CRANFIELD UNIVERSITY

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Develop a framework for engineering change management in an aircraft manufacturing company

School of Aerospace, Transport and Manufacturing
(School of Applied Science)

MSc by Research Thesis
Academic Year: 2013 -2014

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ABSTRACT

The purpose of this research project is to develop a framework for engineering change management (ECM) in an aircraft manufacturing company.

ECM is vital for manufacturers to manage changes efficiently and effectively. As an effective change control technique, ECM has been widely practiced in different industrial sectors. However, adopting an ECM process does not always guarantee the agility of the manufacturing process of the manufacturer. The performance of ECM could be affected by the actual practice followed by the ECM practitioner.

The research was conducted in four phases. In the first phase an extensive literature review was carried out to understand the critical success factors related to the ECM and Configuration Management (CM) activities.

The second phase was to model the current ECM practice in the aircraft manufacturing company by using $IDEF_0$ approach. The actual ECM practice was understood and some gaps were identified in this part.

In the third phase, a survey was carried out to identify the best practices in aerospace and automobile companies. A list of best practices that could promote the performance of the ECM was identified by analysing the result of the survey.

In the last phase of the research, a framework was developed from the model of current ECM process in the company. The best ECM practices identified in the third part of the research were integrated into the model to refine the current ECM process. The framework was validated by experts in the aircraft manufacturing company.

The outcome of this research shows the correlation between the performance of the ECM process and the actual ECM practices. And the framework developed in this thesis can provide benefits for the further improvement of the current

ECM process in the aircraft company. The framework also offers a benchmarking reference for other companies with a similar background to examine their own ECM process and initiate improvement.

Keywords: Engineering change management, Configuration management, aircraft

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LIST OF ABBREVIATIONS

CCB	Configuration Control Board
CCM	Configuration Change Management
CCO	Configuration Control Office
CCT	Configuration Control Team
CIB	Change Implementation Board
CM	Configuration Management
ECM	Engineering Change Management
ECR	Engineering Change Request
ECO	Engineering Change Order
ECP	Engineering Change Proposal
MBOM	Manufacturing Bill of Material
NPD	New Product Development

1 Introduction

1.1 Background and Motivation of the Research Project

Commercial aircraft is a complex product which usually consists of hundreds of thousands of components and embodies with advanced technologies. The number of engineering changes (EC) for a jet engine only could be in the region of 3,000 (Leech & Turner, 1985). For the whole aircraft, there can be more changes. Due to the complexity and the degree of innovation, changes are easy to happen in the new product development (NPD) phase (Fricke et al., 2000). During the NPD phase, changes may be triggered for different reasons such as implementing customer's requirements, physical interfere and correcting design document errors. The safety of a commercial aircraft primarily relies on its design property as well as its conformity with the intended design. On behalf of public interest, airworthiness authority requires high standards of ECM in aircraft manufacturers. The aircraft manufacturer must guarantee that the as-built configurations are in conformity with the approved as-designed configurations at any stage.

The smooth running of manufacturing system can be disrupted by ineffective and inefficient management of engineering changes. To ensure the conformity of product, all changes of requirements, specifications and drawings must be tracked until these changes are implemented into the product. In aerospace sector, the impact of an engineering change of an aircraft can propagate among different functional departments in a company. Given its large number and complexity, it is a major challenge for the ECM system to manage these changes especially in the development phase of a new aircraft.

The motivation of this thesis starts from the recognition that ECs are probably the most important interface between the R&D centre and the manufacturing centre. The coordination and implementation of the ECs are the main theme of the routine work within the manufacturing centre. The inefficient management of ECs may cause delay of assembly work and frustration among involved people. Although ECM is already performed within the company, there are still room for improvement in tracking changes and controlling change implementation in existing ECM system. The planning and implementing of EC are embodied diversely among different functional departments. It is noticed that the cooperation between different functional departments in the current ECM system remains on a low level. A framework for ECM is needed to improve the performance of ECM process in the aerospace manufacturing company, which is why this research project was carried out.

1.2 Brief introduction of the Aircraft Manufacturing Company

The aircraft manufacturing company involved in this thesis is a manufacturing and final assembly centre for two types of commercial aircraft, a regional airplane with fewer than 100 seats and single aisle airplane which can accommodate around 150 people. The aircraft manufacturing company is a subsidiary of COMAC. The company needs to cooperate with the R&D centre which is another subsidiary of COMAC responsible for the design of the airplane. The cooperation between the manufacturing company and the R&D centre is comprised of two domains. The first domain is to evaluate the impact during the initiation of EC (e.g. how many products will need to be reworked or scraped). Another domain is to implement the EC into the product after it is released from the R&D centre.

During the development phase of the regional airplane, this company has been facing thousands of ECs from the R&D centre every year. Although ECM process is established in the company to guarantee the decent evaluation and implementation of all the ECs, it is discovered that there are still limitations of the current ECM. Sometimes assembly work is delayed because of the inefficient coordination or planning of the EC. Thus the current ECM process in the company still needs improvement to enhance the capability of the ECM.

1.3 Research Scope

The scope of this thesis is limited to engineering change management (ECM) in the selected aerospace company. Mention to other industrial domain is used for reference only.

The scope of this thesis does not include the management process related to variance to approved configuration baseline, because variance is usually treated as agreed derivation or concession which requires the approval of the design authority rather than the change of the product configuration.

1.4 Aims and Objectives

This research aims to develop a framework for ECM in the aircraft manufacturing company.

The specific objectives of this research project are:

- Perform a study of ECM practices via literature review. Identify the critical success factors which can affect the performance of ECM.
- Investigate and model the current practices in ECM in the aircraft manufacturing company.
- Benchmark the current ECM practices in aerospace and automobile industries and identify the best ECM practice.
- Propose and validate a framework for ECM in the aircraft manufacturing company for further improvement.

2 Literature review

2.1 Introduction

The literature review is used for answering the research objective “Perform a study of ECM practices via literature review and identify the critical success factors which can affect the performance of ECM”. Considering that there is a considerable overlap between ECM and CM (which is discussed in chapter 2.2). The literature in the CM domain is also included in this research. The search strategy is based on keywords to identify potential sources of ECM and CM research paper in Aerospace industries from various sources such as Science Direct, Scopus, Google Scholar and various books, theses, etc.

2.2 Engineering Change Management and Configuration Management

US Military Standard 480B (1988) consider an EC to be “an alteration in the approved configuration of a product related item”. Engineering changes involve the change of product configuration information that occurs after the configuration baseline is approved and released during the lifecycle of product (ISO, 2003; EIA-649, 1998). The scale of the change can range from small changes to a single component to system-level changes. Different definition for engineering change is given in EIA-649 and other academic literatures.

- “Any alteration to a product or its released configuration documents. Effecting an engineering change may involve modification of the product, product information and associated interface products.”(EIA-649, 1998)
- “An engineering change (EC) is a modification to a component of a product, after that product has entered production” (Wright, 1997)
- “An engineering change is an alteration made to parts, drawings or software that have already been released during the product design process. The change can be of any size or type; the change can involve any number of people and take any length of time.” (Jarratt et al., 2011)

ECM has a close link with configuration management (CM). ECM is particularly focused on the controlling of configuration change to the product. Configuration Management can be defined as “a management process for establishing and maintaining consistency of a product’s performance, functional, and physical attributes with its requirements, design and operational information throughout its life” (EIA-649, 1998).

According to ISO10007, Configuration Management is “a management activity that applies technical and administrative direction over the life cycle of a product, its configuration items, and related product configuration information”. Configuration management is a technique used by many companies to support the control of the design, manufacture and support of a product.

ECM can be regarded as part of the CM. One of the key functions of CM is the control of ECs because uncontrolled ECs may result in a catastrophic outcome on the quality of the product. Thus the ECM process is viewed as the core process of the larger Configuration Management process (Pikosz and Malmqvist, 1998). The main requirement for ECM is to control dynamic changes of the product and its engineering data over the time (Müller, 2013).

Each change of the design and specification of product causes a change in product configuration. ECM offers a tool to ensure that all changes to released configuration documentation are managed properly.

However, it was noted by Jarratt et al. (2011) that although the ECM and CM are highly inter-related, they are not the same. A formal ECM process is viewed as indispensable for a CM system. On the contrary, a formal ECM process does not mean the company is following the CM practice. It is not necessary for firms producing products of low complexity to adopt a process as complicated and bureaucratic as CM.

2.3 Critical Success Factors for ECM

A number of critical success factors which could affect the performance of the ECM were identified in academic literature and case studies in industrial organizations. These factors can be categorized into four groups on the basis of product, process, organization and support tools.

2.3.1 Nature of the Product

The ECM process can be deeply influenced by the nature of the product. The nature of the product can be categorized as product complexity, product architecture and the degree of innovation (Jarratt, Eckert, Caldwell, & Clarkson, 2011).

The complexity of a product can be described from different aspects. Felipe, Kumar, Abdon and Bacate (2012) described the complexity of a product as the function of the capabilities it requires. The number of unique parts of the product could be used as a parameter to distinguish the complexity of different products. For example, the number of unique parts in a simple bicycle was around one hundred, whereas the same figure for a large commercial aircraft could be more than hundreds of thousands. It was noticed by Jarratt et al. (2011) that firms producing products of high complexity usually adopted robust ECM processes. Products of high complexity such as commercial aircraft went through a large number of changes between the first prototype and the final certificated version. As pointed out by Altfeld (2000, p255), there were usually many thousands of changes over the life-cycle of a new airplane in Airbus.

The degree of innovation of the product can also increase the complexity of the product. In highly innovative projects, it is very common that the development process is often disturbed when implementing new technologies because there is no sufficient information and knowledge with such products (Eckert et al. 2009) .

Product architecture was defined by Ulrich and Eppinger (2008) as "(1) the arrangement of functional elements; (2) the mapping from functional elements to physical components; (3) the specification of interfaces amongst the interacting physical components". There were two main types of product architecture: modular and integrated (Jarratt et al. 2011). A modular architecture can be defined as a certain product structure consisting of a group of modules with different functions and minimum interaction among themselves which mean the components within the module should be highly integrated. Parts have to interact with each other in a complex product which means that changes to one part can cause another change to a linked part. Base on their affect on change propagation, parts can be divided into four approximate types: constants; absorbers; carriers; multipliers (Eckert, Clarkson & Zanker, 2004).

1. Constants do not affect the complexity of the change problem. Constants neither absorb other changes nor cause changes themselves.

2. Absorbers lessen the complexity of the change issue. Absorbers can contain more changes whist passing on less further change to other parts.

3. Carriers can absorb the same number of changes as they create afterwards. Carriers do not increase the complexity of the product.

4. Multipliers act as an amplifier to the changes. Multipliers can generate more changes than they absorb.

The purpose of adopting modular product architecture is to control the change propagation. But the behaviour of a certain module still depends on its design attributes such as tolerance margins (Eckert et al., 2004) or interfaces with other modules (Altfeld, 2000, p80). If the impact of the change exceeds the tolerance margin or the interface boundary, the module can become a multiplier to the change. Both the tolerance margins and the interfaces need to be managed with significant attention to guarantee the module acts as an absorber thus the change propagation can be limited within certain modules when new change happens. The case study carried out by Kaariainen (2007) also confirmed that the management of interfaces is crucial in large projects. If interfaces are not managed properly, difficulties can be generated in the downstream phase.

The critical success factors identified in this section are summarised in Table 2-1.

Critical success factors for ECM.			
Category	Factors	Initial guidelines for ECM	References
Product	Product complexity	Changes increases with the level of the product complexity.	Jarratt et al.(2011)
	Product architecture	Product architecture can affect the change propagation	Ulrich and Eppinger (2008), Eckert et al.(2004) Altfeld (2000) Kaariainen (2007)

Table 2- 1 Critical success factors for ECM (Nature of Product)

2.3.2 Process

The entire ECM process is subdivided into different phases by different authors.

Tavcar and Duhovnik (2005) generalized the ECM process into five steps including: (1) Change request, (2) Change preparation, (3) Change approval, (4) Change of documentation, (5) Implementation in production

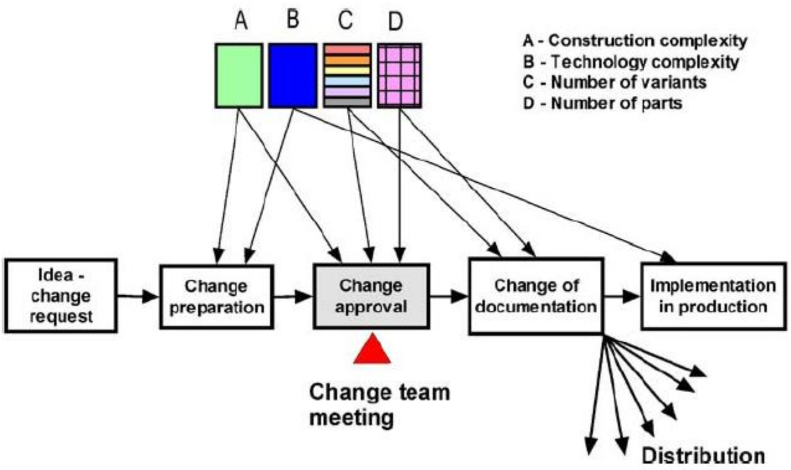

Figure 2- 1 Generalized Change Process. (Source: Tavcar and Duhovnik (2005))

Jarratt et al. (2004) suggested a more comprehensive six process steps based on three approval stage with 4 break points. The generic process covered the whole lifecycle of a change from the change request to the final implementation and review.

