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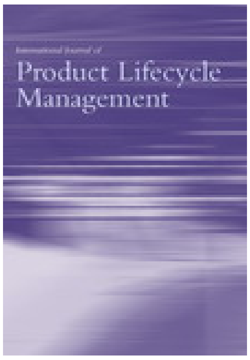

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Engineering change management: comparing theory to a case study from aerospace

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Abstract: Engineering change (EC) is omnipresent in product development and, hence, in the aerospace industry. Engineering change management (ECM) is therefore needed. Various research studies have proposed different ECM processes to manage ECs. However, there may be differences between the ECM processes described in theory (scientific literature) and those used in practice (real world). This article intends to explore the similarities and differences between the ECM processes in theory and in practice. This article investigates and analyses one case study in an aerospace company. The authors analysed the ECM terminology, the flow of data and documents, activities, and functionalities of the IT tools in the aforementioned case study. The results of the case study were then compared with the ECM process from theory through ECM stages and activities. This comparison between theory and practice enhances the implementation of ECM in practice and deepens the understanding of ECM in the literature.

Keywords: product lifecycle management; PLM; engineering change management; ECM; engineering change; EC; design change; comparison.

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1 Introduction

In the era of Industry 4.0, complex product design and manufacturing calls for the cooperation of large networks of specialists (Immonen and Saaksvuori, 2013). Such situations involving complex products force companies to specialise (Terzi et al., 2010). Product lifecycle management (PLM) has been defined to enable the integrated management of all product information and processes throughout the entire lifecycle (conception and design, production, distribution, maintenance, and retirement) (Terzi et al., 2010).

Changes are common and inevitable in complex regulated businesses like aero-space industry. Changes need to be managed, especially through the lifecycle of the product definition from the original design in engineering to manufacturing, and aftermarket. However, it is important to distinguish between the general concept of change and engineering change (EC) (Jarratt et al., 2011, 2005).

The ECs are inevitable according to the competitive environment of manufacturing and can influence the quality and cost of the products (Huang et al., 2003). Furthermore, EC is a mandatory requirement in the regulated aerospace industry for tracking both major and minor design changes. Implementing manufacturing changes aims to streamline production processes, reduce costs, and enhance overall quality. Various definitions have been proposed for EC (Jarratt et al., 2011, 2005; Huang et al., 2003; Hamraz, 2013; Rouibah and Caskey, 2003; Kocar and Akgunduz, 2010; Wright, 1997; Huang and Mak, 1998; Shivankar et al., 2015; Department of Defence, 2020; ISO 10303-242:2022, 2022; ISO 10303-239:2012, 2012). For instance, ECs are considered as the 'changes/modifications to released structure (fit, forms and dimensions, surfaces, materials, etc.), behaviour (stability, strength, corrosion, etc.), function (speed, performance, efficiency, etc.), or the relations between functions and behaviour (design principles), or behaviour and structure (physical laws) of a technical artefact' (Huang et al., 2003).

One of the proposed definition of EC is from Jarratt et al. (2011, 2005).

- 'An EC is an alteration made to parts, drawing or soft-ware that have already been released during the product design process. The change can be of any size or any type; the change can involve any number of people and take any length of time.' (Jarratt et al., 2011, 2005).

ECs are playing a critical role in the product development process (Rouibah and Caskey, 2003). For instance, the research of Quintana et al. (2012) identify that Bombardier Aerospace company dealt with 13,967 ECs in 2001.

It is important to note that although there are some similarities between managing EC in other industries, such as the construction industry (Pourzarei et al., 2022), and EC in the aerospace industry, there are also significant differences. The focus of this article is to explore the management of EC within the context of the aerospace industry.

It should be noted that managing ECs effectively is a costly and time-consuming process in most industries (Huang et al., 2003). In addition, engineering change management (ECM) is considered an important practice. According to Hamraz (2013) 'ECM can be summarised according to its goals to

1 avoid or reduce the number of engineering change requests (ECRs) before they occur

2 detect them early when they occur

3 address them effectively

4 implement them efficiently

5 learn continuously for the future.

ECM process, in simple terms, is an engineering process to identify, track, and manage the ECs. Various engineering management processes have been proposed for managing ECs (Jarratt et al., 2011; Kocar and Akgunduz, 2010; Shivankar et al., 2015; Pourzarei et al., 2022; Dale, 1982; Maurino, 1993; Rivière et al., 2003; Lee et al., 2006; Tavcar and Duhovnik, 2006; Wu et al., 2014; Ouertani et al., 2004; Guess, 2002).

Several recent articles address the challenges and propose solutions to enhance the ECM process. Pan and Stark (2022) emphasise the difficulty in identifying change impacts and introduce a machine learning-based decision support system to predict and ex-plain EC requests using local interpretable model-agnostic explanations, significantly improving efficiency and transparency. Eltaief et al. (2022) focus on change propagation and present a matrix-based risk assessment approach, emphasising the importance of impact assessment for quantitative and qualitative change characterisation. Meißner et al.

