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Towards a Universal Model of Engineering Change Management

Jakub Tryczak[1] · Anna Lis[2] · Paweł Ziemiański[2] · Jacek Czyżewicz[3]

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Abstract

The paper deals with the issue of engineering change management (ECM). ECM has received much less attention in the literature than general change management. Moreover, due to their specifics (complexity and multifaceted nature), hitherto developed ECM models are difficult to implement in companies. The paper aims to develop a simplified, universal, and hence easily applicable model of ECM. We based our assumptions on a case study of a manufacturing company with low-volume production, representing a high-mix type, posing the following research question: how to improve the ECM process to make it simpler and more quickly adaptable in companies with the analyzed type of production when compared to the existing models? To answer this question, an exploratory qualitative study was conducted in late 2021/early 2022 using in-depth personal interviews. The research sample included 31 employees involved in ECM processes. Conventional qualitative content analysis was the primary technique for analyzing and interpreting the data. The study identified gaps and bottlenecks in the existing ECM model. On this basis, a proposal for a new ECM model was developed, distinguished by its simplicity and versatility (it can be implemented in companies operating in various industries). Particular emphasis was placed on ensuring the flow of information and circulation of technical documentation between the departments involved and clarifying the role of the change administrator. The paper sheds new light on how to implement engineering changes in organizations and has considerable application value.

Keywords Engineering change management · ECM · Engineering change model · Manufacturing · Industry

Introduction

Change management and engineering change management (ECM) processes have become increasingly important in manufacturing companies. While the change management process is well grounded in the literature, the engineering change management

Extended author information available on the last page of the article

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process needs more focus because of its relative newness. As the available databases (Web of Science, Scopus, ProQuest) show, between 2019 and 2022, over 700 publications concerning change management were released each year. Most of them covered topics of organizational and social changes (Todnem, 2005; Galli, 2018; Hughes, 2007). The engineering change management process has received considerably less attention. As will be shown in the literature review, several researches describe ECM models in manufacturing companies. More so, each describes a different type of production and covers different aspects of management — either managing stakeholders or fulfilling a market gap (Masmoudi et al., 2017), which limits their universality. Moreover, previous publications on ECM describe it as an overly complicated process involving a significant number of people (Maceika & Toločka, 2021; Sjögren et al., 2019; Reddi & Moon, 2011; Pikosz & Malmqvist, 1998; Tavčar & Duhovnik, 2005). The complexity of this process is likely to be too high for the actual company's needs. In many cases, a triumph of form over content takes place as a proposed process requires connecting many departments and stakeholders with their particular interests and creates overly complicated dependencies and linkages. It is possible to simplify this process and make it easier to implement. Preparing an audit that allows to clarify the actual process is a necessary starting point. Devoid of its complexity, the process can allow process owners to avoid mistakes and misunderstandings.

The present paper intends to fill a gap in the literature. In the present article, we aim to show that the ECM process can be simple and universal, which, in manufacturing companies, requires establishing the role of an engineering change administrator (Mo & Caporaso, 2021). The sources of the engineering change management process should be distinguished depending on the location of the change — it might concern a new product or changes introduced in an existing one. The present article focuses on the latter — modifying an existing product. In our paper, we refer to the results of an exploratory study aimed at answering the following research question: How to improve the ECM process to make it simpler and quickly adaptable in manufacturing companies with low-volume and high-mix type of production? We based our assumptions on a case study of a manufacturing company with low-volume and high-mix type of production. Our intention is to create a universal ECM model, especially for enterprises with the type of production described.

The article is divided into five parts. The first part includes the literature review on the topics of change management and engineering change management. The second includes the research methodology employed in the conducted study, and it is followed by the description of the research results presented in the third part. In the fourth part, the authors discuss and propose a universal and simplified model of planned engineering change. Finally, the fifth part includes discussion, practical implications, further directions of research development, research limitations, and conclusions.

Literature Review

In order to identify scientific papers closely related to the research topic and identify the most important findings in the analyzed area, we conducted a traditional literature review. In doing so, we relied on Web of Science, Scopus, and ProQuest databases, performing searches by query: (engineering change OR engineering change management OR technical change) AND (change management OR change management process). Searches were further narrowed to publicly available articles, published in English and related to the discipline of management.

