issues reported and the validity of the issues is thus considered high. In the case analysis the following approach have been followed: (1) identification of relevant capability areas for each of the 135 issues on the consolidated issue list by utilization of the ECM capability framework (2) clarification of number of issues in the case study pointing at each of the capability areas (3) identification of additional capability areas for issues not covered by existing areas.

3 LITERATURE ANALYSIS

A broad representation of both case studies, surveys and a single literature review are included in the literature analysis based on the fact that different types of studies enable different findings and the belief that having a broad representation of literature within engineering change will enable a more comprehensive clarification and strengthen the framework. The broad representation is possible as regardless of e.g. general issues in industry on ECM is clarified in a survey, or e.g. a solution for a specific problem is reported in a case study, these finding are used to point at areas important for ECM. In the following each of the capability areas are introduced together with the central reasoning

3.3 Identification of ECM Capability Areas

By review and analysis of the literature listed in Table 1 each of the areas described in the following have been found stated as important for efficient ECM, and thus an area which within a company needs to develop its capabilities. The overall process areas introduced e.g. ECM process, Information systems & IT tools etc. have been identified by classification and categorisation of the more concrete capability areas.

3.3.1 ECM Process

All of the analysed literature indicates in several ways that having capabilities within an engineering change management (ECM) process is essential in order to ensure an efficient handling of changes. Within this theme or overall capability area seven more concrete capability areas are identified.

(1) Change identification, prediction and (request) proposal: One of the practices highlighted by most of the authors is identifying or predicting needed changes and doing change request proposal. Some of the activities pointed at within this area are e.g. identification of prior attempts to raise the same or similar changes (Jarratt et al., 2011), early detection of change (Huang and Mak, 1999), capturing all necessary information on changes in a change proposal Hölttä et al. (2010) and anticipating or predicting necessary changes (Eckert, Clarkson & Zanker, 2004).

(2) Change evaluation and impact analysis: Another area of practice for effective and efficient ECM mentioned in most of the literature is ensuring a proper evaluation of the proposed change based on impact analysis, e.g. Huang and Mak (1999) propose that evaluating changes quickly as one of 13 guidelines for efficient ECM, similarly Eckert, Clarkson & Zanker (2004) conclude that successful ECM requires knowledge on the consequences of a change on product quality, cost, and time to market. Change evaluation and impact analysis is also addressed as a separate theme in several other publications, e.g. (Koh, Caldwell & Clarkson, 2012), (Aurich and Rößing, 2007) etc.

(3) Change follow up & Cost Management: In contrast to the change evaluation and impact analysis this capability area concerns the follow up or evaluation of change and its impact being done not only upfront but throughout the entire change lifecycle. As highlighted by Jarratt et al.(2011) this is done to ensure that only those changes that actually provide an overall benefit to the business should be allowed to proceed to the end of the process. Fricke et al. (2000) state in a study of German manufacturing firms, that only 40–60% of engineering changes in the studied companies were technically necessary, underlining the importance of both continuous and terminal follow up on change objective(s) and target(s). Huang and Mak (1999) also describe doing audit or review of that the change has achieved its objective(s) together with analysing the change effects in terms of costs and benefits of a change, as two of 14 central activities involved in ECM.

(4) Process for controlling of engineering changes: Most of the literature analysed seems to support the necessity of developing capabilities in the having more formal and uniform approach at ECM, e.g. the Aberdeen study argues that "Best-in-Class" companies are nearly three times as likely as "Industry Average" companies to use formal workflows for ECM (Brown and Boucher, 2007).

(5) Process for scaling and tailoring of the ECM-process: The literature not only points at the importance of having a formal ECM process but also that the need for capabilities in a flexible approach. Several case studies report on companies having a differentiated ECM, e.g. (Shankar, Morkos & Summers, 2012) describe in a case study use of a separate and fast track process for manufacturing containment action to bypass of the formal change documentation normally required. Eckert, Clarkson & Zanker (2004) also report use of a differentiated approach in a case study based on observation of two distinct strategies for ECM in the same case company. The need for a flexible approach to processes is also known in other domains, e.g. software development, where agile processes and process scaling and tailoring are often reported as means for coping with the demand for rapid changes (Boehm and Turner, 2005).