(2021) introduce model-based systems engineering to enable rapid ECM by linking system parameters and domain-specific models, offering the potential for semi-automation. Arica et al. (2020) provide a taxonomy for ECM tailored to engineer-to-order (ETO) firms, aiding in mapping current practices and enhancing ECM efficiency. Yin et al. (2022) propose an evaluation model for change propagation, integrating logical relations between components to optimise design change solutions, particularly in complex systems. Altner et al. (2022) offer an ECM process for wiring harness development in the automotive industry, consisting of eight defined steps and trigger classifications, improving transparency and coordination among stakeholders. Collectively, these articles underscore the significance of ECM in managing product development and propose various innovative approaches to address its challenges. They also signal the need for further research and investigations to refine and expand these methodologies to meet the evolving demands of complex ECM processes.

The ECM process includes various elements such as terminology that include different terms and concepts, different methods and IT tools, different activities, and the involvement of various departments. In addition, different documents are used in the ECM process. According to Huang et al. (2003), these documents could be classified into three categories based on their special function related to ECM: the first category includes the documents that are used to signal the need for an EC in the initial stage. The second one includes the documents that are used to evaluate the impacts and effects of an EC, and lastly, the third one includes the documents that are used to notify others of an approved EC. It is important to mention that the aforementioned descriptions of the ECM process are quite different in various industries as well as there are also some differences between ECM description in theory (scientific literature) and ECM description in practice (real world). By theory we a referring to what is described in the scientific literature, and by practice we are referring to what happens in the real world.

Although the current ECM process description, in theory, presents valuable viewpoints, there appears to be a lack of comparative analysis between ECM in theory and in practice. Conducting such an analysis could yield a more comprehensive understanding of the ECM process, potentially uncovering best practices related to its characteristics and functionalities, ultimately leading to its improvement. To put it differently, this comparison can potentially uncover whether the theory presented aligns with practical implementation.

In this article, we will be addressing the following research question: to what extent do theoretical description of ECM process and tools align with their practical implementation in an aerospace product design organisation? We investigate these similarities and differences by exploring, documenting, and analysing a case study that presents the ECM process from an aerospace company. Then, we compare the ECM description in practice with the ECM description from theory. This comparison will be presented through the comparison of the ECM processes and activities. The objectives of this article are:

1. Explore, document, and compare the ECM process and activities used in practice in an aerospace company.
2. Compare the ECM process and activities used in practice in an aerospace company with those found in theory so as to identify similarities and differences.

This article is broken down into six sections. Section 2 presents the research methodology. Section 3 reviews the results of the case study. The comparison of ECM processes (both theory and practice) is presented in Section 4. Section 5 discusses the results. Section 6 presents the conclusion and future work.

2 Research methodology

This article intends to compare the ECM description between theory and a case study from aerospace. The theoretical description of the ECM process are analysed and evaluated by the previous research study (Pourzarei et al., 2022). There-fore, this article is using the theoretical part from the aforementioned research.

At the beginning, we must identify a company as an industrial partner to provide us with the case study. This led this research to the aerospace industry, which is an industry that has been using PLM for decades, having a well-implemented ECM pro-cess, and also manages many ECs per year. An aircraft engine manufacturer was selected to be our industrial partner and provide us with the case study.

However, there were various restrictions in front of this research project such as the COVID-19 pandemic as well as confidentiality issues. The whole collaboration between the authors and the research teams at the company was conducted through online meetings. In total, we had five meetings with our industrial partner and the average length of each meeting was about one hour and thirty minutes. These meetings included interviewing the experts for both documenting and validating the extracted ECM process.

This article introduces a methodology that consists of the following steps: document analysis and interviewing the experts, business process mapping, analysis and comparison of the results. These steps are briefly explained hereafter.

At first, we reviewed various industrial standards and documents that are used by the industrial partner. '*Structuring principles and reference designation: part2: classification of objects and codes for classes* (IEC 81346-1)' (IEC 81346-2:2009(en), 2022) and '*General requirements of Digital Mock-Up for mechanical product* (ISO 17599 (DMU))' (ISO 17599:2015(en), 2015) are two examples of these standards. Then, various meetings were conducted with the company's experts for extracting the information as well as the validation.

Then, the ECM process is described by using business process model and notation (BPMN). This BPMN process has the following elements:

1 The activities involved.

2 The flow and types of documents used.

3 The tools used.

4 The roles and names of the involved departments.

The BPMN model then was presented to our industrial partner for validation purposes.

Next, the authors created a 'metamodel' based on the extracted ECM process. This metamodel helped to organise the information and be able to compare the processes. The proposed metamodel helped this article to organise the ECM description elements into the following four categories:

1 The stages and activities of the ECM process.

2 The tools and their functionalities.

3 The terminology used.

Finally, the information from the metamodel is compared with the findings of the theoretical studies conducted in previous research (Pourzarei et al., 2022) based on the aforementioned categories (stages of ECM process and activities) to identify the similarities and differences.

The following section presents the case study.

3 The case study

A case study in the aerospace industry is presented in this section. A short description of the industrial partner is presented at first and then followed by describing the terminology, IT tools, as well as the activities of the ECM process.

3.1 The industrial partner

The aerospace is one of the most common industries that record many ECs. For instance, Bombardier Aerospace recorded 13,967 EC in 2001 (Quintana et al., 2012). This is why the authors decided to choose an aerospace company as an industrial partner. However, because of confidentiality issues of the aerospace industry, access to the information is usually limited.