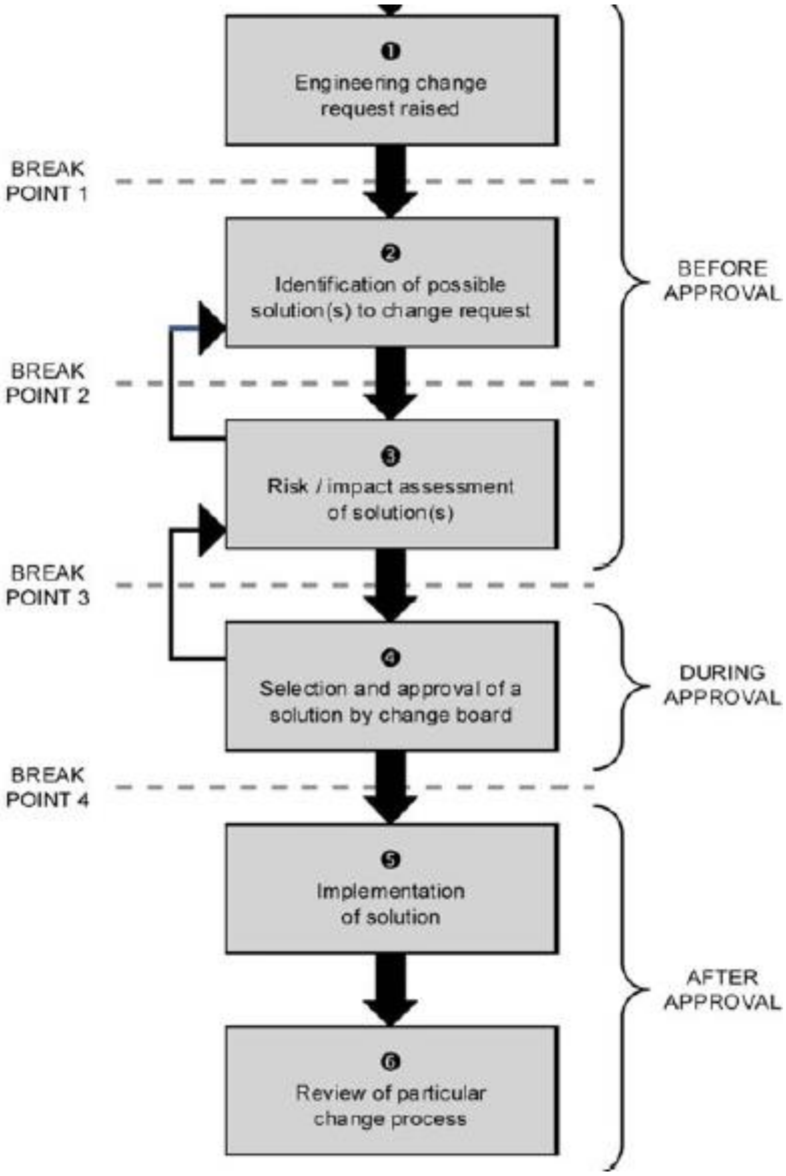

Figure 2- 2 Six-step change process. (Source: Jarratt et al. (2004))

Lee et al. (2006) introduced a four-stage model based on a case study in automobile development in South Korea. The process was integrated with the workflow in reality which included initiating an engineering change request (ECR), evaluating the ECR, issuing engineering change orders (ECOs), and storing and analyzing the ECOs.

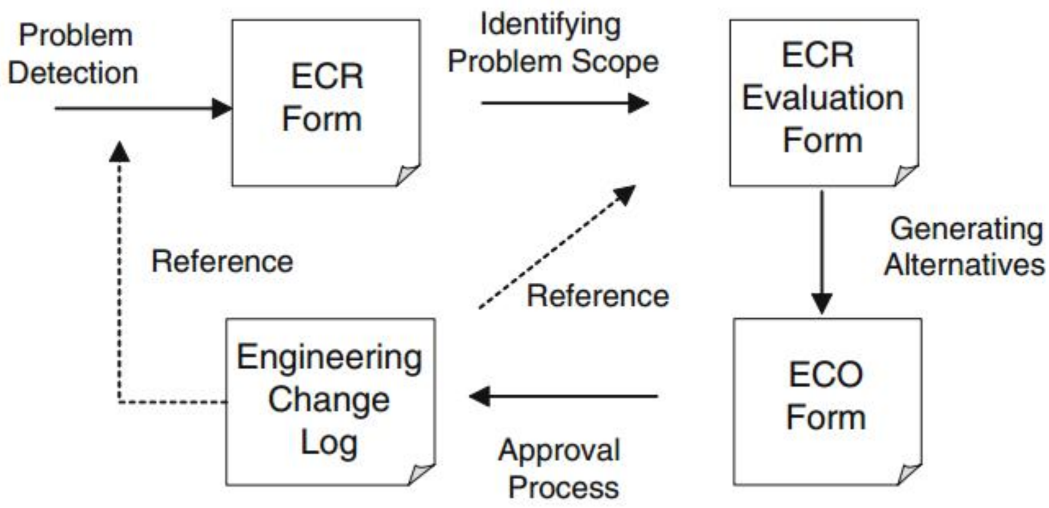

Figure 2- 3 Four-stage change process. (Source: Lee et al. (2006))

There are still some other ECM modules summarized by other authors. Maull et al. (1992) divided the ECM process into five steps (1) filter proposal, (2) design investigation, (3) appraise design, (4) authorize change, and (5) execute change while Rivière et al. (2002) proposed it in a three-stages modal, (1) change proposal, (2) change investigation, and (3) change embodiment.

Although these proposed processes contain different stages and employ different terminology, they all generically cover the similar concept of the change process which can be demonstrate in Figure 2- 4.

Tavcar and Duhovnik (2005)	Jarratt et al. (2004)		Lee et al. (2006)	Maull et al. (1992)	Rivière et al. (2002)
idea -change request	Engineering change request raised	Change Process	Initiating an engineering change request (ECR)	Filter proposal	Change proposal
Change preparation	Identification of possible solution(s) to change request		evaluating the ECR	Design investigation	Change investigation
	Risk/Impact assessment of solution(s)			Appraise design	
Change approval	Selection and approval of a solution by change board			Authorize change	
Change of documentation	Implementation of solution		Issuing engineering change orders (ECOs) to relevant participants	Execute change	Change embodiment
Implementation in production	Review of particular change process		storing and analyzing the ECOs for management purposes		

Figure 2- 4 Overview of the different ECM process

Figure 2- 4 shows that the ECM process can be viewed as a sequential process. All the processes contain possible gateway, at which the change process can be distributed to the next stage or terminated by the control mechanism.

Limitations of the sequential ECM process were observed in the literature. The first limitation of the sequential change process is that only one user can process the change at a time. The investigation published by Rowell et al. (2009) revealed that the an engineering change could consume 126 days in average just in the impact analysis phase of the ECM process. Under most circumstances, different functions need to participate sequentially in the change process at certain stages. Such sequential process can generate an excessive throughput time. The situation became even worse if the change package was rejected to the first stage for re-processing (Huang, Yee & Mak, 2003).

The second limitation is the demanding for coordination and communication. Due to the diversity of the change impact, many functional departments and even suppliers could be affected when the configuration of the product need to be changed. In order to be approved by all involved persons affected by the change, all the change repercussions from different stakeholders should be gathered for evaluation. Negotiation meetings need to be organized to arrive at a consensus if necessary. Coordination beyond functional departments and between companies requires extensive communications among many people. In aerospace industry, some vital changes must be submitted to regulators for approval which makes the process even more complex than normal. It is also confirmed by Ali and Kidd (2013a) that the implementation of CM has been greatly affected by decentralization of the process.

However, improvement could be achieved by measuring the performance of the ECM process. Huang et al. (2003) suggested that the efficiency of the ECM process could be measured by three parameters:(1) number of active changes; (2) calendar time taken to deal with an change; (3) cost or effort (person hours) needed to process an change. The importance of measuring the performances of ECM process was also highlighted by Riviere et al (2002) who proposed a set of indicators to help improve the ECM performance.

The classification of change was also suggested by several researchers to increase the ECM efficiency. In the case study presented by Barzizza et al.(2001), each change was classified into the categories of ‘scrap’, ‘rework’ and ‘use as is’ based on the impact of the change. Different management process would be followed depending on the category of the change. Wu et al. (2012) proposed a solution to help improve the ECM performance in the motorcycle industry. ECs were categorized into full-track or fast-track processes by the change review board. Then change notice and implementation plan were created based on the decision made by the board. Significant performance improvement was observed after the solution was implemented.

The critical success factors identified in this section are summarised in Table 2-2.

Critical success factors for ECM.			
Category	Factors	Initial guidelines for ECM	References
Process	Sequential change process	Excessive throughput time; Demanding for coordination and communication	(Huang, Yee & Mak, 2003) Ali and Kidd (2013a)
	ECM performance measurement	Improve the ECM performance	Huang et al. (2003) Riviere et al (2002)
	Change classification	Increase the ECM efficiency	Barzizza et al.(2001) Wu et al. (2012)

Table 2- 2 Critical success factors for ECM (Process)

2.3.3 Organization

The process of ECM can cross the boundary of different functional departments such as engineering, manufacturing, quality and procurement. It was pointed out by Tavčar and Duhovnik (2005) that communication should be encouraged in the organizational structure. However, Fricke et al. (2000) pointed out that one of the reasons for the explanation of inefficient ECM processes was a lack of communication and coordination between different functional departments.

The survey conducted by Huang and Mak (1999) showed that over 80% of investigated UK firms regarded "poor communication" as a barrier to effective ECM. Some unnecessary ECs were due to poor communication among the functional departments involved in product development. And over 70% of the surveyed companies also viewed ‘‘people indifference’’ and ‘‘internal departments are not cooperative’’ to be major influential factors for the performance of ECM.

Huang and Mak (1999) also noticed that large companies in UK usually appointed EC coordinators to process EC-related activities. Special team was employed in some companies to take the responsibility of ECM. Regular meetings were held to manage the issues triggered by the ECs. Same organization structure was also found in Hong Kong manufacturing industries by Huang et al. (2003).

Tavčar and Duhovnik (2005) proposed an approach to improve the ECM performance. The approach was to assign several persons to monitor the ECs. The responsibility of these people was to manage the implementation of each EC and take appropriate actions if the process is delayed.

In order to overcome the weakness of the sequential ECM process, the concept of “Integrated Engineering Change Management” was proposed by Lindemann et al. (1998) to improve this situation. The concept of ‘‘matrix teams’’ was introduced to break the boundaries between different departments in large project teams. The “matrix teams” can encourage knowledge sharing among these departments and thus promote the efficiency of ECM. The critical success factors identified in this section are summarised in Table 2- 3.

Critical success factors for ECM.			
Category	Factors	Initial guidelines for ECM	References
Organization	Communication	Poor communication is a barrier to effective ECM	Huang and Mak. (1999)
	Change monitor	The implementation of each change is manageable and appropriate actions can be taken when delay occurs	Huang and Mak. (1999) Tavcar and Duhovnik. (2005)
	Matrix team	To break the boundaries between design groups in large project teams and encourage knowledge sharing	Lindemann et al. (1998)

Table 2- 3 Critical success factors for ECM (Organization)

2.3.4 Supporting Tools

A number of studies illustrated that computer-based tools were essential to support ECM in manufacturing companies (e.g. Huang & Mak 1999; Huang & Mak 2003; Lindemann et al. 1998). User friendly software (tool) was also identified by Ali and Kidd (2013b) as a critical success factor for CM.

Computer support for ECM was also addressed by Pikosz and Malmqvist (1998) in a case study in three Swedish engineering companies. Although in the studied companies the level of support from computer for the ECM was still low in 1997, the usage of PDM system still helped the companies to enable a faster ECM process.

Lack of effective CM tools was identified by Ali and Kidd (2013a) as a barrier to effective configuration management application. Limitations of current ECM tools were highlighted by Riviere et al. (2003). And prototype software was developed to overcome these limitations. Huang and Mak (1998) also confirmed that the potential benefits of computer support for ECM were not fully exploited in practice by the companies surveyed in UK. Although the surveyed companies did show interests in using computer-aided ECM systems, most of their ECM activities were operated manually with limited computer assistance. A similar study was also conducted in Hong Kong manufacturing industries by Huang et al. (2003). The findings of the study illustrated that no computer-aided ECM systems were used in the surveyed companies.