(6) Solution development and selection: Establishing different solution strategies and concepts is mentioned by several authors, e.g. Pikosz and Malmqvist (1998) who based on a multiple case study of ECM in three Swedish engineering companies highlight investigation of possible solutions as good practice to cope with ECM. Eckert, Clarkson & Zanker (2004) also highlight the practice of assessing design alternatives in the early stages by looking at the trade-offs with regard to the impact of changes.

(7) Solution review: Only a few scholars mention review of the proposed solution as an activity area important for ECM. Shankar, Morkos & Summers (2012) describes how the company being studied utilizes solution and drawing review by the product support manager before the documentation is released. Similarly Eckert, Clarkson & Zanker (2004) reports that the case company studied utilise review and approval of agreed solutions in a three-step process.

3.3.2 Engineering & New Product Development (NPD) Processes

Another overall area that based on the literature analysis is found important to build capabilities within in order to enable an efficient ECM but which do not exclusively concern ECM is the engineering & product development processes. This area is found to point out three more detailed capability areas.

(1) Design processes: One of the more broad and general NPD processes indicated important for ECM is the design processes, e.g. Eckert et al. (2009) reports based on a multiple case study that several companies see integrated system engineering process enabled by virtual engineering methods as vital approach to handle changes. Huang and Mak (1999) also include having a structured, transparent and concurrent approach at product development as one of 13 guidelines for efficient ECM. Design processes are strongly connected to the solution development, but suggested as a separate area to build capabilities within based on its more general nature and broader scope.

(2) Design For X (DFx) processes: Identifying infeasible or costly designs as soon as possible by drawing on knowledge from different domains in order to minimise redesign and reduce the overall cost of making the product is the core of DFx. This area, which in some firms is enacted by specific processes, is also important to build capabilities within for efficient ECM, e.g. Fricke et al.(2000) highlight the importance design for changeability, i.e. implementing changeability within the system architecture to make late changes cost-efficient.
(3) Quality processes & Requirement management: There seems to be general agreement within the ECM literature that avoiding changes is one of the key strategies for efficient ECM, mentioned by among others Fricke et al. (2000). As highlighted by Eckert et al. (2009) a central element in avoiding change is understanding the customer requirements, also termed “Voice Of the Customer (VOC)”, and managing these throughout the design process.

3.3.3 Information systems & IT tools

The importance of information systems and IT tools for efficient ECM is highlighted in nearly all the papers analysed and the necessity of building capabilities within this area is thus indisputable. (Wright, 1997) also argues in an early literature review on engineering change that computer tools and methods is one of two dominating perspectives within the literature on ECM.
(1) ECM system: In relation to information systems, one of the obvious areas to build capabilities within is the dedicated systems to manage change retrieval, storage and workflow, also called ECM systems which in some companies as reported by Pikosz and Malmqvist (1998) are legacy systems and in other companies integrated in the PDM and PLM systems.
(2) PDM/PLM systems: As highlighted in most of the literature analysed PDM and PLM systems besides the handling of changes also constitute important assets for efficient ECM as the documentation handling is pivotal for ECM. A wide range of PLM systems today enable a more integrated approach at documentation handling with embedded configuration systems that only further enhance the importance of this capability area.
(3) CAD, CAM, CAPP/MRP systems: In order to enable earlier design verification and integration of the various value chain stakeholders, organisations are moving towards virtual engineering (Eckert et al., 2009), a trend that enforces the need for solid visualization methods. Computer aided tools as e.g. CAD and CAM are also reported as one of the influential factors of ECM (Huang and Mak, 1999).