Our industrial partner is an aircraft engine manufacturer. It designs, develops, manufactures and service aircraft engines. The ECM process in the examined case study involved different departments in the company such as the configuration management (CM), design office, etc. Indeed, it is important to emphasise the ECM has a central role in our industrial partner's business and has continuously evolved over time.

3.2 Terminology

Interestingly, the extracted terminology from our industrial partner is quite same as the terminology in theory, with slight differences. The following table is presenting the terminology.

Not surprisingly, our industrial partner is utilising common ECM terminologies such as EC, ECR, and engineering change order (ECO). On the other hand, the company adopts some other terms based on their needs. For instance, the design intent document (DID), a document that en-compasses the design intent, and daily issue list used in the company address the characteristics of engineering change proposal (ECP) (Department of Defence, 2020) and engineering change notice (ECN) (ISO 10303-239:2012, 2012) respectively. It is important to note that some of the terms (e.g., DID, IPT, etc.) are described as defined by our industrial partner.

Besides the change board team who approves the change in the ECM process, there is an integrated product team (IPT), in the analysed case study, that is built to analyse the requested change, propose a solution as well as analyse it. In other words, within this study, the IPT consists of professionals whose goal is to examine the requested change and propose a solution. Conversely, the change board team serves as the responsible group tasked with assessing the proposed solution and granting approval for its implementation in response to the requested change.

The IPT includes various professionals such as engineers and designers that are selected by the design manager. It is important to note that the membership of the IPT team can be varied based on the needs of the requested change.

Table 1 Terminology used in the case study

Term used	*Description*
Engineering change (EC)	‘An engineering change is an alteration made to parts, drawing or software that have already been released during the product design process. The change can be of any size or type; the change can involve any number of people and take any length of time’ (Jarratt et al., 2011)
Engineering change request (ECR)	‘A form available to any employee used to describe a pro-posed change or problem which may exist in a given product’ (Jarratt et al., 2005)
Design intent	A Design Intent is defined as ‘the functional requirements provided by customers; that is, a set of geometric and functional rules which the final product have to satisfy. The design intent is represented by parameters, constraints, features and design history’ (Mun et al., 2003)
Engineering change order (ECO)	‘A document which describes an approved engineering change to a product and is the authority or directive to implement the change into the product and its documentation’ (Jarratt et al., 2011)
Daily issue list	The daily issue list provides easy access to publish engineering changes
Integrated product team (IPT)	‘The integrated product team (IPT) is composed of representatives from all appropriate functional disciplines working together with a Team Leader to build successful and balanced programs, identify and resolve issues, and make sound and timely recommendations to facilitate decision-making’ (Meister, 1996)
Timestamp	‘The timestamp authenticates the time when the data is generated by certain technical means, so as to verify whether the data has been tampered with after it is generated’ (Wu et al., 2023)
Classified ECO	The classified ECO signifies distinct statuses of the ECO re-port, visually represented by different colours, indicating the presence of any restrictions on the ECO
Engineering approval form	A documentation form designed to obtain customer approval for an engineering change

The company is also using two interesting terms: timestamp and classified ECO. The timestamp serves as a project milestone, indicating the creation of a new draft of the ECO. In essence, each time a new draft of the ECO is generated, a corresponding timestamp is created to mark the event. On the other hand, the classified ECO presents the status of the ECO report. This is a flagging system that shows if there are any restrictions on the ECO. For instance, when there is a restriction (such as there is a need for customer approval), the ECO colour would be different from when there is not any.

3.3 IT tools

IT tools play an important role in the ECM process, as they offer essential functionalities to support the process. For instance, these functionalities could facilitate document sharing, communication, version management, etc. This section is presenting the functionalities of the used IT tools by the industrial partner. Table 2 illustrates these IT tools as well as their functionalities.

Table 2 The IT tools used in the case study and their functionalities

Tool used	Functionalities
PLM platform (version 2014)	A collaborative platform for:
	Sharing data and information (e.g., ECO reports)
	Mark-up drawings
	BOM modifications
	3D function
	Version management (Version control)
	Lifecycle management
	Collaborating and integrating with other applications (e.g., in-house applications)
In-house applications	Record the post-related changes as a repository
	Prepare and issue the change orders, releases, design evaluation changes, obsoletion documents
	Manage and release the revisions
	Provide central item control for all product definition data and all engineering business systems
	Task tracker
MS suites tools (e.g., Excel)	Used to transfer the data and information between the PLM platform and in-house applications
Adobe acrobat	Adobe applications mainly are used to extract the final version of the documents (e.g., ECO report)
Internal search platform	Used as a search engine and to connect the user to the internal databases
Documentum	Used to getting e-signatures

As mentioned before, according to the confidentiality for this research project with our industrial partner, it is not possible to reveal more features of these applications, precisely in-house applications.

The company is using a PLM platform version 2014 and moving shortly to PLM platform version 2021. This PLM platform is offering various functionalities as a collaborative platform such as sharing data and documents, version management, lifecycle management, etc.

The in-house applications are created/developed in the company based on their needs. These in-house applications offer various functionalities such as managing the information system (e.g., record and control the information) as well as tracking the tasks. For example, internal search platform is an internal search engine that is developed by the company. The main difference between internal search platform and search in the PLM platform is that the search in internal search platform is giving more filtered results rather than all the results.