As determined by the literature review, change management is a process of continuously renewing a direction and structure and adjusting for internal and external clients (Moran & Brightman, 2001; Yin et al., 2022). Todnem (2005) asserted that in the change management literature, there was a general consensus regarding two aspects. Firstly, in the current business environment, the magnitude and pace of changes are greater than before (Burnes, 2004; Carnall, 2003; Kotter, 1996; Luecke, 2003; Schuh et al., 2017). Secondly, change can be triggered by external or internal factors and can take a different form in different organizations or industries (Burnes, 2004; Carnall, 2003; Kotter, 1996; Luecke, 2003). The purpose of this process is a transformation from the actual state to the target state. On this path, a few steps should be considered, which are covered in change management models.

Among the most popular change management models are Kurt Lewin's change management model, Kotter's 8-step change management model, ADKAR change management model, and the McKinsey 7-S change management model. Lewin's model (1951) proposed only three main phases of change management: unfreezing, transition, and refreezing. Kotter's model includes the sense of urgency creation, core coalition creation, strategic vision development, vision plan sharing, employee empowering, short-term wins gathering, gains and producing changes consolidation, and changes initiation. It is important to emphasize that the model proposed by Kotter (1996) was the first one that depicted change as a circular rather than a linear process. The name of the next model, ADKAR, is the acronym for Awareness, Desire, Knowledge, Ability, and Reinforcement, which are the phases of the change management process that describe the appropriate approach and reacting to employees' needs. The McKinsey 7-S model describes a group of interrelated factors influencing the company's ability to introduce changes: strategy, structure, systems, skills, staff, style, and shared values (Singh, 2013).

Engineering changes are changes or/and modifications in fits, functions, materials, dimensions, etc., of a product and its components introduced after it is released (Huang et al., 2003; Sonzini et al., 2015). The process of introducing planned engineering changes has its purpose in production standardization, product quality improvement, or modification of one of the components (Tavčar & Duhovnik, 2005). Furthermore, the process of engineering change management supports production management departments in ensuring a fluent flow of documentation (Knaus, 2022). The main purpose of this process is to clarify communication between departments and efficiently prepare change of documentation by establishing communication channels and providing an appropriate information-gathering system (Tavčar & Duhovnik, 2005). While ECM may not be equally important for all types of organizations, it is crucial for manufacturing companies (Tavčar & Duhovnik, 2005). To gain as much market share as possible, they prepare many types and modifications of their products that require appropriate technical documentation.

ECM is a particular type of change management. Its primary purpose is the management of technical documentation and information flow in technical departments related to the production department and product manufacturing. Engineering changes are intended to correct engineering failures, exploit new market opportunities, reduce production costs, or increase advantage over competitors (Reddi & Moon, 2011). Balakrishnan and Chakravarty (1996) suggest that the positive and negative effects of engineering changes should be analyzed. The former category includes the effects of changes related to the company's position on the market as they allow increasing advantage over competitors. However, certain consequences of engineering changes for the manufacturing company can be negative as they are connected with increased costs and additional workload.

Several systematic literature reviews on ECM have been conducted. They were performed by the following authors: Wright (1997), Jarratt et al. (2011), Hamraz et al. (2013), and Ullah et al. (2016). Wright (1997) prepared an analysis of specific engineering change topics covered in publications between 1980 and 1995. He noticed two main perspectives in analyzing the ECM process: engineering change tools and engineering change methods. Further considerations allowed him to divide those perspectives into subareas. The perspective pertaining to tools was divided into the subareas of data storage (covered in four publications) and design aids (covered in four publications), whereas the perspective pertaining to methods was divided into five subareas: elements of control (covered in eight publications), the effect on customer (covered in two publications), implications for a new product (covered in one publication), single company case studies (covered in three publications), and case studies covering two companies (included in four publications) (Hamraz et al., 2013).

In their analysis, Jarratt et al. (2011) identified five topics. They include a generic outlining of the process, its context and other related activities (the first topic), the nature of the change process, and challenges that arise from change propagation (the second topic). The third describes tools for designers in ECM. The fourth topic includes product-focused aspects, whereas the last describes the connection between the product or process and selecting the appropriate strategies and methods.

Hamraz et al. (2013) divided the research about ECM into four main groups, each consisting of additional subgroups. The first group concerns the pre-change stage and includes people-oriented, process-oriented, and product-oriented aspects, documents, and considerations. The second group is focused on the stage of introducing the actual change and concerns organizational issues, strategic guidelines, ECM systems and processes, methods, and IT tools. The third group describes research that analyses the engineering change impact: delays, cost, quality, pre-manufacturing stage, manufacturing, post-manufacturing stage, and general effects. Finally, the last group involves general studies. In their considerations, Ullah et al. (2016) organized publications on ECM differently, according to the adopted definition of EC, product architecture, change propagation, engineering change process, and tools that support engineers in the ECM process. Furthermore, several different types of engineering changes and their causes can be found in the literature, including customer specification changes, misunderstanding between customer specification and technical requirements, production problems, problems that are a result of prototyping, quality issues, and development for future use (Pikosz & Malmqvist, 1998; Maceika & Toločka, 2021).