One reason presented by Huang and Mak (1998) for the low usage of computer-aided system is that the current software cannot satisfy the user's requirements. According to study on configuration management implementation by Ali and Kidd (2013b), product lifecycle management (PLM) and product data management (PDM) software have made contributions to the automation of the ECM process. But problems can still happen during implementation phase of the software.

Gagné and Fortin (2007) pointed out that current PDM systems could not fulfill the needs of manufacturing process planning although they seemed to be capable in supporting the development of a new product from the engineering perspective. And more attention should be paid to the integration of the ECM in design and manufacturing.

Lee et al. (2006) argued that current systems for ECM mainly focus on "storing documents related to the ECs" or "simply automating the approval processes". More attention should be paid to the capture and management of knowledge which is learned from decision-making processes and collaboration. The survey conducted by Cantamessa et al. (2012) showed that the use of knowledge management system reduced the design mistakes in Italian aerospace industry. Reduction on the design mistakes leaded to a less probability of new change. The critical success factors identified in this section are summarised in Table 2-4.

Critical success factors for ECM.

Category	Factors	Initial guidelines for ECM	References
Supporting Tools	Computer-Aided tools	Computer-Aided tools have made a lot contributions to the automation of the change process yet still creating	Pikosz and Malmqvist (1998)

		problems during implementation	Ali and Kidd (2013a) Huang and Mak (1998) Ali and Kidd (2013b)
	Knowledge management tool	The management of knowledge is able to reduce the design errors which can lead to a decrease in the number of ECs	Lee et al.(2006) Cantamessa et al. (2012)

Table 2- 4 Critical success factors for ECM (Supporting tools)

2.4 Knowledge Gap

In this chapter, a comprehensive view of ECM was introduced. A study of ECM practices within industrial sector was performed to identify the critical success factors which could affect the performance of ECM. From the literature review, it can be identified that the research on ECM has been carried out for many years and many critical success factors for ECM have been addressed from various perspectives in literature. But It seems that the nearly all the reviewed literature on ECM were focused on the product development domain. There is no sufficient guideline for the development of the ECM framework for the manufacturing company. Hence, steps should be taken to identify the best ECM practice for the manufacturing company.

3 Research Methodology

3.1 Introduction

This chapter describes the research approach and methods applied to complete the goal of the whole research project.

A benchmarking approach was studied and used in this research to improve the performance of the ECM practice in the aircraft manufacturing company. Survey tool was selected to support the data collection of the benchmark.

3.2 Benchmarking Process

The benefit of benchmarking was addressed in literature as a successful tool that could lead to improvement and better competiveness. Camp (1989, p12) defined benchmarking as “Benchmarking is the search for industry best practices that lead to superior performance”. Codling (1998, p3) described the benchmarking as “a powerful tool for gaining and maintaining competitive advantage”, because it “drives best practice continuous improvement through the organisation”.

In order to achieve the ultimate goal of benchmarking, “best practice” should be identified first. Camp (1989, p34) defined it as the practices “the sure route to superior performance”.

The benchmarking process was divided into four subcategories by Camp (1989, p60-65) based on the selection of the benchmarking objective:

- Internal Benchmarking
- Competitive Benchmarking
- Functional or Industrial Benchmarking
- Generic Benchmarking

The definition of each subcategory given by Camp (1989, p60-65) is illustrated in Figure 2- 5

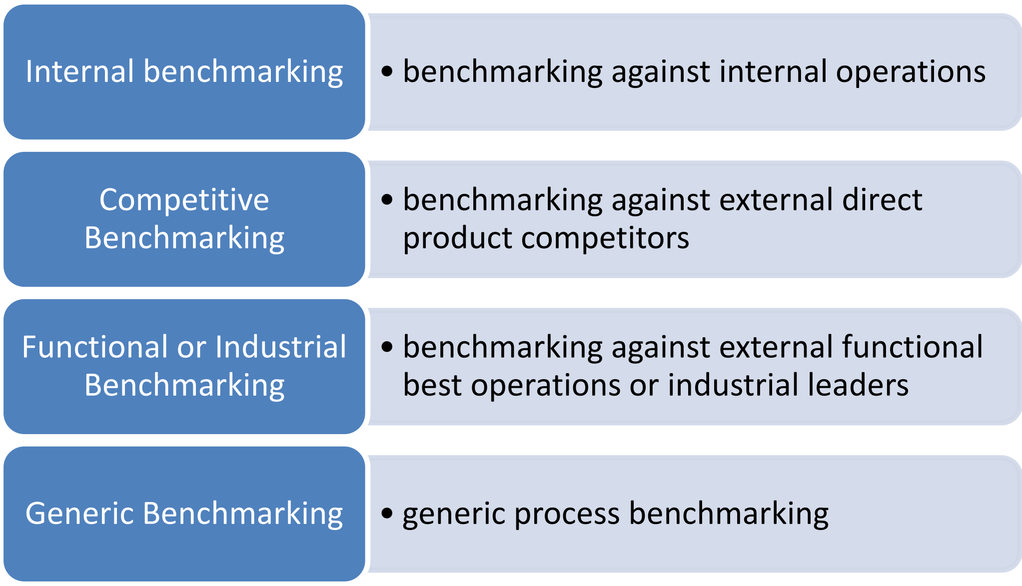

Figure 2- 5 Definition of each subcategory. Source: (Camp, 1989, p60-65)

Camp (1989, p16-19) also proposed a five-phase model with twelve key steps in detail to describe the benchmarking process.

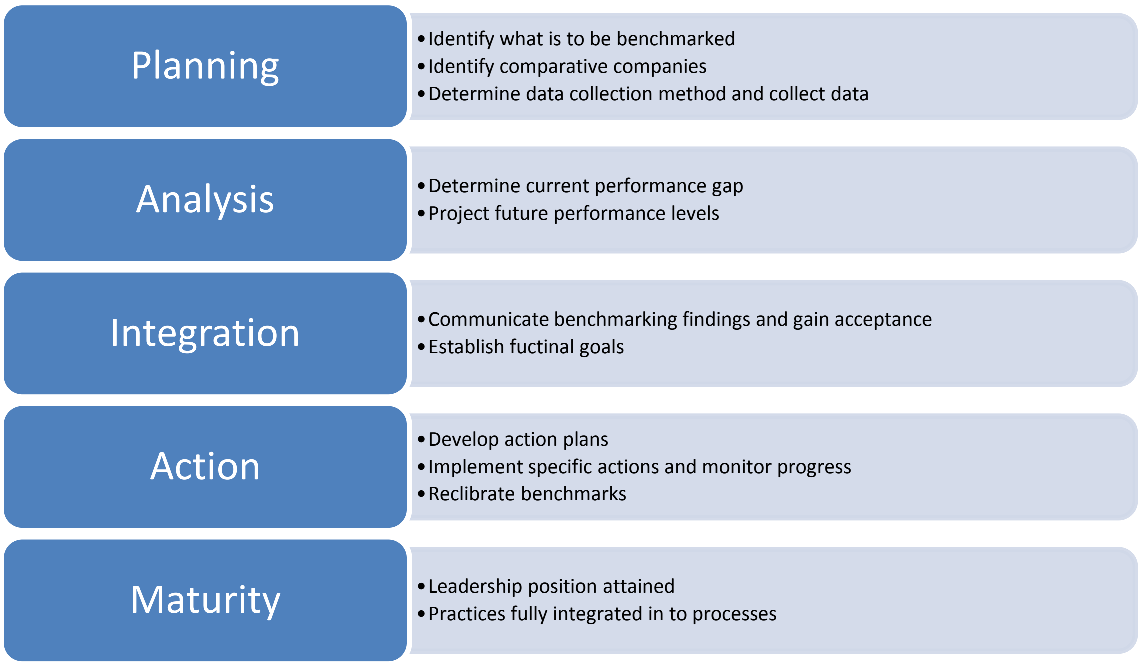

Figure 2- 6 Benchmarking model. Source: (Camp, 1989, p16-19)

3.3 Research Approach

The research approach was designed following the benchmarking model. Table 3-1 presents the objectives, key tasks and outputs in each research phase. This research involves four main phases which are shown in Table 3-1.

Phase	Objectives	Key Tasks	Key Output
1	Perform a study of ECM practices via literature review. Identify the critical success factors which can affect the performance of ECM	Perform a study of the critical success factors affecting ECM via literature review	Literature Review report focusing on the areas of ECM
2	Investigate and model the current practices in ECM in the aircraft manufacturing company	Obtain data of the internal ECM practice; Model the current ECM practice	The $IDEF_0$ model of current ECM practice in the company
3	Benchmark the current ECM practices in aerospace and automobile industries and identify the best ECM practice	Investigate the current ECM practices and identify the best practice for ECM based on by survey	Best practice for successful ECM
4	Develop the and validate the framework for ECM in the aircraft manufacturing aerospace company	Develop the framework for ECM in the selected aerospace company; Validate the framework by consulting expert in the aerospace company	A validated Framework for ECM in the aircraft manufacturing company;

Table 3- 1 Research Approach

3.3.1 Phase one

The first phase of the approach was based on literature review, with the objective of identifying the diverse problem and the focal points of the analysis of current ECM practice. A comprehensive literature review was undertaken within the research domain. The main task on this stage was to learn the common experience and practice though literature and identify a selection of success factors for ECM.

3.3.2 Phase two

The purpose of this phase was to achieve a comprehensive understanding of the ECM activity in the selected aerospace company. The main task of this stage was to obtain the data of the current ECM practice in the aerospace company.

The current ECM practice in the selected company was modelled by using the $IDEF_0$ approach. The current ECM practice was understood and gaps were identified in this part.

3.3.3 Phase three

At this phase of the research, a survey was conducted to identify the best ECM practice in aerospace and automobile manufacturers. A qualitative analysis was performed after data was obtained from the respondents. Best practices that could promote the performance of the ECM were identified by analysing the result of the survey.

3.3.4 Phase four

This objective of this phase was to develop the framework for ECM in the aerospace company based on the findings and analysis in the previous phases. The best practices identified in phase three were used to develop the framework. The framework was validated by experts in the aerospace company. At last validated framework was proposed for guiding the ECM practices in the aerospace company and some generic guidelines were also introduced for the implementation of the framework.

4 The AS-IS ECM Process in the Aerospace Company

This purpose of this chapter is to understand and model the current ECM practice in the aerospace company. Information was captured to achieve a comprehensive understanding of the current ECM practice. The whole ECM practice was modelled using an $IDEF_0$ (Integration Definition for Function Modelling) approach.

4.1 Introduction of $IDEF_0$

$IDEF_0$ is a system modelling tool that can be used to illustrate the functional relationships in a given system. It offers a clear representation of the workflow and objectives that are involved in a process. The basic component of an $IDEF_0$ model is the functional block. The function block can also be decomposed in to sub-functions (usually between three and six) to allow a process to be described in a detail level as desired. The functional block is comprised of the inputs, the outputs, the controls and mechanism that used by the function as shown in Figure 4- 1. (Wu, 1994)

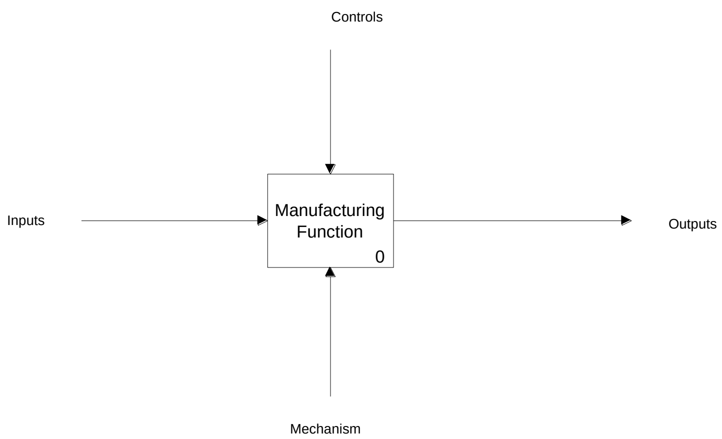

Figure 4- 1 $IDEF_0$ functional block. Source (Wu, 1994)

4.2 Modelling of the AS-IS ECM Process

4.2.1 Overview of the ECM Process

The entire ECM process in the aircraft manufacturing company is consisted of four sub processes:

- Process of Engineering Change Request
- Process of Engineering Change Proposal
- Process of Engineering Change Order
- Process of Implementation of Engineering Change Order