In addition, the company is running the hybrid environment by using the PLM platform and in-house applications. For instance, the PLM platform kept the ECO authorisation as well as the latest version of BOM. While modifications of BOM (add AND cancel) are generated in in-house applications. This hybrid environment could increase the productivity of the ECM process in the company.

The company is also using the basic daily used applications such as MS Suite tools (e.g., Excel) and adobe acrobat reader. The MS Suite tools, Excel, play an interesting role between the PLM platform and in-house applications. It is used as a tool to transfer/convert the data and information between them. In addition, the adobe acrobat reader is used to extract the final version of the documents.

Finally, our industrial partner utilises some technical and commercial tools that can be integrated into the hybrid environment. For instance, using Documentum for getting e-signatures. They began to use it after they moved to paperless activities in 2016. It is important to note that there is no option in their PLM platform (the version that the company is using) to sign the documents electronically. In addition, this application was the only application authorised by Designated Airworthiness Authority (DAA), so, this is the reason why the company is using it.

3.4 Stages of an ECM process

This section presents the ECM process in the examined case study. The extracted ECM process is classified into five stages (Pourzarei et al., 2022). Precisely, in each stage, there are various activities that are presented in this section. The afore-mentioned five stages are:

1 Request or initiation (ECR) – involves raising the need for an EC.

2 Instruction or proposal (ECP) – includes impact analysis and preparation of the solution.

3 Execution or document issuing (ECO) – involves preparing documents for the chosen solution.

4 Notification or application (ECN) – entails preparing the ECN for implementing the chosen solution.

5 Review and analyse – includes reviewing the implemented solution and identifying lessons learned.

The following sections illustrate each stage of the extracted ECM process that includes the main activities involved in the process, terminology, and IT tools that have been used specifically in each stage.

3.4.1 Request or initiation (engineering change request)

The main objective of this stage is to raise the ECR. The characteristics of this stage are presented in Table 3.

Raising the ECR is the first step to beginning the ECM process. There are a few activities in this stage of the ECM. Identifying the EC and submitting a fulfilled ECR form are the most common activities at this stage. It is important to mention that assigning the budget is done at this stage of the ECM process. Indeed, the ECM process will not be processed unless there is an assigned budget. The budget, as conceptualised here, is intended to cover the expenses associated with compensating the staff actively involved in the process.

Table 3 The characteristics of the first stage of the ECM process–request or initiation (ECR)

	Description
Activities	Identify engineering change (EC)
	Fulfill the engineering change request (ECR) form
	Assign the budget to the ECR
Terminology	Engineering change
	Engineering change request (ECR)
IT tools	PLM platform

Table 4 The characteristics of the second stage of the ECM process–instruction or proposal (ECP)

Description
Activities
Receive/review the ECR
Create an integrated product team (IPT)
Evaluate ECR
Propose solutions (BOM and markup drawings)
Evaluate the solutions
Choose a solution
Finalise evaluation of the selected solution
Create design intent document (DID)
Sign DID
Release DID
Terminology
Engineering change request (ECR)
Integrated product team (IPT)
Bill of material (BOM)
Design intent document (DID)
IT tools
PLM platform
In-house applications
MS suite tools
Internal search platform
Adobe acrobat

In addition, it should be noted that our industrial partner has started the paperless process since 2016, which is why the whole ECM process (e.g., requesting/submitting ECR) is going through different applications. At this stage, the main application is the PLM platform.

3.4.2 Instruction or proposal (engineering change proposal)

After raising the ECR, it is time to evaluate the requested change as well as pro-pose solutions. In this stage, the team of professionals evaluate the change, propose solutions and then choose one solution for the requested change. Table 4 presents the characteristics of this stage.

This stage of the ECM process begins when the design manager receives the ECR. Then, the design manager builds an IPT based on the needs of the requested change. The IPT team evaluates the requested change and then prepares a list of solutions, including BOMs and mark-up drawings, to address the ECR. The evaluation of the solution will go through three evaluations.

First, the proposed solutions will be evaluated by the IPT team. One of these solutions will be considered as the best candidate to satisfy the ECR. Secondly, the IPT team decides whether to choose a solution or not. This evaluation aims to assure that the chosen solution is capable to address the ECR. If the solution will not be selected, it will go back to the previous step, where the IPT team needs to propose alternative solutions. If one solution (including BOM and mark-up drawings) will be selected, it will go to the next step. In the third evaluation, the IPT team and design manager finalise the chosen solution and then the IPD team creates the DID. The DID will be signed and confirmed by the design manager and will be released to the next stage of the ECM process.

All revised documents (e.g., BOMs and mark-up drawings) are updated and accessible in the PLM platform. In addition, the hybrid environment is giving various facilities to the participants in the ECM process such as using internal search platform or in-house applications (record and controlling information).

3.4.3 Execution or document issuing (engineering change order)

This stage of the ECM process will be followed by evaluating the DID by the configuration management and creating the ECO. It is worth noting that the CM holds a significant responsibility in the aerospace industry during the ECM process, as most activities at this stage fall under their control. Table 5 shows the characteristics of this stage of ECM.