ECM process does not only apply to the existing product. It also concerns new product development (Balakrishnan & Suresh, 2019). In this case, engineering change orders (ECO) can generate considerable costs (Clark & Fujimoto, 1991) and have the characteristics of a "snowball effect" (Terwiesch & Loch, 1999). Costs are generated because of multiple iterations, a growing number of stakeholders, and different expectations toward the new product. An additional aspect of the ECM process is the accompanying rush, which can result in wrong decisions (Dostaler, 2010). Dostaler (2010) identified several factors limiting the number of ECOs, such as an additional person from the manufacturing department in a design team, good communication, and project leadership (Wheelwright & Clark, 1992). The process of ECM is vital because it influences the lead time and production costs related to manufacturing new products (Reddi & Moon, 2011). When a few companies from the same group work on the same product, the quantity of their customer–supplier relations increases significantly. In that case, the ECM process is essential for effective cooperation. It structures communication and introduces standards pertaining to collaboration with different stakeholders (Reddi & Moon, 2011). ECM is crucial when the number of collaborators increases, particularly in the case of platform-based development. It is vital due to requirements related to managing changes in elements and standardizing engineering systems used for data sharing (Bergsjö et al., 2015).

There are many situations when a company has to implement changes immediately to maintain an advantage over market competition. However, it is important that each change is thoroughly analyzed to avoid additional problems with implementation (Balakrishnan & Chakravarty, 1996). Changes that have to be implemented ad hoc are called emergent changes in the literature. Emergent changes can be described as a reaction to risk realization (Sjögren et al., 2019). This type of change is often related to the so-called firefighting (Eckert et al., 2017) or troubleshooting (Pinto & Covin, 1989) and creating teams that need to perform such actions. Those teams are groups of specialists detached from their daily activities to solve problems that can be very costly to a company (Sjögren et al., 2018). Other difficulties arise, such as management-related issues, including, for example, the necessity to find the right person and detach that person from the current activities. Additionally, this person may not have sufficient time to delve into the topic because the problems need to be resolved immediately (Hällgren & Wilson, 2008).

Similarly to other manufacturing and business processes, ECM should be standardized to ensure its effectiveness. Such standardization can involve, for example, the following aspects: tracking the impact of changes in the product and its elements, identification of people that have to be informed, determining the sequence of informing participants and stakeholders of the process, or means of tracking the necessary approvals of persons involved in the process (Bueno & Borsato, 2014).

ECM models of different complexity levels are one of the most popular thematic lines in the ECM literature. For example, Sjögren et al. (2019) described the model of ECM in the case of an emergent change. The authors covered the organizational level of each person and the connections between people involved in the change process. Another model, based on the publication by Jarratt et al. (2011), is the most popular model covered in the literature (Grieco et al., 2017; Hamraz et al., 2013;

Ullah et al., 2016). This model was proposed by Reddi and Moon (2011), and it divides the main process into four stages: propose, approve, plan and implement, and document. Each of those elements concerns steps that have to be implemented to achieve the aim of the process. Maceika and Toločka (2021) have proposed a model that is based on market and business analysis. A high complexity level characterizes this model as it includes multiple iteration loops. It focuses on market attractiveness rather than the technical aspects of documentation migration and communication.

The model proposed by Clarkson et al. (2004) is a valid example illustrating the complexity of the previous ECM models. It involves design structure matrices (DSM) (Sharp et al., 2021) and consists of three parts: input, execution, and output methods. In the first part, the requirements for new and existing products are defined. With reference to these elements, the execution methods are selected. Each of the execution methods involves the designer's knowledge and change prediction methods (CPM) algorithm. The input process for each CPM has its own schemes that involve possible interactions and each of them can lead to redesigning the process. A product risk matrix and case risk plot are generated as outputs. In this way, the results of performed analyzes easily move the product back where additional examinations are executed and their results, in turn, can involve the necessity to perform the next actions. In fact, all mentioned models are characterized by a high degree of complexity. It is not our intention to underrate their value and we recognize their importance. We want to, however, propose a simpler model, which is also potentially useful and universal.

