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Viewing the Engineering Change Process from a Lean Product Development and a Business Perspective

Eirin Lodgaard[1] **· Geir Ringen**[1] **·**
Catrine Eleonor Larsson[2]

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Abstract Engineering change (EC) has a major impact on companies' success regarding quality, productivity, time-to-market, customer value, and profitability. EC in product development (PD) is a complex process, involving many actors and functions, especially in the late stages of PD. This article builds on an in-depth single case study from a Norwegian automotive supplier. The study identified perceived enablers and disablers of the EC process, both internally initiated and customer driven, in relation to the front-loading concept as an approach to managing ECs. Based on this, we have outlined a framework with the aim to improve the odds of benefitting economically from customer-driven ECs. Different PD strategies are depicted to consider, depending on the current situation of both internal and customer-driven ECs and the degree of front-loading. An interesting finding from this study is that under certain conditions, for instance when a company faces relatively few internal ECs at the same time as customer-driven ECs increase, a more business-oriented strategy may benefit the company more than would a pure front-loading approach. One important industrial implication of this work is a description of different strategies to consider, depending on the current situation of both internal and external ECs and the degree of front-loading. In additional, the article will provide an important contribution to how companies can organize EC process better for future success. This should also be relevant for the academia.

Keywords Product development · Front-loading · Engineering changes · Enabler · Disabler

✉ Eirin Lodgaard
eirin.lodgaard@sintef.no

[1] Product and Production Development, SINTEF Raufoss Manufacturing, Enggata 40, 2830 Raufoss, Norway

[2] Faculty of Engineering Science and Technology, Norwegian University of Science and Technology, Teknologiveien 22, 2815 Gjøvik, Norway

Introduction

Success in the business of automotive supply depends on the ability to offer customers value in terms of quality, functionality, cost competitiveness, response time, and productivity—and to do all these things while remaining profitable. These capabilities are increasingly important, driving product development (PD) organizations to their effort limits. This article will focus on engineering changes (ECs) and the process of efficiently handling these ECs. ECs are particularly challenging when they occur in the late stages of PD, a point at which the costs of problem solving are considerable higher than in the concept phase (Ahmad et al. 2013). According to Clark and Fujimoto (1991), these changes have become a rule rather than an exception in PD projects. While some ECs are reported as non-value adding, and therefore should have been eliminated, others are regarded as necessary to achieve the required product and process characteristics. This view is supported by Kennedy et al. (2013) who claim that most internal ECs experienced in PD organizations are defined as waste, but seen them from another perspective, they should be viewed as opportunities for improvement. Front-loading of the PD process is reported as a valuable concept to reduce or eliminate costly ECs in the late phase, by shifting the intensity of problem solving from later to earlier phases of the PD process (Thomke and Fujimoto 2002; Kennedy et al. 2013; Halder et al. 2016).

The case for this EC process study is a Norwegian automotive supplier. The trend for the case company is a decreasing marginal contribution for the initial contractual agreement with the Original Equipment Manufacturer (OEM). Hence, the necessity of customer driven ECs after the design freeze is valuable, as it represents an opportunity to increase the marginal contribution (Fricke et al. 2000). How will this trend accord with the concept of front-loading? A literature review by Ahmad et al. (2011) reports that there is little published empirical work aiming to understand EC practises or issues. In addition, the existing literature shows a lack of research about how front loading influences the EC process (Hamraz et al. 2013). Consequently, the following research question is addressed:

How Does the Concept of Front-Loading Fit Strategically with the Engineering Change Process?

By ECs, we mean both internally identified needs to formally change the product or process- and customer-driven changes manifested as new requests from the customer. Fricke et al. (2000) reports the need of more research about understanding for EC process to be able to implement changes efficiently. The literature is sparse in describing the relationship between internal and external changes, and the subsequent enablers and disablers for efficiently executing these perceived loop-backs. Further investigation is needed to establish a holistic perspective about enablers and disablers within PD (Tortorella et al. 2015). This leads to the next research question as follows:

What Are the Perceived Enablers and Disablers for an Efficient Engineering Change Process?

The article is organized as follows: The next section describes the concept of engineering change management (ECM) and front-loading. Next, the case study and research methods are presented, followed by findings and discussions of the business potential of ECs. Finally, we will present a short summary of our findings and reflections.

Engineering Change Management

ECs are changes and modifications to the design of a product or component after the main design concept has been released by the customer. ECs can also lead to changes to the production process. ECs are more or less expected, due to the fact that product designs are often redesigns and modifications of pre-existing products. However, original designs also often result in ECs due to changes in market competition, technological advances, customer demands etc. that force companies to adapt to changes in order to stay competitive (Hamraz et al. 2013, Koh et al. 2015). Furthermore, the PD process is rarely linear in nature; a more iterative design process often results in several changes during the product's design and production phase. Since ECs are almost inevitable, they should not be underestimated, whether they are seen as extra work or as an opportunity for improvement.