This stage of the ECM process can be considered as the core stage of the ECM process of this case study because of its importance to the ECM process. At the beginning of this stage, the CM creates the ECO report based on the requirements of DID. It is important to note that every time the CM creates a new draft of the ECO report, there will be a Timestamp in the ECM process. Then, the ECO report will be sent to the designated groups for evaluation. Designated groups are the relevant groups that evaluate the ECO, more precisely evaluating the requested change, proposed solution, etc. Drafting, customer support, and legal departments are some examples of the designated groups. If designated groups will accept the ECO, they might add some complementary documents to the ECO report and send them to the CM. But if designated groups identify some conflict(s), they will have a meeting with the program manager and DAA to solve the conflict(s).

Table 5 The characteristics of the third stage of the ECM process–execution or document issuing (ECO)

Description
Activities
Create the ECO report based on the DID
Review the ECO report by designated groups
Verify if substantiation has been completed and data is available
Verify if customer concurrence is required
Issuing the classified ECO:
If there will be shipment restriction
If there will be no shipment restriction
To lift the shipment restriction
Raise engineering approval form (if it would be needed)
Receive customer approval
Create a new draft of the ECO report (Timestamp)
Verify and sign the ECO report (by different departments)
Final review and sign the ECO report (by program manager and DAA)
Final check of the sign ECO report (configuration management)
Finalise and release the final draft of the ECO report
Release the ECO, if there is no shipment restriction
Open a new ECO, if there is a shipment restriction
Terminology
Engineering change order (ECO)
Design intent document (DID)
Shipment restriction
Substantiation
Classified ECO
Designated groups
Designated airworthiness authority (DAA)
IT tools
PLM platform
In-house applications
MS suite tools
Adobe Acrobat
Internal search platform
Documentum

In addition, the CM reviews two criteria for the ECO report. The first one is to verify if the substantiation has been completed and data is available. It should mention that the substantiation here is the validation process that is providing the test (e.g., running tests for the design validations). The second one is to verify if customer concurrence is required. If either/both of the aforementioned criteria will not be satisfied, the CM will use the classified ECO, flagging system, to status the ECO and put shipment restrictions. Shipment restrictions here are the restrictions that come from the lack of customer concurrence and/or substantiations, which lead to not delivering to the customer but the productions will not be stopped. The engine(s) will be stored in quarantine till shipment restriction is lifted.

After the aforementioned steps, the CM creates a new draft of the ECO report, Timestamp, and shares it with the change board departments to sign the form, which will be done electronically by using Documentum. The final review and sign of the ECO report will be done by the program manager and DAA respectively.

The CM verifies the signatures as well as supplementary documents (if there are any) and then creates a final draft of ECO report, Timestamp. If there is no shipment restriction, the CM releases the ECO to the next stage. If there is still shipment restriction, the CM will create a new ECO and the ECO stage begins from the first step.

It should be noted that like the previous stage of the ECM process, the hybrid environment) gives various functionalities (e.g., sharing documents) to this stage of the ECM process.

3.4.4 Notification or application (engineering change notice)

After the ECO is approved, it is the time to implement the selected solution for the requested change. The term that used is the daily issue list, is equivalent to the ECN. The following table presents the characteristics of this stage.

Table 6 The characteristics of the fourth stage of the ECM process – notification or application (ECN)

	Description
Activities	Receive the latest version of the ECO report
	Assign the ECO in daily issue list
	Implement the change based on the proposed instructions
Terminology	Engineering change order (ECO)
	Daily issue list
	Configuration management
IT tools	PLM platform
	In-house applications
	Adobe acrobat

According to the above table, there are a few activities at this stage of the ECM process. The latest version of the ECO report will be assigned to the daily issue list and then will wait to be implemented. The implementation could delay if there are any shipment restrictions. In addition, the hybrid environment including the PLM platform and in-house applications will help the relevant departments to access the latest documents and instructions.

3.4.5 Review and analyse

In this stage of the ECM process, the CM reviews and keep the executed change. Our industrial partner mentioned that the executed changes are reviewed and documented in the company database and would be used as the lessons learned. However, according to the confidentiality issue in the aerospace industry, we could not reach this information.

Now that we've examined and analysed the ECM in an aerospace case study, It is time to contrast this real-world ECM with the theoretical ECM processes, including their stages and activities. This comparison will be the focus of the next section.

4 Comparative analysis of the ECM process used in theory and in practice

This section intends to compare the extracted ECM process from a case study with the extracted ECM process from theory. This section therefore compares the ECM process (stages and activities).

The engineering change process is including various activities. Each activity is playing an important role in the ECM process. The extracted ECM process from the case study is compared in this section with the ECM process used in theory (Pourzarei et al., 2022).

This comparison leads this study to distinguish the similarities and differences between the ECM processes used in theory and in practice. This comparison is divided into the aforementioned five stages of the ECM process (Pourzarei et al., 2022)

To compare the ECM process through these stages, a list of activities is presented in each stage. These activities are extracted from three sources: the activities of the ECM processes that are presented in theory (Jarratt et al., 2011; Kocar and Akgunduz, 2010; Shivankar et al., 2015; Dale, 1982; Maurino, 1993; Rivière et al., 2003; Lee et al., 2006; Tavcar and Duhovnik, 2006; Wu et al., 2014; Ouertani et al., 2004), the activities of the ECM process that are proposed in our previous re-search (Pourzarei et al., 2022), and the activities that are presented in the previous section (case study). It is important to mention that the ECM processes in practice have more detailed activities than the ECM processes in theory. The authors extracted a list of activities that play an important role (e.g., evaluation and approval activities) in the ECM process. Importance was judged by systematically going through the high frequency of mentions/citations of each activity and then placing them in order. The highest-order activities were chosen (the first 5 to 10 activities were clearly occurring more often). Then we compare them to identify if they are used in the ECM processes in theory and/or in practice.