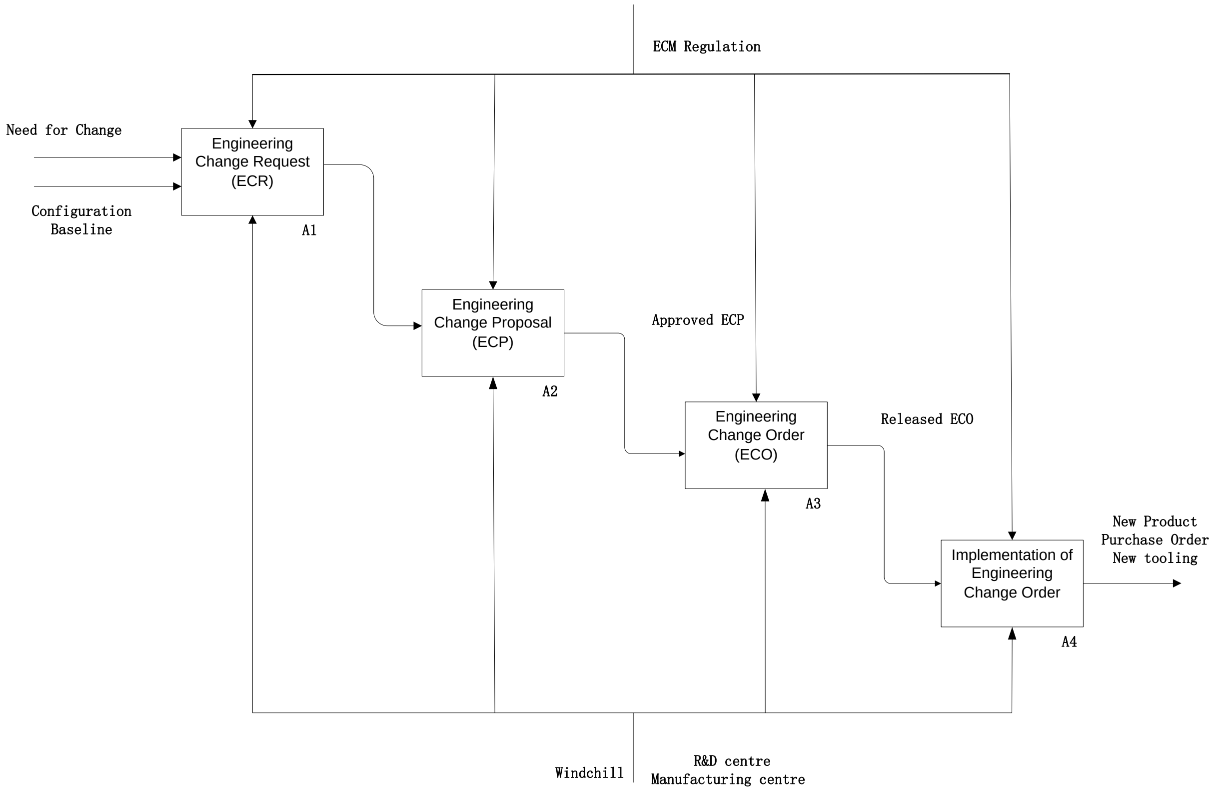

Figure 4- 2 IDEF$_0$ Model of the Entire ECM process

4.2.2 Modelling the Process of ECR

The process of ECR is the first part of the ECM process. This process consists of three major tasks, as listed below and illustrated in Figure 4- 2:

A1 Engineering Change Request

- A11 Initiate ECR
- A12 Evaluate ECR
- A13 Approve/Reject ECR

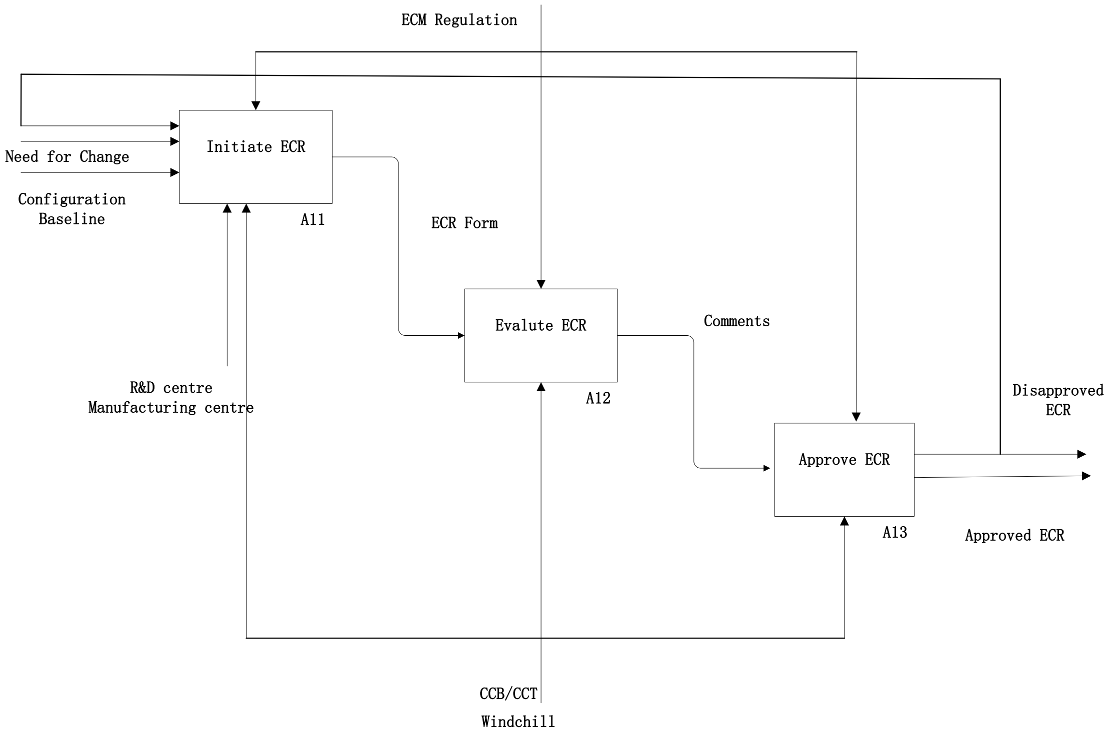

Figure 4- 3 IDEF$_0$ Model of ECR Process

A11 Initiate ECR

ECR is used to collect all the requests for engineering change from design department, manufacturing centre, suppliers and customs. All ECRs should be submitted to the CCT in design centre.

A12 Evaluate ECR

The CCT takes the responsibility of evaluating the ECR. In response to the ECR, CCT shall assign a team member to evaluate the ECR. The ECR will be carefully evaluated from a technical perspective based on system requirements of the relevant systems.

A13 Approve ECR

After the ECR is evaluated, CCT will make the decision whether to approve or disapprove the ECR. In reality, ECRs cannot always be approved. The outcome will be sent to the initiator of the ECR. The Approved ECR will be used as the input of the ECP. The rejected ECR will be sent back to the initiator.

4.2.3 Modelling the Engineering Change Proposal (ECP) Process

The process of ECP is the second part of the ECM process, shown as function block A2 in Fig.A0. ECP is used to describe the proposed EC which will be submitted to CCB (Class I change) or CCT leader (Class II change) for approval in classification as defined. This function block consists of three major tasks, as listed below and illustrated in Figure 4- 4:

A2 Engineering Change Proposal

- A21 Initiate ECP.
- A22 Evaluate ECP.
- A23 Approve/Disapprove ECP.

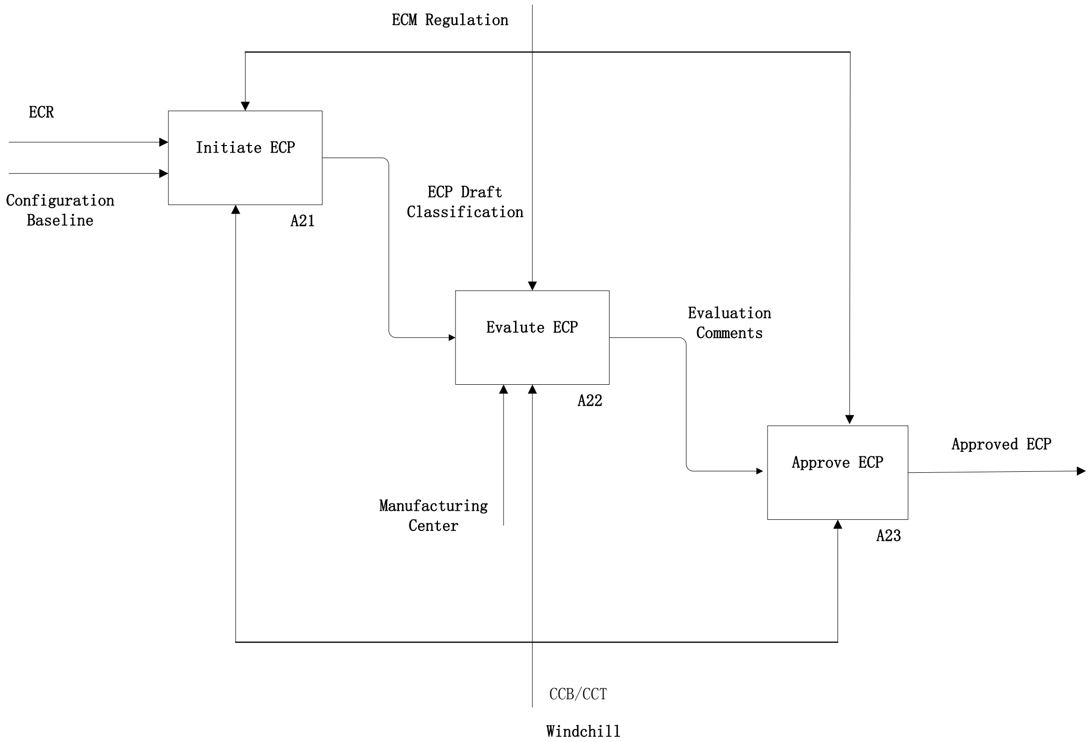

Figure 4- 4 IDEF$_0$ Model of ECP Process

A21 Initiate ECP

The author of the ECP should draft the ECP form. The ECP draft shall contain all the information of the change including the purpose, change description, statement of impact and definition of all affected parties. Check and review are required within the CCT.

An ECP shall be classified as Class I or Class II by the originating CCT in accordance with the criteria defined below:

An ECP classified as Class I is a change to the configuration baseline documentation that has significant impact on the specified factors such as form, fit and function. Class I ECP shall be submitted to the CCB for approval or disapproval. Class I change can be referred as major change.

An ECP which impacts none of the Class I factors specified below shall be classified as Class II. The approval of CCT leader is required for Class II ECP. Class II change can be referred as minor change.

A22 Evaluate ECP

The ECP draft will be distributed to all the affected parties such as affected CCTs and manufacturing centre.

The affected CCT shall review the ECP draft and propose the evaluation of the ECP based on their expertise on the affected system.

The manufacturing centre shall review the ECP draft and evaluation of the ECP based on their expertise on assembly and manufacturing. If the affected components are offered by suppliers, the manufacturing centre shall coordinate the affected supplier to ask for their evaluation on the ECP. The feedback for the ECP should contain the judgment of the ECP draft and the effectiveness proposal for the change. Any suggestions are welcome in this stage.

A23 Approve ECP

After all the affected parties have offered their feedbacks on the ECP draft, the ECP will be submitted for approval. Different authorization level (CCB or CCT leader) is required based on the classification and evaluation of the ECP. The approved ECP is the input of the ECO.

Major changes which are classified as Class I shall be approved by CCB.

Minor changes which are classified as Class II will be valid after the approval of corresponding CCT leader.