ECs can be internal or external. Some ECs are desired and planned for; unwanted unplanned changes are those that cause high and unexpected costs and often necessitate additional changes. The most undesirable ECs are the internal unplanned changes with no profitability, as they result in financial loss. Shankar et al. (2012) present data indicating that no less than 77% of ECs are internal; this indicates that an awareness of the nature of internal ECs is important.

There are numerous of enablers that may influence successful PD projects (Tortorella et al. 2015). Enablers and disablers are elements or characteristics in an EC process that due to their existence or absence, act as catalysts causing development of an efficient EC process or on the contrary restrain or even cause limitation of achieving an efficient EC process within the organisation. Within existing literature identified enablers can be divided into following five main categories; management (Fricke et al. 2000), knowledge (Fricke et al. 2000), collaboration (Fricke et al. 2000, Ström et al. 2009), work flow (Hölttä et al. 2010), and tools and technology (Ström et al. 2009, Wright 1997). The first category, management, is reported by Fricke et al. as an important enabler for coping with ECs to improve cost, time and quality to market. In additional, a lot of changes can be prevented by being more disciplined in making decisions, but this depends on the quality of management. Secondly, creating and capturing of knowledge aiming to improve the product and to learn continuously from changes to do it better in the next project is reported as important (Fricke et al. 2000). Thirdly, an EC will result into a need of information transfer to be able to implement the change (Ström et al. 2009). Consequently, success with collaboration internal within the organization and with the customer is of significance to ensure the quality of information transfer and to make communication easier (Fricke et al. 2000). Fourthly, to ensure efficiently work flow, standardizing of the EC process is defined as important, where a strict process discipline is required to be able to run the ECs successfully (Hölttä et al. 2010). Finally, having a sufficiently overview of ongoing ECs, and dependency on other ECs, it is of pertinent value to apply tools and technology fitting the organisation (Ström et al. 2009). Ström et al. (2009) has proposed the use of a PLM system ensuring all involved actors a sufficient overview of current state of the design and progress of the EC activities. However, there is limited knowledge on how absence of these enablers may cause limitation on an effectively EC process. Hence, it is important to identify improvement points on how to change disablers into enablers to build capability for higher performance of the EC process.

Loch and Terwiesch (1999) show that the administrative process of ECs is congested and complicated and a cause of high lead-time. The high lead-time and the complex process of handling ECs indicate the importance of efficient EC processes for a profitable business. Shankar et al. (2012) classify the sources of emergent changes in automotive manufacture according to design, manufacturing, assembly, materials and purchase, supplier, marketing service, quality, and inventory. The propagation of ECs is here shown to be the main reason for increased complexity. The process of ECs quickly becomes complex due to the interdependencies between departments, teams, employees, products, and manufacturing equipment (Ström et al. 2009). Therefore, additional changes are often required subsequent to an initial EC, resulting in difficulty in keeping track of the actual process of an EC and exactly how much extra work is being generated by a single EC. Shankar et al. (2012) show in their field study that the propagation of changes is spurred by inventory and manufacturing issues and by design error rectification. These internal ECs result in high costs for the organisation.

Previous case studies on ECM suggest several solutions to the challenges of ECs, of which the most noteworthy is Lean Product Development (LPD) (Ström et al. 2009; Hölttä et al. 2010). Despite decades of research within the field of ECM, there are still many challenges and there is room for more research into strategic management of ECs in the manufacturing industry. Previous EC research has focused on seeing changes as a problem area and only a matter of concern (Wright 1997). Efforts to find a solution look to philosophies, models, tools, and techniques to eliminate variation and the most likely sources of change. However, if we could identify enablers of an efficient EC process and change the way we look at the problem so as to see opportunities, these shifts would improve our ability to develop effective strategies in ECM. Increased attention to different approaches to manage and assess change is needed if we are to be able to determine where a company is today and think strategically about where it should be in the future (Ahmad et al. 2013).

Terwiesch and Loch (1999) reviewed and classified the available research that identifies strategies organisations may adopt to reduce ECs, and in this respect, they present the "*Four principles of EC Management*": 1. Avoid unnecessary changes; 2. Reduce the negative impacts of an EC; 3. Detect ECs early; and 4. Speed up the EC process. Strategizing for ECs requires a holistic perspective on the organisation and careful alignment with the overall business strategy. A strategy for ECM takes into account all the aspects of EC order in order to find the most profitable strategy suited to the characteristics of the organisation.