3.3.4 ECM Management, Visualisation & Communication

The importance of a more comprehensive management of engineering changes have increased in pace with the importance of effective and efficient introduction of new products and product variants. Based on the literature analysis management of ECM is found to encompass six capability areas; Communication, ECM strategy, performance-, resource-, knowledge- and visual management.
(1) Communication: As described by Pikosz and Malmqvist (1998) managing changes most often involves a wide range of functions creating a complex web of affected stakeholders. Managing changes not only causes a lot of communication within the company but also between companies, (Hölttä et al., 2010). Huang and Mak (1999) also present poor communication as one of two main challenges concerning change handling in the United Kingdom manufacturing industry.
(2) ECM Strategy: Based on a multiple case study of 13 companies Fricke et al. (2000) identify five strategies to cope with changes, e.g. ensuring that changes occurs as early in the design process as possible, also termed front loading, a frequent mentioned strategy to minimize the impact of engineering changes. With this study Fricke et al. (2000) highlight the importance of having direction and an intentional effort on ensuring an efficient ECM.
(3) Performance measurement & management: Brown and Boucher (2007) have clarified that one of the factors where at Best-in-Class companies differ from the average performing companies is the formal use of metrics to track effectiveness of the engineering change process. Pikosz and Malmqvist (1998) also describe having a clear time target for all team members involved in the EC process as a beneficial strategy for coping with engineering changes.
(4) Resource management: Several studies report that one of the major challenges for ECM is the general lack of focus and support given to ECM in the companies, ironically taking the importance into consideration, e.g Pikosz and Malmqvist (1998) document that the change handling is having a lower status than the creative “first time” design. Managing the resources available and by this

ensuring the necessary support of the ECM tasks thus become a highly important area to build capabilities within.

(5) Visual Management: Having the right information is critical in making better business decisions and ECM is thus highly dependent on communication. The study of Brown and Boucher (2007) reports that many firms use design visualisation, as information often is better communicated visually than verbally, similarly Hölttä et al. (2010) highlight the importance of simple visual communication of change process, status and -performance.

(6) Knowledge management: A much overlooked perspective of engineering changes is the potential value of the accumulation and capturing of engineering and product life cycle knowledge knowledge in the ECM system (Wasmer, Staub & Vroom, 2011). According to Kulkarni and Freeze (2004) the ability to capture and utilize this knowledge is related to one of four knowledge capability areas.

3.3.5 Organisational setup

The importance of having a change process and capabilities in relation to this is already discussed a highly important and dependent factor in relation to process is organisational setup or structure.

(1) Decision making structure/process: Decision-making is perhaps one of the most important areas to build capabilities within for efficient change handling. The study of Brown and Boucher(2007) concludes that successful change management has less to do with the efficiency of the operation than how effective the decision-making process is in the first place Fricke et al. (2000) even argue that change management is decision management.

(2) ECM roles & responsibilities: Roles and responsibilities is another emphasised area, e.g. Hölttä et al. (2010) identify this as one of the common challenges to ECM in a case study of four engineering companies. Several other studies also describe the impact of having ECM-specific roles, underlying the importance of building capabilities within this area.

3.3.6 People, skill & competencies

Having necessary roles and responsibilities defined is of no or limited worth if the right people-capabilities not are present. Two capability areas are identified based on the literature analysis.

(1) ECM Access, permissions and training: The importance of training is pointed out by among other Pikosz and Malmqvist (1998) who clarifies that the change process in one of the case companies studied is not well understood. In another case study Shankar, Morkos & Summers(2012) describe that all employees attend a two-week graded change handling training session so that only employees with satisfactory performance is given access to the ECM system to ensure the right skill level.

(2) Continuous Improvement & Learning: Preventing changes is a frequent mentioned strategy for efficient ECM, a central element in this is to learn from changes being handled. Understanding causes and effects of a change can be a valuable source to optimize the development processes and the product itself (Hölttä et al., 2010). Furthermore the ECM process can be improved by learning continuously from previously performed change processes.

3.3.7 Project Management

Engineering changes can assume a broad variety of size and complexity (Alblas and Wortmann, 2011), from minor changes in a single component enabling immediate implementation to large changes with propagation effects across the entire product involving a significant amount of resources for months or even years. Adding to this the volume of changes the need for project management capabilities for efficient ECM is indisputable.