4.2.4 Modelling the Engineering Change Order (ECO) Process

The process of ECO is the third part of the ECM process. ECO is used to describe the engineering change which has been approved by certain authorization level. This function block consists of three major tasks, as listed below and illustrated in Figure 4- 5:

A3 Engineering Change Order

- A31 Initiate ECO
- A32 Evaluate ECO
- A33 Release ECO

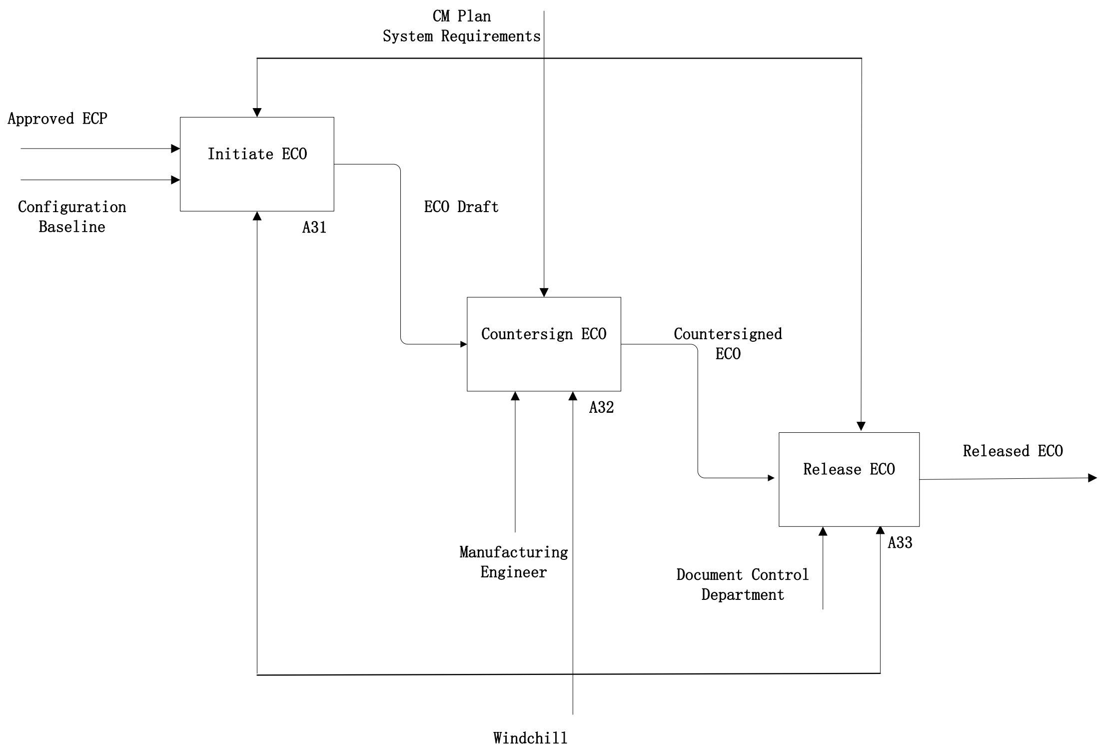

Figure 4- 5 IDEF$_0$ Model of ECO Process

A31 Initiate ECO

The author of the ECP should draft the ECO. The ECO draft is based on the approved ECP and contains the description of the engineering change. The content of an ECO includes part number, revision, effectiveness, and change description. Every change about the drawing and BOM should be presented clearly in the ECO by giving a detailed description about the previous configuration before change and the current configuration after change. Check and review is required within the CCT.

A32 Countersign ECO

The draft ECO will be reviewed by the stress department, general configuration department, weight department, and manufacturing centre. Every department will sign their name after the ECO passed the review. After all the departments have countersigned the ECO, it will be finally approved.

A33 Release ECO

After the ECO is approved, the ECO will be formally released by document control department to the manufacturing centre. The released ECO is the input for the implementation of the change.

4.2.5 Modelling the Implementation Process of ECO

The implementation of ECO is the fourth part of the ECM process. This process consists of three major tasks, as listed below and illustrated in Fig.A4:

A4 Implement ECO

- □ A41 Assign Implementation Task
- □ A42 Plan the Implementation
- □ A43 Implement the Plan

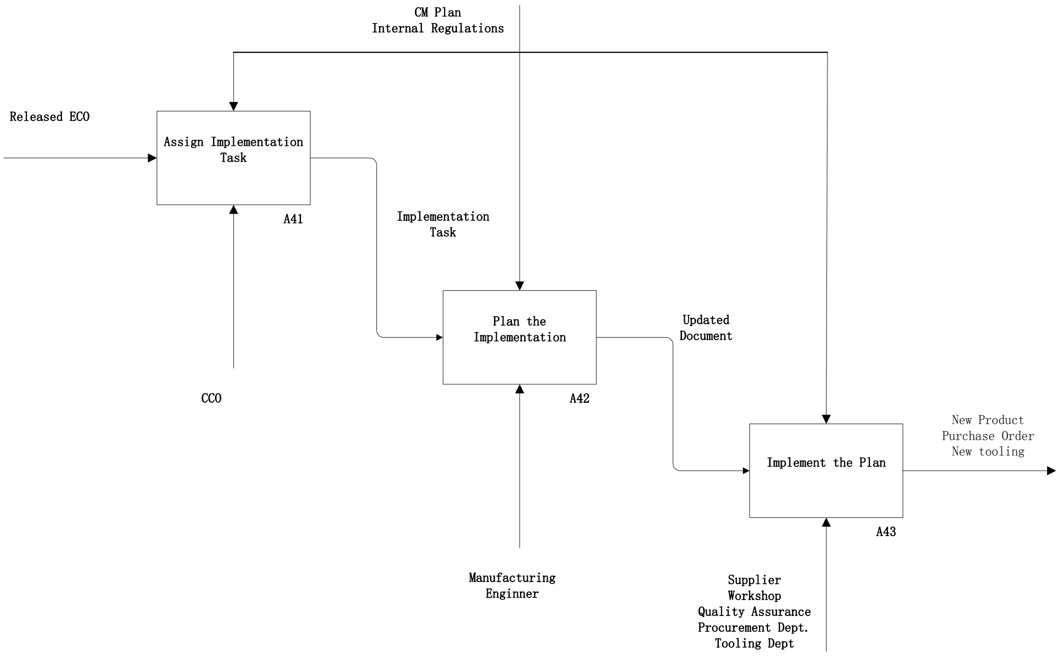

Figure 4- 6 IDEF$_0$ Model of ECO Implementation Process

A41: Assign Implementation Task

When a new ECO is released, it will automatically trigger an assign task in the account of Configuration Control Office (CCO) by a computer-based system. The CCO shall initiate the task for ECO implementation and assign the task into the account of manufacturing engineer who is related to the ECO.

A42: Planning the Implementation

Manufacturing engineer shall identify and revise the document affected by the ECO when receiving the implementation task from the CCO.

When all relevant documents are identified and revised according to the ECO, the manufacturing engineer shall submit all revised documents to a senior manufacturing engineer for review. If there are any mistakes, the revised documents will be rejected and resubmit after correction.

After the revised documents have passed the review of senior manufacturing engineer, the CCO shall verify the integrity of submitted implementation documents and close the implementation task.

A43: The change Implementation

After the revised documents are released to the relevant suppliers and departments such as workshop, tooling and procurement, the responsibility of them is to implement the revised document into their work and documents. The workshops will carry out assembly and manufacturing work based on the new documents. The procurement department will release new purchase order and the tooling department will design and manufacture new tooling.

4.3 Summary of the AS-IS ECM Process and Gap Identification

From the modelling of the AS-IS ECM process in the selected company and also staff interviews, it is clear that a formal ECM process is established in the aircraft manufacturing company. The ECM process covers the whole life-cycle of each EC from the initiation of the change to the final implementation. Different kinds of formal documents are used in order to fulfil the needs in different stage of the ECM process. Organizations such as CCB, CCT and CCO are established as the administration body of the ECs. The ECM process is also embodied in the routine work within the organization. The entire ECM process has guaranteed the company to manage thousands of ECs during the new aircraft development phase in the company as well as with all the suppliers either domestic or foreign. Although the current practice has met the basic needs of engineering change management, problems can still be found in these following areas:

1 No method is used to measure the performance of the ECM process. As a result there is no feedback for continuous improvement of the ECM process.

2 Although the whole ECM process is broken down into sub-processes performed by different organizations and employees, no organization is

established to monitor the entire status of each EC. There is no clear definition of who should be responsible for the whole lifecycle of the ECs.

3 The countersign of the ECs are all based on the decision of manufacturing engineers without the participation of other functional departments such as the procurement department or quality department which brings risk to the implementation if these departments cannot fulfil the requirements of the new released ECs.

4 The process of ECP indicates that there are two different categories of ECs which are described as Class I and Class II. But after the ECP stage is completed, the two kinds of ECs are processed in the same way during the implementation stage in the manufacturing centre.

5 The planning of implementation is only restricted in the manufacturing department. After the documents affected by the ECO are revised and released, there is a lack of central governance of the further execution of these tasks. No information is given to the manufacturing engineer to show when these tasks will be completed.

5 Identify the Best ECM Practice in Aerospace and Automobile Manufacturers

5.1 Survey Design

5.1.1 The Purpose of the Survey

This survey for this research aims to identify the best ECM practices by conducting a benchmarking survey. Based on the identified critical success factors in the literature review and the analysis of AS-IS ECM process in the selected company, a questionnaire was carefully designed and launched for data collection to identify the best ECM practice in the aerospace and automobile industry. Within the scope of ECM, the questions were designed from the perspective of organisation, procedure, activities, responsibilities and supporting tools. The ECM process could be divided into four stages, i.e. identifying, evaluating, implementing, and auditing. This questionnaire has collected the information based on these four activities. By doing this survey, the best ECM practices were identified for developing the ECM framework for the aircraft manufacturing company.

5.1.2 The Search Strategy of the Participants of the Survey

Due to the limitation of resource, the search of relevant industrial companies was based on the FAME database which is available in the university library. The search strategy was carefully designed to capture the group of the relevant companies. Target companies were selected using three criteria.

The first criterion was the state of the companies. The state of the company should be active in the database.

The second criterion was the industrial sectors, aerospace and automobile sectors were selected. The reason for choosing these two industrial domains is because both of them produce high complexity products and share similar ECM process. Engineers, technicians and managers in these industry domains are the main source of participants of this survey.

The third criterion was the size of the company. This survey was focused on medium-sized and large company. According to UK Company Act, the number of employee should be more than 50. The engineers, technicians and managers in industry domain, mainly in aerospace and automotive sectors, were the main targets of this survey.

The email addresses of these companies were gathered for the distribution of the questionnaire in this stage. The search strategy in FAME database is presented in the Appendix B.

Twenty one questions were included in the questionnaire most of which were multiple choice questions. The questionnaire was designed to collect the actual ECM practice based on the degree of satisfaction on the basis of a Likert-type scale, running from very dissatisfied to very satisfied

The questionnaire was divided into six parts. The first part was designed to collect the background information of the participants. The second part was used to obtain a general overview of the ECM practice in the selected company. The other four parts were used to gather the detail information from the identification to the implementation of the ECs. The questionnaire was focused on the following information:

1) Background information of the respondents
2) The rate of the performance of the current ECM practice
3) Core process of the Engineering Change Management (ECM) activities in the company
4) The awareness and understanding of ECM among staffs
5) Strategies and methods for engineering change management
6) The role of different job position in the ECM practice
7) The supporting tool of ECM activities

The questionnaire was developed in a concise manner and tested by volunteers to make sure that the participants could complete it easily in 10 minutes. And the responses could also be used easily for further analysis. Draft questionnaire was reviewed by academic supervisors and five industrial colleagues to ensure that the questionnaire was phrased correctly. All comments were collected and considered for the revision of the draft. After several circles for correction and improvement the final version of the questionnaire was established.

5.1.3 The Distribution of the Online Survey

The online survey was compiled using the university's Qualtrics survey tool. Tests were launched before the final release of the survey to minimize the errors in the questionnaire so that all the participants could participant into an error free survey.

The address for this online survey was sent by the distribution function of the Qualtrics survey tool. The contact information obtained from FAME database was imported into the Qualtrics survey tool to create a panel. Then the tool would send email to all these email addresses to invite people to participate into this survey. All the people that received the invitation to the survey were offered the opportunity to opt-out of receiving future communications.

A statement was made in the survey to inform the participants that they are free to withdraw their participation from this survey at any time. All the responses were kept completely confidential and were only used for this research.

5.2 Identification of the Best ECM Practice

5.2.1 Introduction

All the participants were given three weeks to give feedback to the survey. 31 respondents from different companies have participated into the survey. The data of this online survey is stored in the database of the Cranfield University's Qualtrics survey tool.

5.2.2 General Information of the Respondents

The survey was sent to the contacts in the selected company from FAME database. Q1 and Q2 were designed to obtain the background information about the respondents.

The total work experience of the respondents were categorised in the range of 0-2 years, 3-5 years, 5-10 years and 10+ years. As presented in Fig 5-1, more than 85% of the respondents have been working for more than three years, and nearly 14% is less than 2 years. Although the experience of the respondents covers all the categories, it still shows that the ECM process is performed by experienced employees in general.

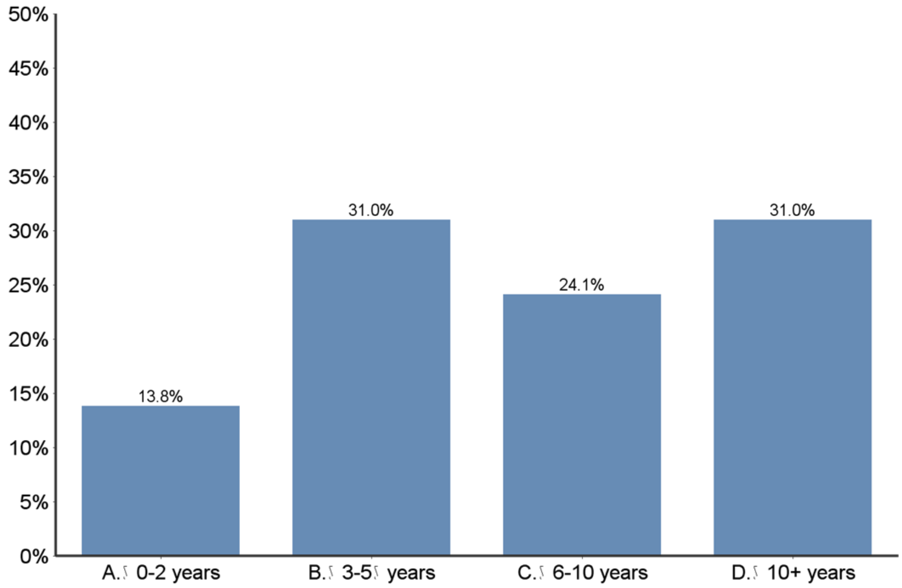

Figure 5- 1 Work experience of the respondents (Q1)

The respondents were asked to rate the performance of the Engineering Change Management practice in their company. The rank of the rate is divided into five levels following the Likert-type scale: Very Satisified, Satisfied, Neutral, Dissatisified and Very Dissatisified. The distrbution of the satisfaction towards the current ECM practice is shown in Figure 5- 2.