Front-Loading

The concept of front-loading is often considered synonymous to what Kennedy et al. (2013) named Set-based Concurrent Engineering in studying the Toyota PD process. Viewing front-loading as a problem-solving strategy underlines the importance of shifting the intensity of problem solving from the later to the earlier phases of the PD process (Thomke and Fujimoto 2002; Kennedy et al. 2013; Halder et al. 2016). A typical and conventional approach to PD holds that designers should freeze specifications as early as possible and select a design concept—a procedure that often results in sub-optimization and numerous product and process iterations later on. According to LPD theories, reduced lead time and accelerated learning processes are enhanced by front-loading resources to explore many design alternatives (subsets), delaying freeze of design specs, systematically eliminating the "weakest" alternatives by trade-off curves, and integrating the knowledge value stream with the project value stream (Welo 2011). In Kennedy's (2013) terms, "*test-then-design instead of design then test*". From a learning perspective, front-loading is about identifying knowledge gaps, or project risks, while there is still time to reduce or eliminate these gaps. Humans generally prefer to begin with the known, since this approach gives the feeling of rapid progress, whether one is conscious or unconscious of the effects of delaying or neglecting problems that might occur in the future. Of course, PD is, as mentioned, by nature, an iterative process driven by trial and error. This statement can be argued to be true because we are not capable of knowing all the issues up front, not even on projects aiming at minor changes compared to prior products and/or processes. Hence, front-loading can enhance the understanding of underlying cause-and-effect factors at an earlier point in time. For instance, it is claimed that Toyota solves 80% of all type of problems prior to the first prototypes (Jensen et al. 2008).

This article aims to relate the concept of front-loading to companies' strategic approach to handling ECs. In theory, the relevance of front-loading to ECs is that improving company's ability to identify risks and knowledge gaps will result in fewer unforeseen change orders later in the PD process. On the other hand, ECs can be viewed as a business opportunity. The following strategic framework is based on the work of Garel and Midler (1998) who discussed the structure of contract and reward systems between suppliers and customers in the automotive industry. They define a contract regime to provide suppliers with a relatively large degree of freedom to change design and tooling concepts late in PD, thereby placing suppliers in a position to initiate a cost negotiation. These late and expensive changes generated an average of 20% revenue increase in the favour of suppliers. Giving OEMs the ability to penalize suppliers for late changes resulted in suppliers' becoming very active in exchanging information about problems and potential solutions early in the design phase to prevent penalties. The findings revealed that the revised type of contract was more cost effective for both parties (supplier and OEM). Under the standard contract, 49% of tooling costs were due to post-design freeze tooling changes, compared to only 15% under the revised contract, demonstrating that contract conditions may change the problem-solving pattern.

Front-loading of the PD is a known lean strategy that has been proposed to prevent the need for ECs in a late phase by eliminating ECs as a root cause in an early phase (Kennedy et al. 2013). Fricke et al. (2000) propose a front-loading approach to PD projects to reduce the need for both product design and production design changes. ECs late in the PD project can cause major cost overruns in addition to delays. But companies operating in low margin markets, with moderate or low hit rates on new projects, may be reluctant to force front-loading due to the investment nature of this PD approach.

Research Method

A case study is one of several ways of doing social science and understanding complex social phenomena, and is used in many situations to contribute to our knowledge of groups, organisations and related phenomena within a real life context (Yin 2009). As Harrison (2002) puts it, case study research is of particular value where the theory base is comparatively weak. Thus, a case study done properly could be said to add more than explanations and descriptions. The essence of a case study is the attempt to understand a decision or set of decisions: why they are taken, how they are implemented, and with what results (Yin 2009).

In order to outline a framework for viewing, the EC process in relation to the front-loading concept in an organisation in additional to explore the enablers and disablers related to the EC process, a quality case study approach was chosen. Findings in this study are based on an in-depth single case study. The research team has gained thorough understanding of their challenges and opportunities in PD projects by working closely with the case company for 6 years.

The case company is a medium sized subsidiary of a larger multinational company and develops and produces automotive-related components. The main business is to develop and produce in the light weight material segment. It maintains long term relationships with strategically important customers. Table 1 summarizes the company characteristics.

This company is engaged in the design, production, and marketing of products to customers worldwide. PD activities are closely related to product design and manufacturing design and extend from the concept and design phase to testing and finally the trial production phase. Our case company operates as a PD headquarters for the development of components in the light weight material segment in addition to the development of respective manufacturing tools for the company's manufacturing sites worldwide.

Prior to conducting the research, a research protocol describing research questions and data collection method was developed and discussed within the research team. To address construct validity, data were collected from multiple sources (Yin 2009). Consequently, data is based on semi-structured interviews, unstructured interviews, long-time observations, access to databases and documents, and several workshops with special focus on the EC process with key personnel at the case company.