(1) Portfolio management: An important means for improving throughput time on change handling is as argued by Alblas and Wortmann (2011) to ensure that the workload is prioritized so that “essential” changes can be distinguished from “desirable” changes. This can as noted by Loch and Terwiesch (1999) be ensured by including prioritization rules and principles for balancing workload in the change assessment. Similarly Pikosz and Malmqvist (1998) describe assigning priorities to ECO’s in order to enable a faster introduction of important changes. All of this considerations that are essential in product portfolio management (Killen, Hunt and Kleinschmidt 2008).

(2) Planning of change process: The importance prioritization and planning of engineering changes is often pointed out, e.g. Eckert, Clarkson & Zanker (2004) highlight establishing a implementation plan for larger changes, the Aberdeen study also report that 70% of “Best-in-Class” companies use a formal plan to determine the optimal way to implement change (Brown and Boucher, 2007).

(3) Team Working: Taking an integrated approach to the change handling is advocated by several authors, one of the key enablers for this is as underlined by Huang and Mak (1999) to strive for team consensus by developing trust among team-mates. Fricke et al. (2000) also highlight this by describing integrated product teams as prerequisites for reliable and sufficient communication.

1.3.8 Supply Chain Management

Product development including several supply chain members creates the need for managing cross-company engineering changes (Wasmer, Staub & Vroom, 2011) .

(1) Supply Chain Collaboration & Integration: Collaborative product development has increased in importance during recent years (Büyüközkan and Arsenyan, 2012), and so has the need for cross-company ECM as argued by Wasmer, Staub & Vrwasoom (2011) who find that improving ECM performance includes a joint ECM process and shared product data standards. The need for supply chain collaboration is also recognized by Alblas and Wortmann (2011) who highlight that ECM involves extensive communication among the supply chain parties involved.

3.4 Proposal of ECM Capability Framework

Based on the findings of the literature review and analysis described in above, the capability framework in Table 1 is proposed. The framework is in this context for the purpose of communication and overview depicted with details on the source of the framework, i.e. which authors supporting each of the capability areas.

Table 1. Overview of literature analysed & ECM Capability framework

		Aberdeen (2007)	Alblas and Wortmann (2011)	Eckert et al. (2004)	Eckert et al. (2009)	Friecke et. al. (2000)	Huang and Mak (1999)	Hölttä et al. (2010)	Jarratt and Eckert (2004)	Jarratt et al. (2010)	Pikosz and Malmqvist (1998)	Shankar et al. (2012)	Wasmer et.al. (2010)	# of issues related to capability area
Type of study														
	Case study (single, multiple, longitudinal)		x	x	x	x		x		x	x	x	x	
	Survey	x					x							
	Literature review								x					
Process area	**Capability areas**													
ECM process	Change evaluation and impact analysis	x	x	x		x	x		x	x	x		x	7
	Change follow up & Cost management		x			x	x		x	x			x	8
	Change identification, prediction & proposal	x	x		x		x	x	x	x		x		6
	Scaloring and tailoring of ECM-process			x						x		x		2
	Solution development & selection	x		x			x	x			x			1
	Process of controlling engineering changes	x	x		x		x	x	x		x		x	9
	Solution review			x			x					x		4
Engineering/ NPD process	Design processes	x			x		x	x		x			x	2
	Design For X (DFx) processes					x	x		x	x				1
	Quality processes & requirement management				x		x			x				2
IT tools	ECM system						x	x	x	x		x	x	25
	PDM & PLM systems	x			x		x	x	x	x	x		x	6
	CAD, CAM, CAPP/MRP		x		x		x		x				x	4
Management & communication	Communication						x	x		x	x		x	5
	ECM Strategy			x	x	x		x		x				9
	Performance measurement & management	x				x	x			x	x			5
	Resource management		x		x	x	x	x		x	x			2
	Visual Management	x			x			x		x	x			3
	Knowledge management							x					x	3
Organisational setup	Decision making structure & process	x		x			x			x	x		x	8
	ECM roles & responsibilities	x		x			x	x			x			7
People, skill & competencies	ECM Access, Permission & Training			x				x			x	x		15
	Continuous Improvement & Learning				x	x		x					x	1
Project Management	Portfolio management		x							x				2
	Planning of change process	x	x	x			x				x		x	8
	Team Working						x	x			x		x	4
SCM	Supply Chain Collaboration & Integration	x	x										x	2

4 CASE STUDY

Utilizing the ECM capability framework in Table 1, the case material, i.e. the consolidated list of issues in ECM, have been analysed according to the method outlined in section 2. In the analysis relevant capability areas have been identified for each of the 135 issues, by which the number of issues in the case study pointing at each of the capability areas has been clarified. Due to the complex nature of the issues, it have been allowed to map issues to more than one area and the total score of issues related to capability areas are based on this 151, which is higher that the number of issues identified.