Material and Methods

In order to answer the research question posed, we conducted an exploratory qualitative study, which fits into the interpretative-symbolic paradigm (Sułkowski, 2012). The study was aimed at identifying gaps and bottlenecks in ECM. The sampling was purposive and based on typical cases. For the study, a manufacturing company with an established type of production (low-volume and high-mix) was selected, which additionally has been implementing a change management process (by making organizational and process changes, preparing documentation, etc.). The selected company is located in Poland, operates in the automotive industry, has been in operation for over three decades, and has approximately 800 employees, 95% of whom work in departments directly related to production.

The study was conducted between December 2021 and April 2022 and included a total of 31 employees working at the selected company. As we intended to capture the perspectives of different stakeholder groups, the research sample consisted of people working in various positions, including 2 specialists, 19 heads of divisions, 8 heads of departments, and 2 project managers. The common denominator of respondents was their direct or indirect involvement in ECM. All positions covered in the study were related to the implementation of the ECM process through participation in the introduction of changes, creation and flow of technical documentation, product development, etc.

Both the analyzed organization and informants stated clearly the necessity to report the data anonymously and to ensure confidentiality regarding the organization and the informants involved. Adhering to these requirements was necessary for establishing conditions under which the researchers could obtain reliable data and describe the findings. The scope of the information about the company and informants provided in the article stems from these requirements (i.e., identifying departments by providing their function rather than an actual name in the organization, limiting details provided about informants and not revealing their individual characteristics).

The study was based on in-depth, semi-structured personal interviews based on four thematic areas: (1) knowledge about ECM, (2) previous experience with ECM, (3) extent of participation in the implementation of the ECM process at the analyzed company, and (4) organizational problems and factors inhibiting the implementation of ECM at the analyzed company. Interviews lasted an average of 105 min, with respondents' rights to confidentiality and anonymity. The primary technique for analyzing and interpreting the data was the conventional qualitative content analysis (Hsieh & Shannon, 2005) and a coding procedure. The interviews were coded separately, and the collected empirical material was analyzed and interpreted gradually based on the method of continuous comparison. The threads emerging from the interviews were continuously compared with each other, which allowed for defining the main codes (and categories), such as defined roles (change administrator, change owner, process owner, etc.), bottlenecks (in terms of cooperation of collaboration, in information flow, etc.), unification and repetition (means of communication, documents accompanying the process, groups of recipients, etc.), and optimization (duration, responses, costs, etc.). In order to help other researchers fully understand the problem under study, in the following section, we have used defined codes and categories in described the insights from actual practice.

In the final step, there was an integration of the results obtained from both the literature review (general assumptions about the creation and development of ECM models, such as departments involved in the process, control points, or responsibilities) as well as empirical research (i.e., the necessity for developing the precise definition of roles, the search for bottlenecks, and the implementation of suggestions from respondents involved in the ECM process). In a narrower aspect, this became the basis for proposing changes to the analyzed ECM model, while in a broader aspect, it contributed to the formulation of more general assumptions for building ECM models.

Results

Actual ECM Process Description

The research conducted allowed for the mapping of the current process of implementing engineering changes along with the documentation path and the links between departments in the analyzed company. The process can be evoked by external or internal triggers. External factors influencing the initiation of the engineering change management process involve placing an order from the end recipient of the product. Input to the process affects individual departments within the company and necessitates the creation of a separate process connecting many departments, in which feedback and communication between individual stakeholders play a particularly important role. Internal factors include the desire to optimize production and reduce production times, the desire to introduce an innovative solution to the market, etc.

The process that currently takes place in the company is presented in Fig. 1. The first identified type of engineering change is a purchasing change (presented on the left in Fig. 1). Employing this type of change, the department responsible for dealing with suppliers and external transportation (sourcing department; Sourc. Dept.) contributes to the process. It can involve, as an input, a change of an element resulting from changing a supplier or modification of a norm requiring elements with strictly specified parameters. A representative of the sourcing department contacts a head or a leader of the design department (Des. Dept.) with a request for indicating a new element that will exchange the previous one. After delivering the described element, an engineer from the design department orders the verification of the selected element in a department responsible for testing new solutions (research and development department; R&D Dept.). After the tests, engineers from the design department and the research and development department validate the test results. If the result is negative and the element does not meet the defined requirements, they indicate the next element that will be tested, whereas in the case of a positive result, they pass the information to the sourcing department and to departments responsible for the production and directly supporting the production process. These departments are combined in a "PRODUCTION" block in Fig. 1. They include a department responsible for the assignment of production nests for products (production technology department; Tech. Dept.), a department responsible for the product configuration (configuration department; Conf. Dept.), a department responsible for gathering the necessary materials and queuing orders in the production plan (planning department; Plan. Dept.), the warehouse (D7), a department responsible for quality maintenance and management in the factory (quality assurance department; QA Dept.), and the production department (Prod. Dept.).