Table 1 Main characteristics of the case company

	Case company
Main product	Light weight solutions for automotive industry
Revenues 2012	1.3 billion Norwegian kroner
Number of employees	502
Number of employees in Research &Development, project management, and product development	70
Main customers	Audi, General Motors, BMW, Mercedes-Benz, Volvo, Porsche, Jaguar Land Rover, Nissan, Renault
Relationship to the customer	Tier one supplier

Interviews are used “to explore the complexity and in-process nature of meanings and interpretations” (Liamputtong and Ezzy 2005). We chose to employ semi-structured interviews consisting of planned interactions between the researchers and the interviewees. The aim was to create an informal setting, more like a conversation, where the interviewee would open up and provide rich detail (Yin 2009). In total, seven people were interviewed, and each interview was tailored to the profession or role of the informant. All the interviews took place over a 2-year period, and they were recorded and transcribed. In additional, the research team has 6 years of experiences in four research projects all including field LPD with the case company. This has given us great amount of detailed document studies combined with of observations, informal interviews related to the EC process.

The collected data were analysed with the objective of identifying the current status of the EC process and create a further proposal to build capability for improved PD performance. The results from the semi-structured interviews and the workshops were analysed by defining a set of common features that become enablers and disablers for different types of strategies in conducting ECs. The next step was to identify improvement points for each category to convert disablers to enablers and to strengthen the existing enablers. This step is important with regard to prepare a company towards utilizing ECs as business strategy.

Since this research is based on a single case study, the findings should be regarded as indicative. The use of a single case gives a greater depth to the analysis, but the generalization of conclusions drawn from it is limited. Biases such as misjudging are disadvantages that may occur due to using a single case. However, a single case study can create an important contribution to knowledge and theory building (Yin 2009).

Findings

In order to handle the EC process, a formal workflow is described in the quality system of the company and categorised into the following: registration, evaluation, feedback, and implementation as shown in Fig. 1. An EC request is initiated either when a problem is detected in a certain internal process, or the customer requests a change on an agreed product design. When an EC request is made, included with the request are the reason, a description of the potential for change, and any communications with the parties involved. Thereby, a review of the change is made to decide either to accept or reject it. Changes that are approved and released use an EC order checklist to manage the implementing process. Normally, an EC meeting is arranged to confirm which tasks are necessary and define responsibilities and a schedule for implementation. The status of the ECs can be tracked in the document handling system designed for the PD projects.

The EC process for the case company consists of both internal changes and changes requested by customers and it is seen as a primary source of uncertainties in the PD projects. In our research, 16 randomly selected PD projects were analysed. All of the PD projects were completed and the products were fully implemented in the manufacturing process.

Table 2 shows the number of documented internal and customer-requested ECs in total for each PD project, including changes in product design and manufacturing

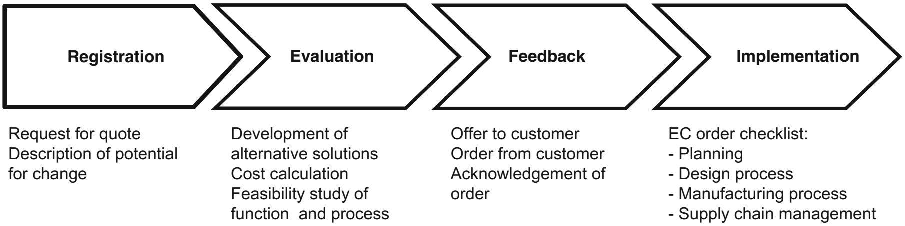

Fig. 1 EC process

design. The total number of registered ECs ranges from 1 to 157 per PD project. These numbers are based on the registered ECs in the company's formal documentation system. However, the listed numbers of ECs in Table 2 are primarily customer-requested changes and do not actually reflect the total number of ECs that occurred.

The reason for this is that the changes that were registered in the company's system consisted mainly of external changes, even though our interviews revealed that in actual practice, there were roughly as many internal changes as external ones. The quality control system of the company formally requires registration of all changes, yet in general, mainly customer-requested ECs are registered according to the prescribed procedures. There may be several reasons for this discrepancy; they will be discussed in the next section.