The result of the mapping of issues to the capability areas is shown together with the capability framework in Table 1 by summing the number of issues mapped to each area. Based on the result shown in Table 1 it is noted that the capability areas in general is supported by the case material, some areas more than others. A significant number of issues have e.g. been reported on the ECM system. A possible explanatory factor for this distribution is that the majority of respondents are from dedicated ECM-functions having high interaction with the ECM system and that the case company utilizes a legacy ECM system with limited support due to an impending system change. As the purpose of this study have been to clarify areas important for ECM and not to document significance values for these areas impact on the ECM performance, this distribution of issues is not considered a problem.

In total 28 issues on ECM reported in the case study does not apply to the capability areas proposed based on the literature analysis, as these issues instead point at other areas as e.g. managing the interfaces, having clear and aligned ECM purpose and scope etc. An obvious area for further research is thus to analyse these issues so that additional capability areas can be proposed and a more comprehensive framework can be developed.

5 CONCLUSION

The purpose of this paper is to add to the existing theory on ECM by clarifying the areas that an organization needs to develop its capabilities within in order to ensure an efficient change handling. The existing literature point out areas companies can focus on to ensure an efficient ECM, no comprehensive guidance is however given on how to improve the ECM performance.

This paper contributes to existing theory with an ECM capability framework defining 27 capability areas within 8 overall areas all relating to the handling of changes. The capability framework is proposed based on a literature analysis of 12 selected papers all identified through literature search and brief review of 62 papers addressing either challenges with the handling of changes or solutions to a more efficient handling. The relevance of the ECM capability framework is tested by utilizing the framework to analyse a list of 135 issues concerning the handling of changes clarified by interviews and a survey in a larger Danish manufacturer. Based on the case analysis all of the capability areas in the framework have been found relevant, i.e. point out areas also identified as significant for the handling of changes in the case study.

The existing literature especially the Aberdeen study also clarifies capabilities for successful ECM within overall areas based on the practices in common for best in class companies (Brown and Boucher, 2007). This study contribute to existing theory in being broader in scope, and with a more comprehensive approach identifying the areas to build capabilities within, i.e. capability areas as e.g. process for solution development and selection.

This study enable areas for further research as validating the framework, clarifying specific capabilities within each of the capability areas, linking capabilities to performance levels and establishing maturity levels, i.e. major milestones, best practices and levers in the transformation to a more mature engineering change handling.

REFERENCES

Ahmed, S. & Kanike, Y. (2007) Engineering change during a product's lifecycle, *International Conference on Engineering Design, ICED*, pp. 28.

Alblas, A. & Wortmann, H. (2011) Managing large engineering changes: the case of a high-tech microlithography equipment manufacturer, *International Journal of Operations & Production Management*, vol. 32, no. 11, pp. 1-1.

Aurich, J. & Rößing, M. (2007) Engineering change impact analysis in production using VR, *Digital Enterprise Technology*, , pp. 75-82.

Bessant, J. & Francis, D. (1999) Developing strategic continuous improvement capability, *International Journal of Operations & Production Management*, vol. 19, no. 11, pp. 1106-1119.