The second and third types of engineering changes are production and quality change. They are presented in the middle of Fig. 1 and can be considered jointly. Even though the process input differs in their case, the rest of the process remains the same. The production department is the input of the production change process, and the quality assurance department plays this role in the case of quality change. The quality assurance department informs a department responsible for resolving current problems in production (production process department; Proc. Dept.), while the production department informs configuration department. Each of the informed departments (production process department, configuration department) informs the design department about the need for change. After the design department develops the change, it releases it to PRODUCTION, with the production technology department as the first recipient. After the required documentation leaves the production technology department, it is passed on to the planning department, and after processing in the planning department, documentation is delivered to the production

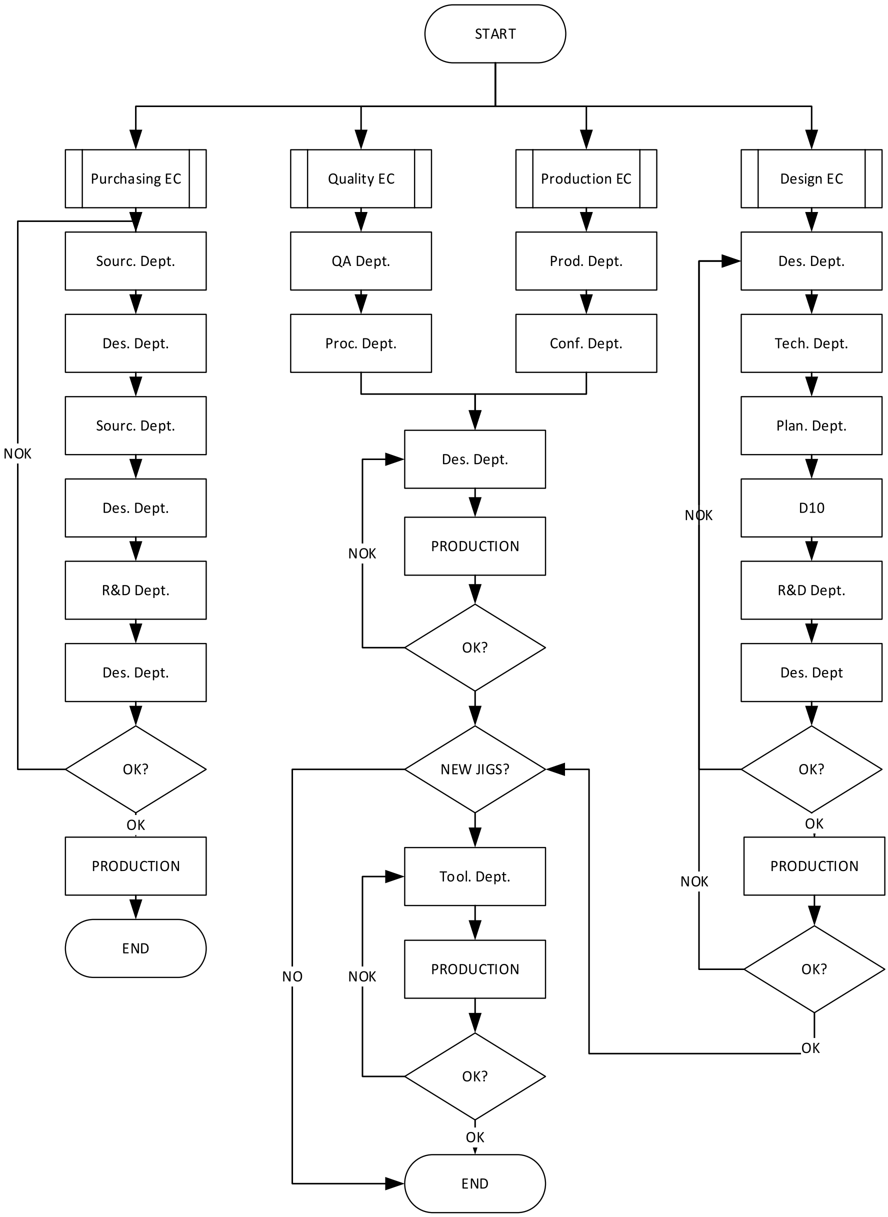

Fig. 1 The actual ECM process. Source: Own elaboration

department. The information about the material is passed on to the warehouse, which supplies production nests. After the production department finishes its work related to manufacturing, the quality assurance department performs another control to verify dimensions in accordance with the control plan.