4.1 Request or initiation

The first stage of the ECM process is requesting or initiating the ECR. Table 7 is illustrating the activities of each of the ECM processes.

Most of the activities in this stage are quite the same in both theory and practice such as collecting or initiating the ECR, submitting the ECR form, and somehow evaluating the ECR.

On the other hand, identifying the need for change is an activity that aims to look for the potential ECs based on pre-defined criteria. The analysed literature does not extensively mention this activity. It should be noted that in the case study that was analysed, no activities were found that identified potential problems based on lessons learned. This activity might be present in other industries.

Table 7 Comparison of activities in the first stage – request or initiation (ECR)

Activity	*Dale (1982)*	*Maurino (1993)*	*Rivière et al. (2003)*	*Ouertani et al. (2004)*	*Lee (2008)*	*Tavcar and Duhovnik (2006)*	*Kocar and Akgunduz (2010)*	*Jarratt et al. (2011)*	*Wu et al. (2014)*	*Shivankar et al. (2015)*	*Pourzarei et al. (2022)*	*Practice*
Identify the need for change	-	-	-	-	√	-	-	-	√	-	-	-
Collect or initiate the engineering change request	√	√	√	√	√	√	√	√	√	√	√	√
Submit the ECR form (describe reason, priority, type of change, etc.)	√	√	√	√	√	√	√	√	√	√	√	√
Evaluate the request	-	-	√	-	√	-	√	√	√	√	√	√
Assign the budget to the ECR	-	-	-	-	-	-	-	-	-	-	-	√

Table 8 Comparison of activities in the second stage – instruction or proposal (ECP)

Activity	*Dale (1982)*	*Maurino (1993)*	*Rivière et al. (2003)*	*Ouertani et al. (2004)*	*Lee (2008)*	*Tavcar and Duhovnik (2006)*	*Kocar and Akgunduz (2010)*	*Jarratt et al. (2011)*	*Wu et al. (2014)*	*Shivankar et al. (2015)*	*Pourzarei et al. (2022)*	*Practice*
Detailed evaluation of the re-quested change (e.g. impact analysis)	-	√	√	√	√	√	√	√	√		√	√
Create a professional team to work on the requested change	-	-	-	-	-	-	-	-	-		-	√
Propose the potential set of solutions (BOMs and Markup drawings)	-	√	√	-	√	-	-	√	-	-	√	√
Analyze the solutions (e.g. impacts analysis)	-	√	√	√	√	√	√	√	√	√	√	√
Choose and propose a proper solution	√	√	√	√	√	√	√	√	√	√	√	√
Evaluate the chosen solution	-	-	-	-	-	-	-	-	-	-	-	√
Finalize the analysis of the solution	-	-	-	-	-	-	-	-	-	-	-	√
Update Markup drawings and documents	-	-	-	-	-	-	-	√	-	-	√	√
Create the engineering change proposal/design intent document	-	√	√	-	-	-	-	-	-	-	√	√

In addition, assigning the budget to the requested change is an important activity of the ECM process and if there is no budget, the ECM process might not be started. Interestingly this activity is not presented in the theory and it might be because the ECM process in practice has more details than the ECM process in theory and this might be a valid activity in most of the ECM processes in other industries.

4.2 Instruction or proposal

After raising the ECR, the ECR should be evaluated and solution(s) proposed. The following table is presenting the activities of this stage of the ECM process.

Various activities at this stage are the same between theory and practice. Detailed evaluation of the requested change, the proposal of the solutions, analyse the solution, choosing a solution are some of these similarities. Although theory and practice are using different terms for ECP, they both address the same activity, which is a document

that includes the proposed solution to address the requested change.

Similar to the previous stage, there are certain activities that are observed in practice but not explicitly addressed in theory. This can be because of the detailed version of the ECM process in practice, for instance, create the professional team, evaluate the chosen solution, update markup drawings and document, and finalise the analysis of the solution. It should be noted that there are some differences in the company's characteristics that might need more comprehensive steps for the evaluation.

4.3 Execution or document issuing (ECO)

One of the most important stages of the ECM process is this stage, which aims to do the final evaluation as well as approve the requested change. Table 9 is presenting the activities of execution or document issuing in the ECO stage.

The activities of the third stage of the ECM process can be classified into two main groups. The first group includes the general types of activities that are the same be-tween theory and practice. Creating ECO, revising ECO, approving ECO, updating documents, and finalising the ECO are the activities of the first group.

On the other hand, the second group includes the activities that are created based on the company's needs and policies. Using classified ECO (flagging system) and lifting the restrictions are two examples of these types of activities.

Finally, it is important to mention that there are certain activities such as raising the engineering approval form that should be similar in theory and in practice. The reason that these activities are not mentioned in the theoretical field would be because the information found in the theory is less detailed than in our case study.