Typical customer required ECs for this company is about changes of the parts about fit, form, or function. One reason for some of the PD project containing great quantity of customer requested ECs is that they get the offer for development of a new product in an early development phase for the customer. In this phase, not all features and requirements is defined from the customer. Consequently, customer requests for new features for the product design during the project period, which normally were on a period of 2 years. Since the customer owns the specific production tools for the new design, a request for a new feature on the product will in additional create a change for

Table 2 Overview of number of ECs in a PD project

Product development project	Number of engineering changes
Project no 1	9
Project no 2	38
Project no 3	8
Project no 4	55
Project no 5	18
Project no 6	60
Project no 7	6
Project no 8	82
Project no 9	32
Project no 10	16
Project no 11	47
Project no 12	1
Project no 13	157
Project no 14	7
Project no 15	143
Project no 16	3
Average	43
Median	25

the production tools. One of the PD projects added 52 new features in the period between received offer and the start of serial production at the customer. Knowing that this also generates changes in production tools, this shows that number of ECs can be of great quantity.

The nature of the project will of course influence the number of ECs; factors include the number of components in total for the project, the number of departments involved, the redesign or new design of the product, etc. Here, we have listed the projects with no consideration to these reasons, simply to get an overview of the actual number of registered ECs. Almost all of the internal changes were unplanned and were seen as undesirable, since they usually generate considerable increased costs for the company. An internal change are changes that the customer has not asked for but a needed change due to internal circumstances. Therefore, one strategy for handling these changes is to combine the unplanned internal ECs with the customer-requested ECs, with the aim of avoiding increased costs for the company.

Different elements are factors that act as enablers and disablers of the EC process. In this study, enabler was classified as an existing factor influencing an efficient EC process and disabler as an existing factor influences in an inefficient EC process. Ideas generated in the workshop were coded and analysed to identify perceived enablers and disablers of an efficient EC process. The enablers and disablers were also reviewed in the light of the semi-structured interview conducted at the case company in additional to the long-term observations. Table 3 summarises the perceived enablers and disablers, categorised into five main categories as follows: management, collaboration, knowledge, work flow, and tools and technology. This is done to pinpoint the different areas in which improvement may be possible. Those categories are stated according to categories for enablers to achieve an efficient EC process described in the theoretical section for engineering change management.

Looking at things from a management perspective, the employees recognise kick-off meetings and team composition as clear enablers to the process, though they understand their own role as managers as important in facilitating this enabler. The lack of internal EC registrations is seen as challenging, pointing at unclear responsibilities in identifying, filing, and communicating ECs. Collaboration between employees and the cross-functional teams within the company, as well as close links to the customer, is seen as essential for being able to handle ECs. On the other hand, this leads to a rather complex process requiring increased coordination between involved personnel as ECs propagate.

The employees are highly skilled and experienced in doing PD projects, a factor which should be viewed as an enabler for an improving the EC process. This knowledge base can be characterized as tacit, as there is no formalised or systematic knowledge and experience-sharing from previous and similar projects. There are routines for EC registration, but the fact that routines are frequently not followed, in combination with the lack of interoperability among the available computer systems, complicates the learning process.

The case company produced at least as many internal ECs than external ones. Internal ECs are to a large extent driven by mismatches between design and what is possible to manufacture in existing and in-house equipment. The complexity of the processes involved and the lack of registration of internal changes create a sense that the process lacks management. To manage the ECs requires a holistic view of all the changes initiated. However, only customer-driven ECs are currently seen as business

Table 3 Perceived enablers and disablers in the EC process

Category	Enablers	Disablers
Management	Formal EC kick-off meeting team composition	Lack of parameters to prove benefit Lack of performance indicators Belief that it is not appropriate to measure their work Unclear when an EC is required Unclear who initiates an EC without a request from the customer (internal EC) Lack of focus on internal EC Lack of registration of internal EC Unclear responsibilities Too much turnover in PD team Insufficient engineering capacity Improper management of EC kick-off meetings Improper negotiation with the customer (external EC)
Collaboration	Customer awareness Tight links to the customer Cross-functional team Close co-operation between functions Open-minded staff	Starting before commitment from customer Many people involved—ties up people unnecessarily Waiting for other who need to perform activities before one can start on one's own activities Lack of feedback on progress Poor or missing information Poor or missing communication Not always the correct people involved Lack of involvement from manufacturing area Missing or improper feasibility study
Knowledge	Right skills High competence	Insufficient focus on post evaluation Lack of training in quality system Improper use of fact-based data Lack of shared knowledge
Work flow	Formal process description Template for EC order – checklist including what, who, when and status	Complex process Missing analysis of "current state" of the EC process Lack of documentation (e.g. FMEAs) Interruption of work Too many internally created ECs—"time thieves" Restrictions imposed by formal procedures Complex process to update BOM, DFMEA, design records, control plan, etc.
Tools and technology	Product Project Archive SAP, PLM application FEM analysis CAD	Lack of system to recalculate changes Lack of system/database to capture knowledge Several systems to document into No PLM system

opportunities, factors that contributes to the lack of a developed management system for internal ECs.