Validation of conducted change is made by the production department, as it is the primary recipient of any change in this regard. Before the process ends, it involves one more department responsible for the automatization of the manufacturing process (tooling department; Tool. Dept.). The tooling department decides whether it is possible to produce a new part using current tools or if it is required to prepare a new tool. In the latter case, the described path that takes place within the PRODUCTION bloc needs to be followed. The production department conducts the final validation because this department will use the designed tools.

The last type of engineering change is a design change. This type of change results from the design department's own initiative to introduce modifications or improve selected elements. It is presented on the right in Fig. 1. After the design department prepares a change proposal, technical documentation is passed on to the production technology department, planning department, and production department. After an element is produced, the research and development department tests it. The design department performs the validation of this process because only specialists from this department know which effect is exactly expected. If the element does not meet requirements, it is retracted to the design stage. In the case of an accurately made element, the configuration department is informed about the need for tests in natural conditions, and the PRODUCTION prepares a low series of new elements. The final step in this process is to decide whether the new version of the product can be installed using the previously utilized tools. The process ends with the final control of the quality assurance department.

The study has revealed significant problems with implementing the ECM process and suggestions for its improvement. The biggest problems were related to communication between the various departments involved in implementing the ECM process, particularly those that contact each other directly. Inadequate flow of information between departments was considered by respondents to be one of the more serious problems in the process, as evidenced by numerous statements regarding this aspect, such as "Communication is the weakest part of this organization. There is a problem with communication both within and between departments," "design department, production process department, production department never inform other departments about changes that are made in the product," or "There is no communication between departments […] If design department asked us (production department) they would know how to make it right the first time." The communication problem stems primarily from the volume of work identified in each department. This is because many departments are involved in preparing product modifications without designating a person responsible for communication and information flow, which causes chaos and misinformation that negatively affects progress in implementing changes. According to respondents, the process should be redesigned to be iterative and more transparent and allow full participation of the various departments (with some departments being expected to participate in the process from the beginning and some only being recipients of information). This is confirmed by sample statements from respondents, for example: "More people should be involved in the change implementation process. People should have the possibility to discuss change, because they can have different points of view, which should be revealed. In my previous job, a designated set of documentation that was delivered to different departments with a description of changes was useful"; "Change must be transparent and clearly prepared. In our company, the process map should be developed from the beginning. And it should be updated according to ISO standards."

The second significant problem is the lack of adequately prepared people to implement the ECM process. This is especially concerning the position of a change manager — a role predisposed to lead the company's change management process and be the process owner. However, the problem is much broader, for it relates to the lack of the required technical preparation of those directly involved in implementing the process. The problems mentioned earlier resonate in numerous statements by respondents, such as: "The most needed person right now is a product manager. It should be the person responsible for the product, deciding about its shape"; "People from sourcing department do not have non-technical knowledge and the will to acquire it." According to respondents, the most needed people in the company are project, product, and change managers. These people should have a broader scope of influence, which thus entails more responsibility for a product or a part of the process.

Respondents also emphasized other concerns related to including changes in the process, their grouping by similarity, and establishing the appropriate KPIs for the process. Changes in the ECM process should not be related to production errors or material availability problems. Grouping similar change requests and collecting all types of changes in one common database allows for a holistic view of all problems and the simultaneity of actions. Regarding KPIs, in addition to basic indicators such as money saved and change implementation time, it is worth considering additional indicators relating to the number of change requests closed at the same time, frequency of occurrence of the same type of change requests, and number of change request according to the elements that are adjacent to the implemented change. All KPIs have on purpose optimization of the ECM process. Time of duration or time needed for the response from particular participants of the process may negatively affect the process, which may be reflected in the costs of implementing change.

Based on the conducted research, a proposal for a universal ECM process model was prepared. In this model, the names of the departments have been changed to the names of the roles that a person or a group of people will play in the process (Fig. 2).

The process starts with an engineering change request (ECR). A change request is described in a form that includes such information as the date of setting up ECR; its setter — this person becomes a change owner (CO); a description of ECR; pictures; recommendations; and priority indicated using a 1–5 scale, where 1 — it can wait, and 5 — it is a safety issue (and hence is given the highest priority). This document has to be entered into a database, where ECRs with lower priority (1–3) are stored in case of the emergence of ECRs with the same subject but a higher priority, and those of higher priorities (4–5) are analyzed as quickly as it is possible.