4.4 Notification or application (ECN)

Implementing the chosen solution is the aim of this stage of ECM process. The following table represents the main activities of this stage.

Table 9 Comparison of activities in the third stage – execution or document issuing (ECO)

Activity	*Dale (1982)*	*Maurino (1993)*	*Rivière et al. (2003)*	*Ouertani et al. (2004)*	*Lee (2008)*	*Tavcar and Duhovnik (2006)*	*Kocar and Akgunduz (2010)*	*Jarratt et al. (2011)*	*Wu et al. (2014)*	*Shivankar et al. (2015)*	*Pourzarei et al. (2022)*	*Practice*
Create the ECO based on the ECP/DID	-	√	-	-	√	-	√	-	√	√	√	√
Revise the ECO (e.g. cost-benefit analysis) by the engineering change board/committee	-	√	√	-	√	√	√	√	√	√	√	√
Evaluate the restrictions for the requested change (e.g. availability of data, or requiring customer approval)	-	-	-	-	-	-	-	-	-	-	-	√
Flagging the ECO if there is any restriction	-	-	-	-	-	-	-	-	-	-	-	√
Raise the engineering approval form (if it would be needed)	-	-	-	-	-	-	-	-	-	-	-	√
Receive customer approval (if it would be needed)	-	-	-	-	-	-	-	-	-	-	-	√
Lift the restrictions	-	-	-	-	-	-	-	-	-	-	-	√
Approve the proposed solution	-	√	√	√	√	√	√	√	√	√	√	√
Update documents (e.g. markup drawings)	√	√	√	√	√	√	√	√	√	√	√	√
Create the final draft of the ECO report	-	-	-	-	-	-	-	-	-	-	-	√
Team notify (e.g. Program Manager)	√	√	√	√	√	√	√	√	√	√	√	√

Table 10 Comparison of activities in the fourth stage – notification or application (ECN)

Activity	*Dale (1982)*	*Maurino (1993)*	*Rivière et al. (2003)*	*Ouertani et al. (2004)*	*Lee (2008)*	*Tavcar and Duhovnik (2006)*	*Kocar and Akgunduz (2010)*	*Jarratt et al. (2011)*	*Wu et al. (2014)*	*Shivankar et al. (2015)*	*Pourzarei et al. (2022)*	*Practice*
Released the latest version of the ECO report	√	√	√	√	√	√	√	√	√	√	√	√
Create a daily issue list/engineering change notice (including textual and graphical information regarding the execution change)	-	√	-	-	-	-	√	√	-	√	√	√
Assign the timeframe for the execution	-	√	-	-	-	-	-	√	-	-	√	√
Inform the people who are concerned about the requested change (team notify)	-	√	√	√	√	√	√	√	√	√	√	√
Implement the requested change in the production process, servicing, etc., either immediately or be phased in	√	√	√	√	√	√	√	√	√	√	√	√
Update the paperwork	-	√	√	√	√	√	√	√	√	√	√	√

The activities at this stage of the ECM process are quite the same in theory and in practice. Releasing the latest version of ECO, creating a daily issue list / ECN, assigning a time plan for implementation, team notification, and implementing the requested change are similar activities at this stage.

Furthermore, the activity of updating paperwork (Jarratt et al., 2011) is a valid activity in both theoretical and practical contexts. However, it is worth noting that our industrial partner initiated paperless operations and activities in 2016. Through the adoption of a collaborative platform and the implementation of a hybrid work environment, the organisation has the capacity to enhance productivity and transition into a paperless entity. Nevertheless, it is conceivable that this activity remains relevant in different industries.

4.5 Review and analyse

The final stage aims to review the executed change. Table 11 illustrates the main activities of this stage.

Table 11 Comparison of activities in the fifth stage – review and analyse

Follow-up the execution's results to identify if it achieved the initial intent	-	-	-	√	-	-	-	√	√	√	√	√
Evaluate the post-changes impacts	-	-	-	√	-	-	-	√	√	√	√	√
Update deliverables that are affected by the change	-	-	-	-	-	-	-	√	√	√	√	√
Identify and document the lessons learned	-	-	-	-	-	-	-	√	-	-	√	-
Classify and store the lessons learned	-	-	-	-	-	-	-	√	-	-	√	-

The activities at the fifth stage of the ECM process could be classified into two groups. The first group includes the most common activity, which is follow-up the execution's results to identify if it achieved the initial intent. This activity aims to assure that the proposed solution could satisfy and address the requested change.

The second group includes the activities that aim to be used as the lessons learned. Identify and document the lessons learned as well as classify them are some examples. It is worth mentioning that, although our industrial partner does not have the activities for the lessons learned, they might be different in other industries.

As observed in the preceding stages, it is apparent that the level of detail within the ECM process varies even among the ECM processes in the theory that has been presented.