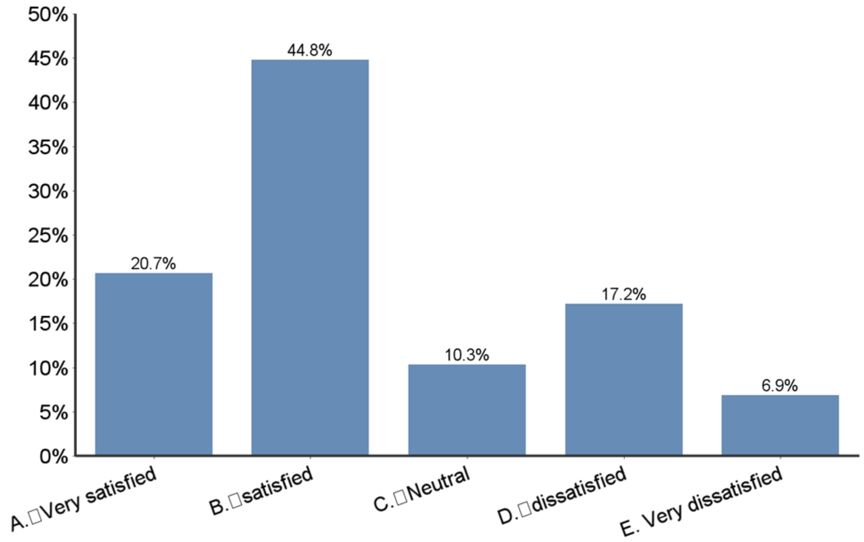

Figure 5- 2 The distribution of satisfaction (Q2)

5.2.3 The identification of Best ECM Practices

In this part, the result of the survey is analysed to identify the best ECM practice. The outcome of this survey shows the relationship between the actual ECM practice and their level of satisfaction towards the overall ECM performance. The cross-tabulation is a basic technique for examining the relationship between two categorical factors. The column gives the rate of satisfaction oragnized in Likert-type scale from 1(Very dissatisfied) to 5 (Very satisfied) on each practice while the actual ECM practice is presented in the row. The frequency of the each rate category is marked from "f_1" to "f_5", and "$\bar{x}$" is used to stand for the average satisfaction. So the equation for caculating the "$\bar{x}$" is shown in Equation 5- 1:

$$\bar{x}_i = \frac{\sum f_{ij} x_i}{\sum f_{ij}}$$

Equation 5- 1 Average satisfaction of each ECM practice

		The rate of satisfaction given by respondents					
		5(Very satisfied)	4(Satisfied)	3(Neutral)	2(Dissatisfied)	1(Very dissatisfied)	Average of satisfaction
Does the company follow a certain practice?	Yes	f_{11}	f_{12}	f_{13}	f_{14}	f_{15}	$\bar{x}_1$
	No	f_{21}	f_{22}	f_{23}	f_{24}	f_{25}	$\bar{x}_2$

Table 5- 1 The concept of caculating the "$\bar{x}$"

The value of "$\bar{x}$" illustrates the average satisfaction of different ECM practice, if the $\bar{x}$ in the "yes" category is larger than the $\bar{x}$ in the "no" category, it means the companies who are following the certain practice are more likely to have a higher rate of satisfaction about their ECM performance. Based on the survey data analysis and interpretation, the practice which can generate a higher "$\bar{x}$" is recongnized as the best practice for ECM. All the $\bar{x}$ for each different ECM practice are illustrated in Table 5- 2 and Table 5- 3:

Question No.	The category of different practice in respondents' companies		Percentage	$\bar{X}$
3	Does your company have a formal process for the Engineering Change Management?	A. Yes	93.6%	3.6
		B. No	6.4%	2.5
4	How are Engineering Changes processed in your company?	A. Processed individually	77.4%	3.4
		B. Processed in batch	0.0%	N/A
		C. Depends on its classification	22.6%	4.0
5	Does your company use any methods to measure the performance of the Engineering Change Management Process?	A. Yes	54.8%	3.8
		B. No	45.2%	3.1
6	What is most important for measuring the performance of the ECM Process in your company?	A. Cost from initiation to implementation	0.0%	N/A
		B. Time from initiation to implementation	35.3%	3.5
		C. Cost and time from initiation to implementation	52.9%	3.8
		D. Other	11.8%	4.5
7	Does your company use any PLM (Product Life-cycle Management) software for Engineering Change Management?	A. Yes	32.3%	3.5
		B. No	67.7%	3.5
8	Does your company have a formal process for identifying the Engineering Change?	A. Yes	96.8%	3.5
		B. No	3.2%	2.0
9	Does your company have certain criteria to classify the identified Engineering Change?	A. Yes	87.1%	3.6
		B. No	12.9%	2.5
10	What is the criterion classifying the Engineering Change in your company?	A. Purpose (e.g.1 Enhance; 2 Error Correction)	48.2%	3.6
		B. Urgency (e.g.1 Immediate; 2 Convenience)	7.4%	2.5
		C. Effect (e.g.1 Scrap; 2 Rework; 3 Us-as-is)	11.1%	3.0
		D. Others	33.3%	4.1
11	Does your company have a formal process to evaluate the impact of Engineering Change?	A. Yes	67.7%	3.6
		B. No	32.3%	3.2
12	Who is responsible for evaluating of the impact of Engineering Change in your company?	A. Designer	16.1%	3.6
		B. Project Manager	16.1%	4.0
		C. Assigned EC coordinator	12.9%	3.3
		D. Manufacturing Engineer	6.5%	4.0
		E. Quality Engineer	6.5%	3.0
		F. Change Committee/Team/Board	29.0%	3.3
		G. Nobody	3.2%	1.0
		H. Others	9.7%	4.0

Table 5- 2 $\bar{x}$ for each different ECM practice

Question No.	The category of different practice in respondents' companies		Percentage	$\bar{X}$
13	Does your company use any methods in evaluating the impact of Engineering Change?	A. Yes	58.1%	3.8
		B. No	41.9%	3.0
14	Which following method best describing the current practice of evaluating the impact of Engineering Change in your company?	A. Committee/Team/Board for reviewing the Engineering Change	44.4%	4.0
		B. Tools for predicting impact of the Engineering Change	22.2%	4.0
		C. Others	33.3%	3.5
15	Does your company have a formal process for the implementation of Engineering Change?	A. Yes	87.1%	3.7
		B. No	12.9%	2.3
16	Who is responsible for the implementation of Engineering Change in your company?	A. Designer	16.1%	3.4
		B. Project Manager	6.5%	5.0
		C. Assigned EC coordinator	12.9%	3.3
		D. Manufacturing Engineer	19.4%	3.0
		E. Quality Engineer	12.9%	3.5
		F. Change Committee/Team/Board	19.4%	3.5
		G. Nobody	3.2%	1.0
		H. Others	9.7%	4.7
17	Does your company use implementation plan to control the implementation of Engineering Change?	A. Yes	67.7%	3.8
		B. No	32.3%	2.9
18	Does your company use any ERP software to implement or help to implement the Engineering Change?	A. Yes	58.1%	3.4
		B. No	41.9%	3.5
19	Does your company have a formal process to audit the implementation of the Engineering Change?	A. Yes	58.1%	4.1
		B. No	41.9%	2.7
20	Who is responsible for the audit of the Engineering Change to ensure corrective implementation in your company?	A. Designer	0.0%	N/A
		B. Project Manager	6.5%	4.5
		C. Assigned EC coordinator	0.0%	N/A
		D. Manufacturing Engineer	3.2%	5.0
		E. Quality Engineer	35.5%	3.5
		F. Change Committee/Team/Board	12.9%	3.8
		G. Nobody	22.6%	2.1
		H. Others	19.4%	4.2
21	Which one is the closest to the frequency of the audit in your company?	A. Daily	12.9%	4.5
		B. Weekly	3.2%	5.0
		C. Monthly	22.6%	4.0
		D. Quarterly	19.4%	3.5
		E. Yearly	19.4%	3.5
		F. Never	22.6%	2.1

Table 5- 3 $\bar{x}$ for each different ECM practice

5.2.4 Findings from the survey

Q3-Q21 were designed to collect the actual ECM practice in the surveyed companies. In this section, the result of the survey is shown and interpreted.

Q3 Does your company have a formal process for the Engineering Change Management?

The vast majority (93.6%) respondent companies have adopted a formal process to manage the ECs. The average satisfaction ($\bar{x}$) of this group is 3.6. Only a small number of surveyed companies (6.4%) do not own a formal ECM process and the number of $\bar{x}$ for this group is 2.5 which is below the level of neutral. It could be deduced that the importance of having a formal ECM process is acknowledged by most of the respondent companies and a high degree of satifaction is enjoyed by these companies.

Q4 How are Engineering Changes processed in your company?

The result shows that 77.4% of the respondent companies have chosen to process all the ECs individually. And only 22.4% of them choose to process ECs according to their classification. Although dealing with ECs in a individually manner is perfered by most of the surveyed companies, the mean degree of satisfaction ($\bar{x}$=3.4) is lower than those processing ECs according to its classcifiaction ($\bar{x}$=4.0). This result prove that processing ECs by classification can benefit the performance of the ECM.

Q5 Does your company use any methods to measure the performance of the Engineering Change Management Process?

Q6 What is most important for measuring the performance of the ECM Process in your company?

The survey shows that 54.8% of the surveyed companies are measuring their ECM proformance of which the $\bar{x}$ is 3.8 while the opposite group are with a lower $\bar{x}$ which is 3.1. To use combination of cost and time to indicate the ECM performance is the most popular way (52.9%) and gernerate a average satisfaction at 3.8.

Q7 Does your company use any PLM (Product Life-cycle Management) software for Engineering Change Management?

There are a certain number of PLM softwares designed to fullfill the needs of ECM aviliable on market. Despite the importance and advantages of PLM softwares have been addressed by several literatures, however, this survey revealed that PLM software had not been widely used in the respondent companies, only a little more than a third of the respondent companies replied that they employ PLM software in the ECM process and the rest of the respondent companies are not using any PLM software. The the $\bar{x}$ of the companies using PLM software is 3.5 while the $\bar{x}$ of the opposite group is the same. This outcome means using PLM software or not actually does not affect the ECM performance in these investigated companies.

Q8 Does your company have a formal process for identifying the Engineering Change?

According to the survey, 96.8% of the sample companies have a formal process for identifying the engineering change. And the $\bar{x}$ for this group is 3.5. The $\bar{x}$ of the rest 3.2% companies is only 2 which means the performance of the ECM can fell dramatically without a formal process.

Q9 Does your company have certain criteria to classify the identified Engineering Change?

Q10 What is the criterion classifying the Engineering Change in your company?

Although the majority of respondent companies have formal process for classifying the engineering change, 12.9% of the respondent companies do not have a classification of the engineering change. It is observed that the classification of ECs can help these companies obtain a higher degree of satisfaction ($\bar{x}$ = 3.6) of ECM performance while $\bar{x}$ of the opposite group is only 2.6. The distribution illustrate that the companies who have a classification for the engineering change are more likely to be satisfied with their ECM process.

Q11 Does your company have a formal process to evaluate the impact of Engineering Change?

Q12 Who is responsible for evaluating of the impact of Engineering Change in your company?

The result of Q11-12 shows that the companies which have a formal process for evaluation are more likely to be satisfied with their ECM performance. The largest proportion of the sampled company uses Change Committee/Team/Board to take the responsibility of evaluating the change. Another popular way is to let the project manager be responsible to the evaluation of ECs which can achieve the highest ECM performance ($\bar{x}$ = 4.0).

Q13 Does your company use any methods in evaluating the impact of Engineering Change?

Q14 Which following method best describing the current practice of evaluating the impact of Engineering Change in your company?

From the survey result of Q13-14, it can be seen that 58.1% of the survey companies have established certain method to facilitate the change evaluation 44.4% of which establish Committee/Team/Board for reviewing the Engineering Change while 22,2% of them employ tools for predicting impact of the Engineering Change. The high degree of satisfaction ($\bar{x}$ = 4.0) of this group shows the establishment of a change committee can lead to a better ECM performance.

Q15 Does your company have a formal process for the implementation of Engineering Change?