The next step is a validation of ECR. Its purpose is to verify if a given ECR should, in fact, be considered an element of the engineering change process. A change administrator (CA) verifies if ECR is complete. If it is incomplete or requires clarification, CA can move ECR back to a CO. The role of CA is also to check in the database if a similar ECR already exists. This can lead to closing several ECRs

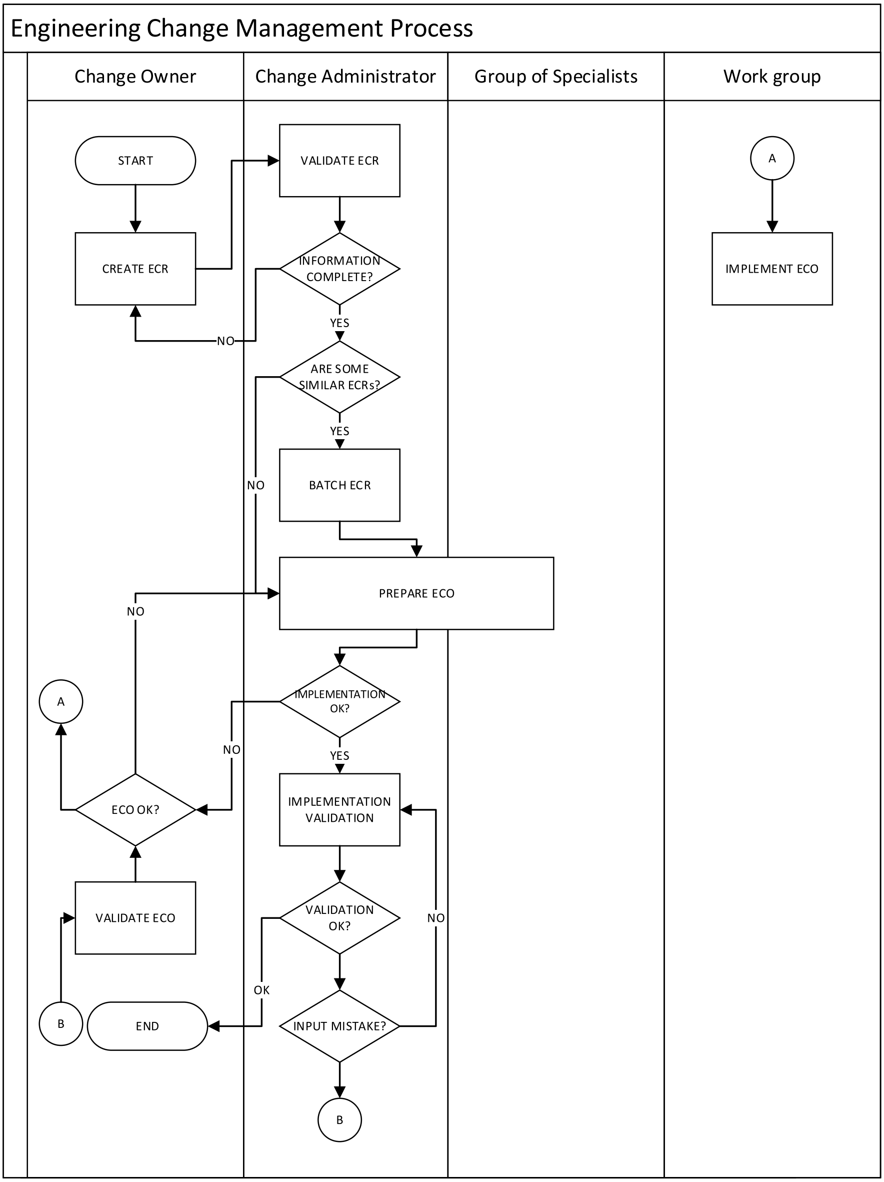

Fig. 2 The proposed model of engineering change management process. Source: own elaboration

at the same time. ECR, or group of ECRs, approved by CA as complete become an engineering change order (ECO). ECO is included in a form that describes ECR together with comments and recommendations of a group of specialists (GoS) from different departments that have contact with clients and know the product. CO is not a part of GoS. A quick response time between those groups of process stakeholders may positively influence the process's overall shape and costs because additional changes wouldn't be registered.