Boehm, B. & Turner, R. (2005) Management challenges to implementing agile processes in traditional development organizations, *Software, IEEE*, vol. 22, no. 5, pp. 30-39.
Boer, H., Caffyn, S., Corso, M., Coughlan, P., Gieskes, J., Magnusson, M., Pavesi, S. & Ronchi, S. (2001) Knowledge and continuous innovation: the CIMA methodology, *International Journal of Operations & Production Management*, vol. 21, no. 4, pp. 490-504.
Brown, J. & Boucher, M. (2007) Engineering change management 2.0: Better business decisions from intelligent change management, *Aberdeen Group: A Harte-Hanks Company, Tech.Rep*, .
Büyüközkan, G. & Arsenyan, J. (2012) Collaborative product development: a literature overview, *Production Planning & Control*, vol. 23, no. 1, pp. 47-66.
Chrissis, M.B., Konrad, M. & Shrum, S. (2003) *CMMi*, Addison-Wesley.
Cross, N. (1989) *Engineering design methods: strategies for product design*, Wiley Chichester,, UK.
Dale, B. (1982) The management of engineering change procedure, *Engineering Management International*, vol. 1, no. 3, pp. 201-208.
Eckert, C., Clarkson, P.J. & Zanker, W. (2004) Change and customisation in complex engineering domains, *Research in Engineering Design*, vol. 15, no. 1, pp. 1-21.
Eckert, C., De Weck, O., Keller, R. & Clarkson, P. (2009) Engineering change: drivers, sources and approaches in industry, .
Fricke, E., Gebhard, B., Negele, H. & Igenbergs, E. (2000) Coping with changes: causes, findings, and strategies, *Systems Engineering*, vol. 3, no. 4, pp. 169-179.
Hölttä, V., Mahlamäki, K., Eisto, T. & Ström, M. (2010) Lean Information Management Model for Engineering Changes, .
Huang, G. & Mak, K. (1999) Current practices of engineering change management in UK manufacturing industries, *International Journal of Operations & Production Management*, vol. 19, no. 1, pp. 21-37.
Huang, G., Yee, W. & Mak, K. (2003) Current practice of engineering change management in Hong Kong manufacturing industries, *Journal of Materials Processing Technology*, vol. 139, no. 1,
Jarratt, T.A.W., Eckert, C., Caldwell, N.H.M. & Clarkson, P. (2011) Engineering change: an overview and perspective on the literature, *Research in Engineering Design*, vol. 22, no. 2, pp. 103-124.
Koh, E.C.Y., Caldwell, N.H.M. & Clarkson, P.J. (2012) A method to assess the effects of engineering change propagation, *Research in Engineering Design*, , pp. 1-23.
Kulkarni, U. & Freeze, R. (2004) Development and validation of a knowledge management capability assessment model, *Proceedings of the 25th International Conference on Information Systems*, pp. 657.
Loch, C.H. & Terwiesch, C. (1999) Accelerating the process of engineering change orders: capacity and congestion effects, *Journal of Product Innovation Management*, vol. 16, no. 2, pp. 145-159.
Nightingale, D.J. & Mize, J.H. (2002) Development of a lean enterprise transformation maturity model, *Information Knowledge Systems Management*, vol. 3, no. 1, pp. 15-30.
Otto, K.N. & Wood, K.L. (2000) *Product design*, Prentice hall Englewood Cliffs, NJ.
Pahl, G. & Beitz, W. (1988) *Engineering design: a systematic approach*, .
Paulk, M.C., Curtis, B., Chrissis, M.B. & Weber, C.V. (1993) Capability maturity model, version 1.1, *Software, IEEE*, vol. 10, no. 4, pp. 18-27.
Pikosz, P. & Malmqvist, J. (1998) A comparative study of engineering change management in three Swedish engineering companies, *Proceedings of Design Engineering Technical Conference, Atlanta*.
Shankar, P., Morkos, B. & Summers, J.D. (2012) Reasons for change propagation: a case study in an automotive OEM, *Research in Engineering Design*, , pp. 1-13.
Wasmer, A., Staub, G. & Vroom, R.W. (2011) An industry approach to shared, cross-organisational engineering change handling-The road towards standards for product data processing, *Computer-Aided Design*, vol. 43, no. 5, pp. 533-545.
Watts, F. (1984) Engineering changes: a case study, *Production and Inventory Management Journal*, vol. 25, no. Part 4, pp. 55-62.
Wright, I. (1997) A review of research into engineering change management: implications for product design, *Design Studies*, vol. 18, no. 1, pp. 33-42.