Q16 Who is responsible for the implementation of Engineering Change in your company?

The responses to these two questions show that the companies which have a formal process for implementation are also more likely to be satisfied with their ECM performance. 19.4% of the surveyed company uses Change Committee/Team/Board to take the responsibility of implementing the change. Although the same percentage of the respondents let manufacturing engineer to be responsible for the implementation, the degree of satisfaction ($\bar{x}$ = 3.0) is actually low than those using the change committee ($\bar{x}$ = 3.5). However the highest degree of satisfaction ($\bar{x}$ = 5.0) is achieved when the project manager is taking charge of the change implementation yet only 6.5 % of the companies are following this practice.

Q17 Does your company use implementation plan to control the implementation?

The result shows that 67.7% of the respondent companies have chosen to use implementation plan to control the change implementation. The the $\bar{x}$ of the companies using implementation plan is 3.8 while the $\bar{x}$ of the opposite group is the only 2.9. This distribution of response means using implementation plan is well accepted practice in these investigated companies and it can also bring notable benifit to the ECM performance.

Q18 Does your company use any ERP software to implement or help to implement the Engineering Change?

Compared to the usage of PLM software, ERP software is more widely used in the respondent companies, 58.5% the respondent companies replied that they employ ERP software implement or help to implement the ECs in the ECM process. However the the $\bar{x}$ of the companies using ERP software is 3.4 while the $\bar{x}$ of the opposite group is the 3.5. This result shows that using ERP software may not be able to incease the performance of ECM.

Q19 Does your company have a formal process to audit the implementation of the Engineering Change?

Q20 Who is responsible for the audit of the Engineering Change to ensure corrective implementation in your company?

Accoring to the result, 58.1% of respondents have responded that their companes have a formal process to auit the implementation of the Engineering Change. The average satisfaction of this group is 4.1. The rest responsed indicates that they do not own a formal auit process and the $\bar{x}$ of this group is only 2.7.

The shows qulity engineer is responsible for auiting the change implementation in 35.5% of the surveyed companies and the average degree of satisfaction about the ECM in these companies is 3.5.

Q21 Which one is the closest to the frequency of the audit in your company?

The outcome of Q21 shows the link between the degree of satisfaction and the frequency. The degree of satisfaction is relatively high when the audit frequency is under monthly.

5.2.5 Summary of the Survey Data Analysis and Interpretation

The main objective of this survey is to identify the best practice that can promote the performance of the ECM practice in the survey companies. Based on the survey data analysis and interpretation, the findings of this survey can be summarized as follows:

1. A formal ECM process can generate higher degree of satisfaction than an ad hoc process. The entire ECM lifecycle is broken down into four stages in this survey: identification, evaluation, implementation and audit. This survey reveals that the formal process should cover all these four stages in order to obtain a better ECM performance. As can be seen in Table 5- 4, the respondent companies that have a formal process in these four stages take

up a higher percentage and also have a higher degree of satisfaction towards their ECM.

The category of different practice in respondents' companies		$\bar{X}$	Percentage
Does your company have a formal process for the Engineering Change Management?	A. Yes	3.6	93.6%
	B. No	2.5	6.4%
Does your company have a formal process for identifying the Engineering Change?	A. Yes	3.5	96.8%
	B. No	2.0	3.2%
Does your company have a formal process to evaluate the impact of Engineering Change?	A. Yes	3.6	67.7%
	B. No	3.2	32.3%
Does your company have a formal process for the implementation of Engineering Change?	A. Yes	3.7	87.1%
	B. No	2.3	12.9%
Does your company have a formal process to audit the implementation of the Engineering Change?	A. Yes	4.1	58.1%
	B. No	2.7	41.9%

Table 5- 4 Findings about formal ECM process

2. The performance of the ECM process can be improved by classifying the ECs. It is observed that classifying the ECs by purpose takes up the majority part (48.2%) among all the other criterions.

Does your company have certain criteria to classify the identified Engineering Change?	A. Yes	3.6	87.1%
	B. No	2.5	12.9%
What are the criterion classifying the Engineering Change in your company?	A. Purpose (e.g.1 Enhance; 2 Error Correction)	3.6	48.2%
	B. Urgency (e.g.1 Immediate; 2 Convenience)	2.5	7.4%
	C. Effect (e.g.1 Scrap; 2 Rework; 3 Us-as-is)	3.0	11.1%
	D. Others	4.1	33.3%

Table 5- 5 Findings about classification of ECs

3. It is highlighted by this survey that improvement can be achieved by measuring the performances of ECM process.

The category of different practice in respondents' companies		$\bar{X}$	Percentage
Does your company use any methods to measure the performance of the Engineering Change Management Process?	A. Yes	3.8	54.8%
	B. No	3.1	45.2%
What is most important for measuring the performance of the ECM Process in your company?	A. Cost from initiation to implementation	N/A	0.0%
	B. Time from initiation to implementation	3.5	35.3%
	C. Cost and time from initiation to implementation	3.8	52.9%
	D. Other	4.5	11.8%

Table 5- 6 Findings about formal ECM process

4. The importance of formally established Change Committee/Team/Board is identified by this survey. This organization is playing an important role in the EC lifecycle in the largest proportion of the surveyed companies. And the companies following this strategy are benefited from this practice.

The category of different practice in respondents' companies		$\bar{X}$	Percentage
Which following method best describing the current practice of evaluating the impact of Engineering Change in your company?	A. Committee/Team/Board for reviewing the Engineering Change	4.0	44.4%
	B. Tools for predicting impact of the Engineering Change	4.0	22.2%
	C. Others	3.5	33.3%

Table 5- 7 Findings about the utilization of the Change Committee/Team/Board

5. The utilization of implementation plan can generate a higher ECM performance.

The category of different practice in respondents' companies		$\bar{X}$	Percentage
Does your company use implementation plan to control the implementation of Engineering Change?	A. Yes	3.8	67.7%
	B. No	2.9	32.3%

Table 5- 8 Findings about the utilization of implementation plan

1. This survey also reveals that the usage of PLM and ERP software does not affect the performance of the ECM practice in the respondent companies.

The category of different practice in respondents' companies		$\bar{X}$	Percentage
Does your company use any PLM (Product Life-cycle Management) software for Engineering Change Management?	A. Yes	3.5	32.3%
	B. No	3.5	67.7%
Does your company use any ERP software to implement or help to implement the Engineering Change?	A. Yes	3.4	58.1%
	B. No	3.5	41.9%

Table 5- 9 Findings about the PLM and ERP software

6 Framework Development and Validation

6.1 Framework Development

6.1.1 Introduction

A formalised framework for engineering change management is shown in this chapter. The development of this framework was based on literature review, questionnaire surveys, and internal analysis of the current ECM practice in the selected company. A list of best practices which can promote the performance of the ECM practice was highlighted by the survey as follows:

- Formal process for each stage of ECM
- The classification of ECs
- The measurement of the ECM performance
- The utilization of the Change Committee/Team/Board
- The utilization of implementation plan

Following that, the concept of this framework was to integrate these best practices into the current ECM practice in the company. Recommendations were made based on these best practices to refine the current ECM practice. The purpose of the new developed framework is to enhance the performance of ECM in the company and provide a guideline for other companies who want to refine their ECM practice.

6.1.2 The Difference between the New Developed Framework and the Old ECM Process

In the current ECM process, when the ECs have entered implementation stage in the manufacturing company, it is observed that there is no established organization for organizing and coordinating the implementation task in different functional departments. Based on the findings from the survey, the recommendation is to establish a Change Implementation Board (CIB) to take the responsibility of managing of the EC implementation.

The CIB will serve as the interface of the ECM process between the manufacturing centre and the R&D centre. And internally the CIB will serve as the organizer of the ECM process in the manufacturing centre. The CIB team should be comprised of members from functional departments that are relevant with the implementation of ECs. The implementation plan will also be classified into Class I and Class II categories based on the classification of the EC. And the following audit process will also depend on the classification of the implementation plan.

The practice of implementation plan is embodied into the new framework. In the current process the implementation of the ECM is carried out separately in different functional departments. In the new framework the implementation plan will serve as an effective tool for the central governance of the EC implementation in the manufacturing company.

In order to measure the performance of the ECM process, indicators should be identified to guarantee the objectives to be completed in time. During the ECR stage, it may be difficult to estimate the cost and time to be consumed by this change because it is difficult to make comparison between ECs which are usually proposed from different technical perspectives. However, after the ECR has been accepted into the stage of ECP, decisions can be made to define the requirement of time and cost after the potential impact of the EC is evaluated.

The whole process of the ECM can be divided into four stages under the control of CIB, namely, coordinating, planning, implementing and auditing of the EC implementation. The detail of the framework is described in the next section.

6.1.3 Framework design

The framework is divided into four stages and described as follows:

Stage 1: The coordinating stage

The objective of this stage is to analyse the feasibility of the implementation of the proposed change.

When ECP is released to the manufacturing centre for review the CIB shall coordinate with CIB members in the relevant functional departments. The ECP is distributed to the members of CIB to request for comments.

The CIB members in the relevant functional departments shall review the ECP to provide their comments about the ECP based on their professional experience. The comments should focus on the influences to the manufacturing triggered by the ECP. Suggestions can be made to help the ECP creator improve the design. The potential barriers for the implementation can also be identified in the comments. If the ECP is not agreed, explanation should be included in the comments to express the reason.

The collection of comments is to reach a consensus in the manufacturing centre about the ECP. Decision should be made by the CIB to either accept or reject the ECP.

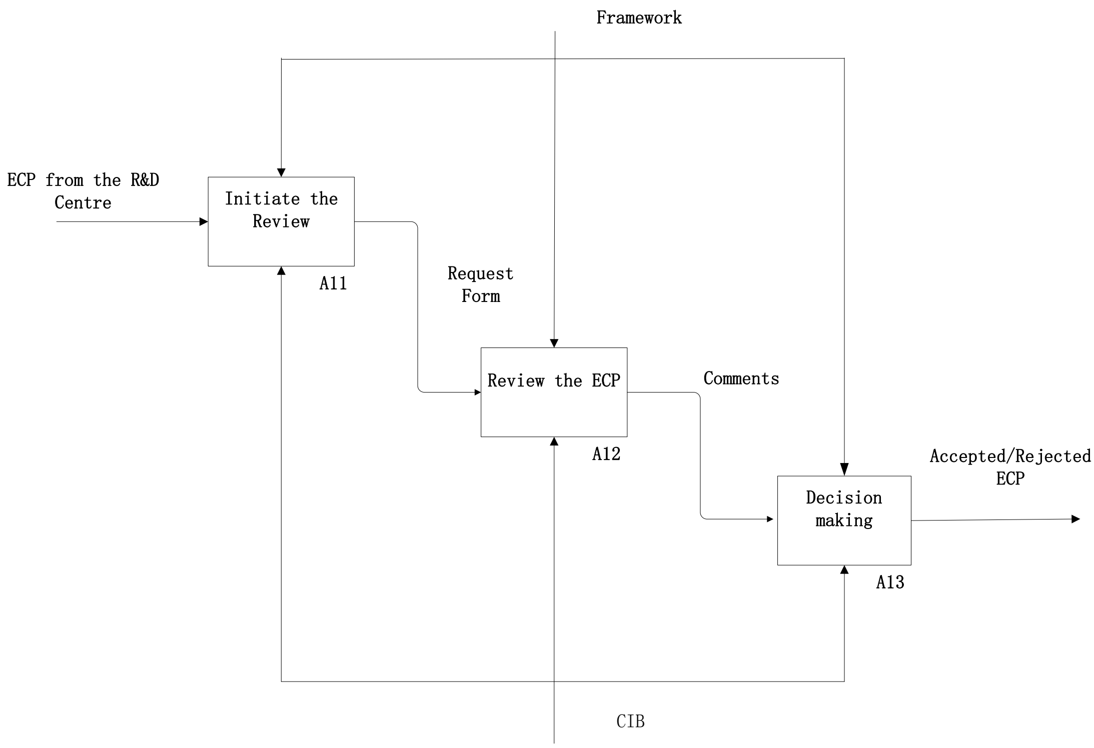

Figure 6- 1 The IDEF$_0$ model of the coordinating stage

Stage 2: The planning stage

The objective of this stage is to output a practical plan for the EC implementation.

After the ECP is accepted, an implementation plan shall be initiated by CIB as the preparation for the future work triggered by the ECP. All the solutions for the ECP from different functional department are collected by CIB to create the overall implementation plan. A final agreed and integrated plan for the implementation of the EC shall be developed by the CIB. This plan should identify all of the required actions, the responsibilities, the timing and schedule as well as the associated resources. The implementation plan should also contain the estimation of the resource that is needed to fulfil the requirement of the EC and tasks for the relevant functional department. Documents should be identified for modification to accommodate the change. The assignment of tasks for the EC implementation should also be included in the plan.