Having identified the perceived enablers influencing an efficient EC process and the perceived disabler influencing an inefficient EC process, the next step was to identify improvement point to manage building the capability of an efficient EC process. The improvement points were structured in the same categories as for the perceived enablers and disabler. The results of the improvement points for each category to convert existing disablers to enablers and to strengthen the existing enablers are summarised in Table 4.

Table 4 Improvements points to build capability for higher performance of the EC process

Categories	Improvements points
Management	Explain the need for improvement Build culture for continuous improvement Define and communicate common goals Use and display internal measures that everyone understands Clarify responsibilities Show engineers that they can benefit from improvement e.g. share savings made Balance workload Create multi-disciplinary team Use of visual tools such as team board
Collaboration	Improve communication in all direction Organize informal communication
Knowledge	Post evaluation Capture past experience and knowledge Utilise knowledge in collaborative environment Introduce rapid closed-loop feedback system (in which the issue-raiser, not the designer, signs it off as solved)
Work flow	Shift the intensity of problem solving from later to earlier phase Implement an early analysis, design, and test loop Get multi-disciplinary team to model the EC process as they actually work it and then identify how it could be improved Standardise
Tools and technology	PLM system Experience database to capture best practises Archive system for PD project

Taking all observations about perceived enablers and disablers, together with the summarised opportunities for improvement in Table 4, leads to consideration of strategic choices regarding ECs. To be able to choose a strategy the company needs to understand the EC process together with the perceived enablers and disablers associated with it. In the next section, we examine these ideas more closely.

Discussion

Why Internal Engineering Changes Are Neglected

The results indicate that identification and recording of internal ECs are two separate things. The interviews conducted made it clear that the case company has at least as many internal as customer-driven change orders. There are probably many reasons for the observed deviation between the real number of ECs and what is to be found in the registration system. In this case study, three main factors were observed:

First, any engineer knows that recording an EC in the system triggers many actions and dependencies across the organisation, and that this sequence in turn requires a coordination effort from the person who initiated the change (Fricke et al. 2000). It is often more comfortable to directly contact the person who is perceived as the problem solver for a particular problem, without initiating the official workflow prescribed in the system. Such behaviour can be linked to the increasing pressure to both reduce PD cycle time and do more with less resources (Crawford 1992). Under such conditions cutting corners, or avoiding a seemingly extra work load, is found to be a frequently-used approach.

Second, recording an internally detected EC is often tantamount to admitting that something is not going according to plan. The preferred action in case of deviance is to try to fix the problem without involving too many people, hoping to resolve it before anyone notices. This approach can be part of what Argyris and Schön (1978) referred to as defensive actions. Such actions are put in place to protect ourselves or our organisations from embarrassment or threat. The unintended consequence of these defensive routines is that they also prevent anyone from identifying the causes of the internal ECs.

Third, management focuses on solving customer driven ECs at the cost of internal ones. An advocated theory at all management levels in the case company is that the customers' word is law. There is nothing wrong with this statement, but building a customer-oriented culture over time will necessarily affect day to day operations and decisions (Senge 1990)—in this case, underestimating the potential in effectively solving internal ECs.

The three detected and summarised possible reasons why internal ECs are not handled as supposed to are related to time pressure, admitting that something is not going according to plan, and management focus. Referred to the research question addressing enablers and disablers for ECs, these identified, and natural, reasons are prerequisites for companies to act upon in order to view ECs as business opportunities.

Potential for Customer Driven Engineering Changes

Managers in the case company realize that initial contractual agreements with OEMs in the automotive industry give relatively marginal long-term benefits. This is due to over-capacity in the market, combined with an unfavourable cost level that results from producing in a high-cost country (Gottschalk and Kalmbach 2007). Thus, customer driven ECs are seen as an opportunity to increase price, and may be quantified in terms of unit price, investment in tooling, or a combination of the two. This is, of course, an opportunity in general, but it is explicitly stated as a future path for companies in high-cost locations.

There are also trends in the automotive industry challenging the supplier technology base. For instance, there is developed a common practice of two-step bidding rounds, in which OEMs dictate that revealed leading technology from round one is made available to all bidders for further price negotiations in round two. This approach forces awareness of ECs to a new level. Below, we discuss the validity of this strategic direction, and its further implications and requirements.