5 Discussion

ECM is an important practice in different industries and more precisely in aerospace product design organisation. The ECM process includes various elements such as terminologies, documents, stages and activities, and IT tools. This research study investigated and documented the ECM terminologies, ECM stages and activities, and the functionalities of the IT tools for the ECM from one case study in the aerospace industry

5.1 ECM process

Unsurprisingly, the ECM process is more detailed in practice compared to the ECM process in theory. The results of this comparison indicate that while theory describes using lessons learned to identify potential changes, in practice, the process begins only when there is a request for the change. Another interesting point is that the ECM process in practice begins when there is a defined budget for it, which is not mentioned in theory. Furthermore, our industrial partner has started to implement paperless activities, which indicates that practice is moving towards the digital transformation world.

Our observation also show that ECM process can vary depending on the complexity of the requested change and the resources required. For example, a change in the size of a yoke, control wheel, may be less complex than a change in the infusion pumps in an airplane engine. The duration of the ECM process, the number of departments involved, and the engineering change costs will differ between these two examples of ECs.

It is noteworthy that the client may be a potential member of the approval team for the ECM process. For instance, in the aerospace industry, the client's approval might be a critical activity in the ECM process, whereas in a general manufacturing context such as electronic goods, such approval may not be necessary.

Furthermore, the ECM process is highly adaptable, offering the flexibility to meet the unique requirements of various industries. For example, our industrial partner introduced a flagging system within the ECO stage to efficiently manage the imposition and lifting of restrictions. Variations in activities can arise depending on industry-specific needs. The evaluation of requested changes and pro-posed solutions may differ, reflecting the specific focus areas and priorities of each industry. Additionally, the documentation of lessons learned can vary across sectors, with some emphasising post-implementation reviews for continuous improvement. These examples illustrate the ECM process's dynamic nature, capable of accommodating diverse industry requirements while maintaining a high-level view presented in theoretical ECM processes.

5.2 Limitations

The limitations of the work conducted could be classified into three groups. The first and foremost is the confidentiality issue in the aerospace industry. This limitation did not let us investigate deeply through whole ECM process in the company and limited our collaboration to the second stage, instruction or proposal (ECP), and third stage, execution or document issuing (ECO), of the ECM process. Although the importance of the aforementioned stages, investigating the other stages could reveal more information. In addition, the other stages of the ECM process from practice are extracted based on the documents used in the company (e.g., standards), which were validated with our industrial partner and stayed at a high level. The second limitation of this research study is that the whole collaboration between the research team and industrial partner is held in online collaboration according to the COVID-19 pandemic. This reason led to this research study last more than the time was expected. And the third limitation is that the current results rely on having only one case study, there-fore, if we aim to generalise, it would be necessary to include more than one case study.

6 Conclusions and future research

ECs are modifications made to a product or a part definition after it has been released. ECs likely impact the product design, manufacturing process, and operations. Therefore, it is important to manage them efficiently. ECM process is therefore an important practice in the aerospace product design organisation, which needs to track and manage ECs.

Various processes have been proposed as ECM process to manage the ECs in scientific literature – or theory. On the other hand, different ECM processes are used in practice. This article aimed to investigate the similarities and differences between the ECM processes in theory and practice. Hence, this article is investigating the most cited ECM processes in theory and comparing them with one case study in aerospace industry.

The contributions are the following. First, the terminology used in theory and practice is remarkably similar. The primary terms of the ECM process, such as ECR, ECO, and EC, are utilised in both theory and practice. Nevertheless, some modifications have been made to certain terms, such as the implementation of a 'classified ECO,' by the industrial partner to streamline the ECM process. Secondly, although there are similarities between the ECM processes in theory and practice, there are some differences in the activities that stem from the detailed ECM process in practice, as well as customised activities tailored to the company's specific needs. Some of these differences include identifying potential changes and creating the IPT team. However, it should be noted that although the activity of assigning a budget to the ECR is not explicitly mentioned in theory, it is likely to be a crucial aspect in most ECM processes. This emphasises the fact that the ECM pro-cess cannot begin without a budget allocated for the requested EC. Nevertheless, the initial budget may necessitate additional discussion, especially in the case of complex changes. Finally, the adoption of IT tools in practice varies, with certain industries showcasing a high level of integration and successful implementation. Our industrial partner has notably designed and developed distinctive IT tools, which are in-house applications, and has successfully integrated them with the PLM platform to establish a hybrid environment.

This study contributes to the understanding of ECM processes, particularly within the aerospace industry. However, it is important to acknowledge the limitations of a single case study in presenting a comprehensive view of real-world applications. To better address this, future research avenues can include a comparative analysis of ECM processes across various industries, allowing for a broader examination of industry-specific variations. Furthermore, delving deeper into the integration of IT tools and budget allocation considerations in different sectors remains essential. As digitalization continues to reshape industries, investigating how ECM processes adapt and evolve within the context of digital transformation remains a pertinent field of study. In summary, while this study provides valuable insights within the aerospace sector, it is important to recognize its specific scope and the potential for broader research to enrich our understanding of ECM processes in various contexts.

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Appendix

List of abbreviations

Abbreviations	*Description*
BOM	Bill of materials
BPMN	Business process model and notation
CM	Configuration management
DAA	Designated airworthiness authority
DC	Design change
DID	Design intent document
DMU	Digital mock-up
EC	Engineering change
ECM	Engineering change management
ECN	Engineering change notice
ECO	Engineering change order
ECP	Engineering change proposal
ECR	Engineering change request
ETO	Engineer-to-order
IPT	Integrated product team
PLM	Product lifecycle management