A prepared document is sent to CO, who approves the proposed solution and confirms if ECR was correctly understood. In case of doubt, ECR goes back to CA and GoS, who prepare changes of ECR and later is sent once again to CO for approval. After ECR is prepared correctly, an appropriate document is sent to a workgroup (WG). WG has the possibility to check if the proposed solution is fully suitable for the product or might result in problems and complications. In this case, WG can submit corrections and move ECR back to the preparation phase. If the required information is described and prepared correctly, WG fulfills its objectives, which are to design, compile, produce, and test the solution that was proposed in ECR. At the end of the process, a committee that includes CO, CA, and GoS validates the result of the ECR. The committee's goal is to identify the reasons behind not meeting any of the intended results. If it pertains to product quality, the process is moved back to ECO implementation phase. If the problem stems from wrong assumptions, it is moved back to ECO validation performed by CO. If the intended results are met, CA closes ECO (Fig. 2).

The described process proposal is universal and fits three of the four defined types of engineering changes that occur in manufacturing companies: quality engineering change, purchasing engineering change, and design engineering change. It solves the problem of the lack of information in some departments because departments related to the process are involved in it. It also minimizes the risk of miscommunication or even the lack of communication between the involved departments because all people who should be informed are involved in meetings where the shape of changes is developed. This process also presents how vital the role of the change administrator is — this person needs to control the whole process and know the company structure and dependencies between departments.

Discussion

The originality of the model rests on the fact that it was prepared based on a stakeholder analysis and highlights the primary role of a change engineer in the process. The existing models, although they deal with the entire process and mention its actors, do not sufficiently address the aspect of the crucial importance of these people. It is worth mentioning that, likewise, the aspect of communication requires careful attention in the ECM process. Communication was considered insufficient in the case of the studied company and is also likely to be noticed in all companies facing the challenges related to ECM.

The proposed model was created at the optimum level of detail in order, on the one hand, not to introduce excessive details due to the specifics of the analyzed company (which would nullify the intention of generalizing the results) and, on the other hand, to provide a clear enough description so that the described changes can be applied in other companies. Having this intention in mind, it is important to address the issue of the transferability of the model more thoroughly. We believe that several aspects should be considered universal: the role and functions of different stakeholders and the general process flow. Its details, however, may vary across organizations based on their specificity and it might be required to adjust particular steps. We propose that the model should be particularly useful for production companies in which the company's size influences and requires the division of responsibilities, which do not manufacture large quantities of standardized products (i.e., are not mass production companies), whose production process is not based on an assembly line, and where there is high product variability and the volume of changes is significant.

It is also important to identify several limitations to the study. The first was the small research sample, for the model was developed based on the experience of a single company, which narrows the research perspective. The second, related limitation pertains to the specificity of the organization's culture which may influence how the ECM process is implemented. Therefore, in order to verify the assumptions made in the ECM model, it should be further validated based on the cases of different companies. It is important to validate the model in manufacturing companies with different models of production: mass, single piece, or low volume. Automation of the process and development of the tool that can be supportive in engineering change management process are the future direction of the model development. Creating a common model for planned and emergent change is another possible avenue for further advancement of the presented proposition.

Conclusions

Our paper contributes to the existing state of the art in engineering change management by proposing a new ECM model that stands out for its simplicity, which is rare in previously developed ECM models, and its versatility, as it can be implemented in companies operating in different industries. The proposed model can be treated as a unification of engineering change management models that are described in the literature. Another advantage of the created model is that it ensures information flow and technical documentation circulation between the departments involved. A model based on documents typical of process ECM, such as ECR and ECO, was proposed. These documents are flexible and can be adapted to the needs of a company that will implement them. The practical implication of this research is the possibility of implementing the planned engineering change management process model in companies with a similar type of production in the proposed way. This model is suitable for companies with a relatively large number of ECOs, and it can be implemented in organizations with various types of final products — mechanic, electric, etc. The model clearly emphasizes the role of the change administrator.

Declarations

Competing Interests The authors declare no competing interests.

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Authors and Affiliations

Jakub Tryczak[1] · **Anna Lis**[2] · **Paweł Ziemiański**[2] · **Jacek Czyżewicz**[3]

✉ Jakub Tryczak
jakub.tryczak@gdansk.merito.pl

Anna Lis
anna.lis@zie.pg.gda.pl

Paweł Ziemiański
pawel.ziemianski@pg.edu.pl

Jacek Czyżewicz
jacek.czyzewicz@pg.edu.pl

[1] WSB Merito University in Gdańsk, Gdansk, Poland

[2] Faculty of Management and Economics, Gdańsk University of Technology, Gdansk, Poland

[3] Faculty of Mechanical Engineering and Ship Technology, Gdańsk University of Technology, Gdansk, Poland