One implication of comments made by managers who expressed the importance of making profit from ECs may be that the organisation adapt to behaviours that lead to more EC orders than necessary. In this case, it can be concluded that the company is not in compliance with core lean principles. For instance, LPD theories claim that risk mitigation through extensive knowledge creation in the early stages of projects ensures fewer change orders, at least in the late project stages when the costs of changing critical design elements are exponentially higher than in the concept phase (Kolb 1984;

Hedberg and Wolff 2001; Haque and James-Moore 2004; Morgan and Liker 2006; Kennedy et al. 2008; Osono et al. 2008). However; which actions should the case company emphasize and/or undertake to accomplish a strategy that goes against the road map laid out by the LPD theory? Resident product engineers employed at the case company are placed at central OEM PD offices. This have for years been part of the company's strategy for early identification of customer needs and wants (Ringen 2010). Their participation gives them increased opportunity to play an early and decisive role in this particular "black-box" product segment, in which weight, functionality, and adaptability are constantly contested attributes. The input of the resident product engineers at central OEMs makes it possible to ensure that the minimal criteria is fulfilled—saving some potential for forthcoming ECs that may be negotiable with respect to price.

Another important consideration is how to build an organisation for this new kind of business model. The people who receive requests for customer-driven ECs are typically different from sales or key accounts. The task of dealing with changes is allotted to project managers, designers, tooling personnel, and so on. Therefore, an important prerequisite to profiting from ECs is determining to what degree the organisation is trained in, and acts in accordance with, business principles. Everyone involved must understand which costs are influenced, the exact amount incurred, and the tolerances accepted by customers; only then can the organisation be sure to calculate the real implications of change orders and in turn profit from them.

This calculation process is highly dependent upon many of the categories listed in Table 3 especially the collaboration category which highlights the fact that accuracy increases as a function of the number of actors involved. The latter holds if tools and technology are adapted to the real workflow (Morgan and Liker 2006). Many of the informants stressed the importance of a trusted system for recalculation of costs, redesign, product documentation and process documentation, parts distribution in the value chain, etc. as a key enabler for efficient and successful implementation of all types of ECs. For instance, does the company have to make sure that the entire pipeline of components, often involving many sites worldwide, is emptied before a redesigned product is fed into the global value chain? Such changes are most common in late stages – and any mistake can be severely costly (Dyer 1997). The last identified enabler is extensive knowledge and control of critical product and process characteristics, ensuring that requested customer change orders are rapidly and correctly evaluated. Arguing for an extensive change order business strategy is somehow controversial to acknowledge LPD theory. However, LPD enablers such as; structure for early identification of customer needs and wants, a business minded and involving organisation, and technology and systems supporting the workflow, and control of critical product and process limitations are basic principles that help in understanding baseline and which suit the subject of making product development processes more efficient.

The next step could be to ask which benefits a pro-EC strategy gives the supplier-customer relationship as well as benefits given the case company over its competitors. Typical benefits for the case company include long term relationships with strategically important customers. This continuity is of great importance to understand each other's needs and to reach a point at which a shared meaning between the parties is institutionalized (Hult et al. 2007). The same authors have defined a measurement scale for entrepreneurial orientation, which involves the way in which actions are initiated in one organisation to which other organisations respond. In this measurement, scale both positive and negative actions are allowed, where the latter describes how relations may be strengthened in solving crises and change orders. The ability to show vigour from the supplier side to handle problems and technological challenges is valued and can lead to even stronger ties between experts who work together to solve specific problems. Of course, if a crisis remains unsolved, it may threaten the critical path of the OEM's main project, in which case the OEM will naturally turn to other suppliers if possible. However, experience demonstrates that under certain conditions, numerous customer-driven ECs strengthen the ties between the parties. A well-functioning EC strategy may also link the internal core- and support processes better together. For a mass producer competing in a low margin segment, accuracy in knowing the products, processes, value chain, and cost elements are important. This level of accuracy requires trusted systems and a high degree of multi-competencies and teamwork. Firms closing in an operational level of zero defect manufacturing, where systematic errors are minor, will have a favourable baseline for applying a pro-EC strategy.

Different Strategic Choices

This article demonstrates that there are several strategic ways of handling ECs, but the identified enablers and disablers for each strategy are of different natures. Figure 2 outlines four different EC positions based on the number of both internal ECs and customer driven ECs, giving directions for how a company can benefit from, or navigate between, positions. Important measures as price, cost, quality, and time to market are linked to Fig. 2 by the following reasoning. The vertical axis represents business opportunities and the basis for price negotiation in supplier favour; given that added functionality and quality can be delivered according to original time schedule.

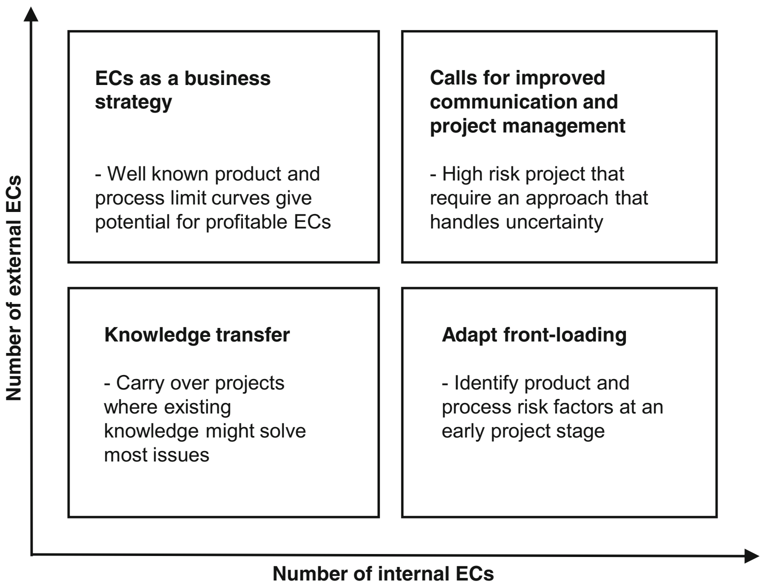

Fig. 2 Framework for viewing ECs as strategic positions at company level

The nature of business does not allow time delays. Moving towards the right axis, the cost function as the sum of quality and time interruptions has to be balanced according to risk. Thus, ECs coming from customers may add to the top-line, whereas internal changes for the most add cost and erodes the bottom line. Quality may be regarded as a constant in this equation, and for this particular industrial case. We claim that the more internal ECs a company identifies, the more focus should be directed towards up-front risk assessment. Companies that frequently experience the lower right hand position are likely to identify problems with product designs and manufacturing processes, which in turn cause several design iterations. A natural PD strategy for this position may be increased focus on front-loading and early risk mitigation. For the opposite position, the upper left corner, in which customer-driven ECs outnumber internal ones, it is possible to think of change orders as something that could be seen as opportunities to profit from customers' lack of knowledge when projects are initiated. Thus, one can transform ECs from something happening to product development to a higher level of business. To recall from the discussion above, that to fully realise the potential of this position, there must be a set of enablers in place.

The bottom left position reflects projects that proceed according to plan, an outcome which may be due to good project management and/or relatively low project risk; the latter often found in carry-over projects. For this position, we will emphasize the value of efficient reuse of previously discovered knowledge. If companies realize that their situation exemplifies the fourth position, the upper right corner, there is a multitude of possible actions to improve their current state. One could imagine that both internal and external communication processes cause misunderstandings and unnecessary cycles of activity. On the other hand, project risks may have been underestimated—for example, the company may have undertaken a project that should have been considered a research project. For all positions, it is important to note that the point in time when an EC occurs can influence further strategic choice. Hence, a third dimension representing time, from concept and design phase to testing and trial production phase, could either add complexity to a single position on the chart or in some cases significantly overlap two or more positions. The industry companies operate in is also of consideration, meaning that high degree of front-loading can be a costly strategy and therefore more suitable for high risk projects.

Conclusion

This article has focused on the EC process and enablers and disablers to the process, in relation to the front-loading concept as an approach to managing ECs. Results from the case company used in this study show that there are numerous ECs in the sample projects. Even though front-loading might be able to reduce or even eliminate ECs, we have raised the issue of the value of ECs for the case company and then pointed out that to make ECs desirable for a company, a strategy for ECM needs to be assessed. Managers tend to prioritize customer-driven ECs at the cost of internal ones due to the following motives: the potential to benefit economically from customer-requested ECs, the opportunity to demonstrate vigour and customer focus, and the importance of building a stronger relationship and shared meaning between two parties. However, we have outlined a set of principles that should be in place to improve the odds of benefitting economically from customer-driven ECs, given that added functionality and quality can be delivered according to original time schedule.

Awareness of how ECs are managed is essential to be able to benefit strategically from ECM (Fricke et al. 2000). We suggest a framework describing different PD strategies to consider, depending on the current situation of both internal and customer-driven ECs and the degree of front-loading. The main finding from this study is that under certain conditions, for instance when a company faces relatively few internal ECs at the same time as customer-driven ECs increase, a more business-oriented strategy may benefit the company more than would a pure front-loading approach. Using the case company as an example, we have shown that this company might not benefit from increasing front-loading but should rather focus on using ECM as a business strategy approach. Thus, ECs coming from customers may add to the top-line, whereas internal changes for the most add costs and erodes the bottom line.

To enhance the findings more research is needed. Further research will be undertaken to outline a detailed map of actors, information flow, decisions, and workflow related to ECs, giving us a more comprehensive picture of the complexity of competing product and process changes in global value chains. In addition, we see a potential to add quantitative data such as cost estimate for the existing model compared to the proposed model to verify the study.

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