As mentioned in the AS-IS model of the current ECM practice, each ECP is classified as class I (major change) or class II (minor change) based on the nature of the ECP. In this framework, it is also recommended that the implementation plan should also be classified as class I or class II following the classification of ECP.

To the class I changes, a set of indicators can be fixed by the CIB to estimate the cost and schedule of the implementation. These indicators can be used to compare with the actual cost and time to identify potential room for further improvement after the implementation is completed. A possible element of this implementation plan is shown by Table 6- 1

Tasks	Description	Department	Time Estimation	Cost Estimation
1	*Purchasing new fasteners*	*Procurement*	***	***
2	*Revising relevant document*	*Manufacturing*	***	***
3	*Manufacturing new product*	*Workshop*	***	***
4	Testing the conformity	Quality	***	***
…	……	……	……	……

Table 6- 1 A possible element of implementation plan (class I)

To the class II changes, the implementation plan can be simplified considering that the class II change has no effect on the form, fit and function of the product. Thus only paper work needs to be done to revise the versions of the new released drawings in the relevant manufacturing documents. Thus the implementation plan is designed as shown in Table 6- 2

Tasks	Description	Department
1	*Revising relevant documen*	*Procurement*
2	*Revising relevant document*	*Manufacturing*
3	*Revising relevant documen*	*Workshop*
4	*Revising relevant documen*	Quality
...	......	......

Table 6- 2 A possible element of implementation plan (class II)

After the implementation plan is compiled and released, each functional department will be fully aware of their individual tasks as well as the deadline and budget. When the implementation plan has been compiled, the CIB shall review it to ensure its conformity to the proposed change. If the solution cannot fulfil the demand of time or cost the EC, the CIB shall return the solution to the functional department for revision.

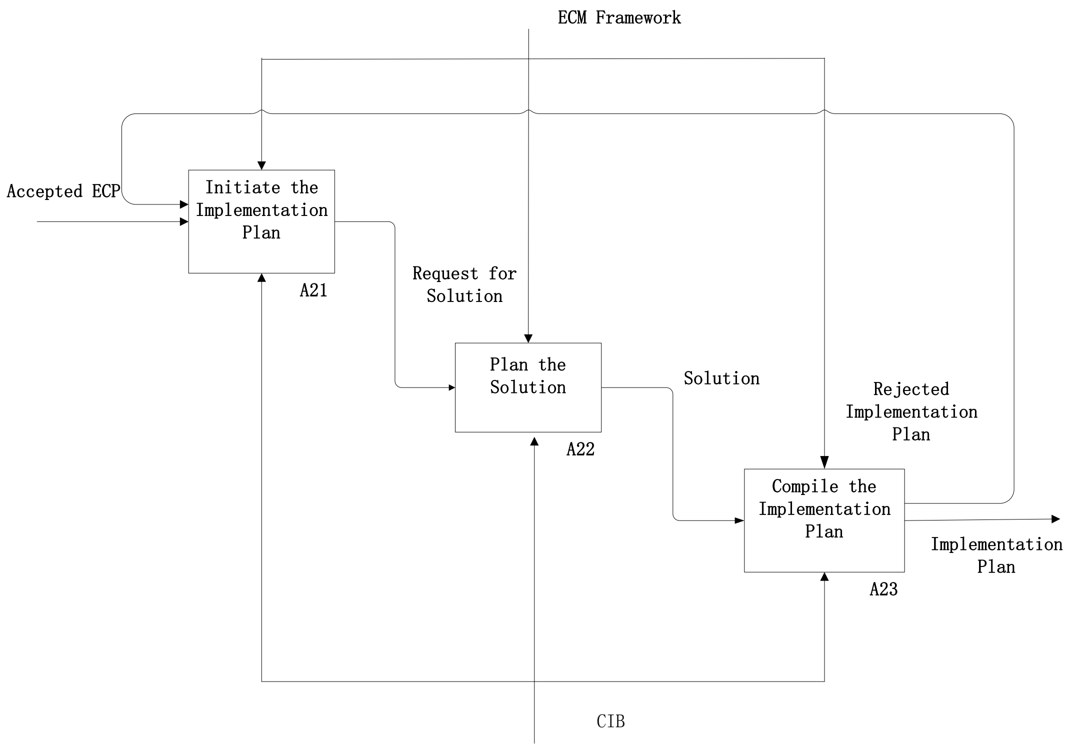

Figure 6- 2 The IDEF$_0$ model of the planning stage

Stage 3: The implementing stage

The objective of this stage is to implement the released implementation plan in the execution phase.

Although the implementation plan is intended to be practical, information should be shared continuously between the CIB and members in the functional department in order to control their discrepancies with the plan. Communication mechanism should be established with the purpose of carrying out risk identification and mitigation during the execution of the plan. Any difficulties encountered when carrying out the assigned task should be reported to CIB. CIB shall conduct impact analysis and make subsequent decision to find solution to settle the problem. The implementation plan can be revised to accommodate changes generated from the potential risk.

After all the assigned tasks are completed, the CIB member in the functional departments shall compile an implementation report and send it to the CIB. The content of the report should include all the actions that are taken to finish the assigned tasks and the real cost and time of the implementation. All the implementation reports shall be combined into one document by CIB as the record of the implementation.

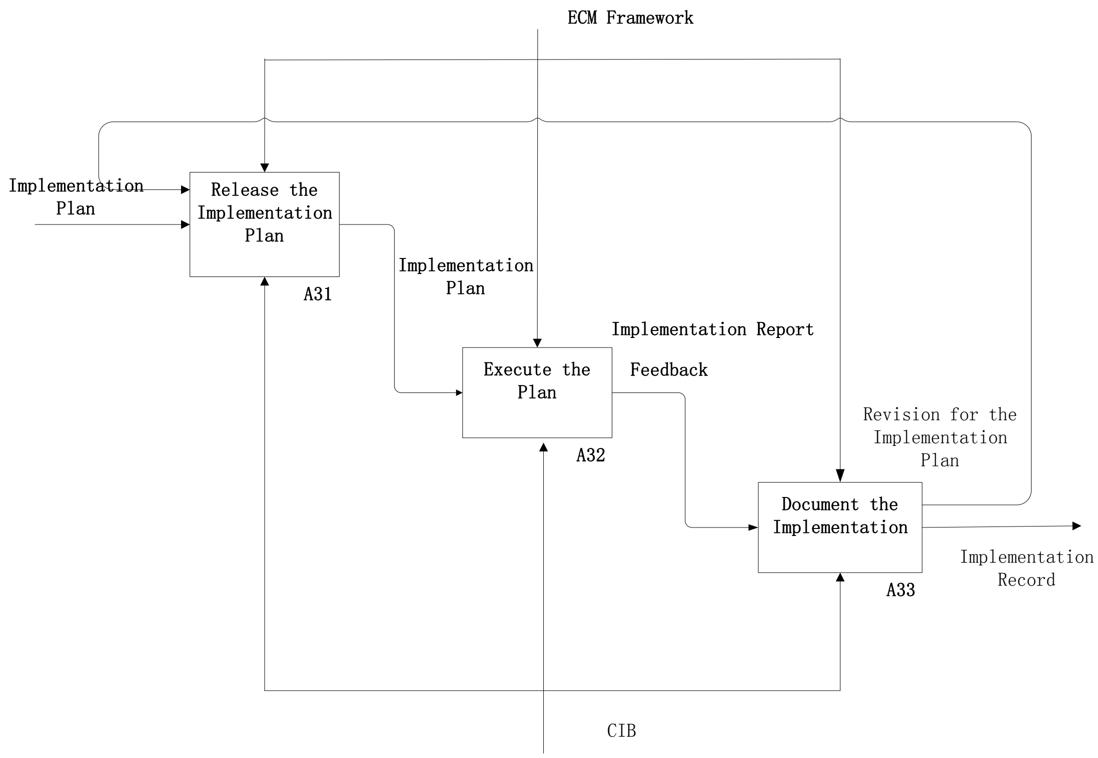

Figure 6- 3 The $IDEF_0$ model of the implementing stage

Stage 4: The auditing stage

The objective of this stage is to ensure that actions taken by the functional departments are in conformance with the tasks described in the implementation plans. New requirements from the EC should be implemented into the documents and products.

Due to the different classification of ECs, the audit shall follow a different process towards each kind of the implementation plan. And based on the finding from the survey, the CIB shall arrange the audit at least monthly.

To the class I ECs, all the ECs should be covered by the audit due to the impact of the EC. The real cost and time captured by the implementation record are used for the measurement of the ECM performance. The performance of the ECM performance can be calculated as shown in Table 6- 3 using real results and estimations in stage 2:

Cost Indicator	Time Indicator
$I_c = \frac{Real\ cost\ of\ the\ plan}{Estimated\ cost}$	$I_t = \frac{Real\ time\ spent\ on\ the\ plan}{Estimated\ time}$

Table 6- 3 Calculation of ECM performance indicators

After the calculation of the indicators, the number of I_c and I_t shall be fed back to the functional departments. The indicators can be used to identify potential room for improvement. The establishment of this feedback mechanism is to ensure that the ECM performance is improved continuously.

To the class II changes, steps should also be taken to maintain the accuracy of the paper work. The audit should focus on the conformity between the ECs and revised documents which are identified in the implementation plan. If any mistakes are discovered during the audit, the outcomes should also be fed back to the functional department for further improvement.

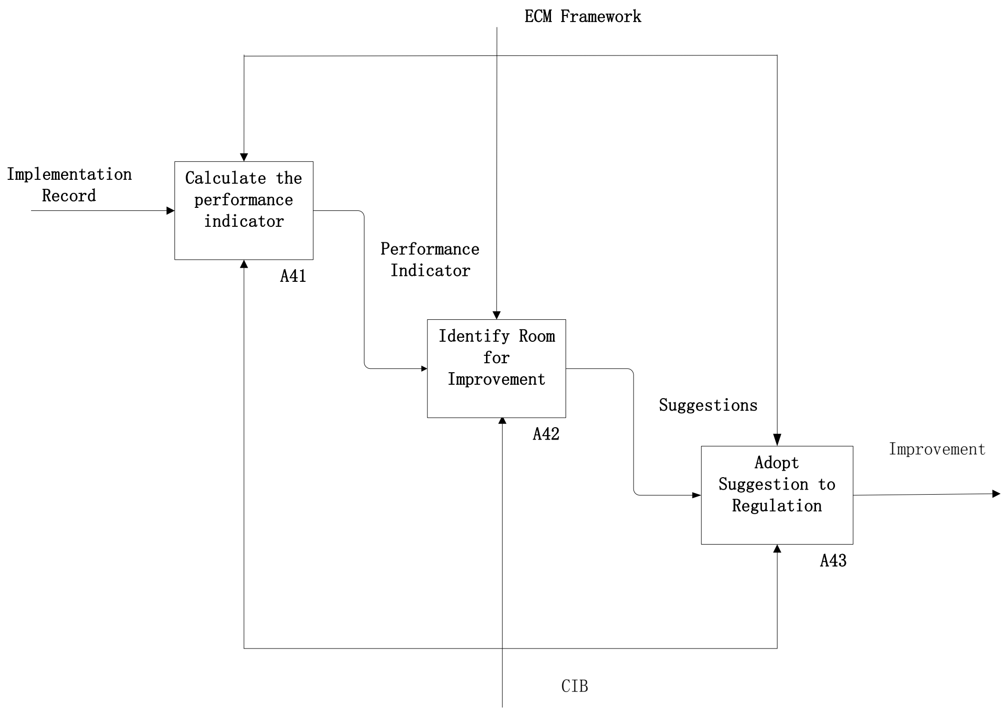

Figure 6- 4 The $IDEF_0$ model of the auditing stage

6.2 Framework Validation

6.2.1 Framework Validation Process

This section aims to validate the developed ECM framework by consulting experts in the aerospace company. Three experts in the aircraft manufacturing company were invited to validate the proposed framework. The draft thesis was sent to the experts by email. Explanation was made through internet to help all experts to understand the research. And the experts could contact the author when they had queries about the research project. A semi-structured questionnaire was also attached to let the experts give comments.

The criteria for selecting the experts were their position and work experience. The experts should have been working in the company for a reasonably time. The criterion of working experience guaranteed that the experts were familiar with the ECM process in the company thus to provide qualified comments for the proposed framework. The background of the three experts is shown in Table 6- 4.

Expert	A	B	C
Position	Senior configuration manager	Senior manufacturing engineer	Configuration manager
Experience	Over five years	Over five years	Over four years

Table 6- 4 Background of the three experts

6.2.2 Expert Comments on the ECM Framework

The feedback from the experts shows that most of the practices proposed in the framework were confirmed by the experts. The comments from the three experts were categorised into two parts: positive comments and shortcomings. Positive comments shows that the experts have confirmed the practice in the proposed framework will be able to provide benefits to the ECM process in the company. Shortcomings were given when the experts thought that there was still room for improvement for the framework.

Positive comments about the ECM framework are shown as follows:

The practice of establishing the CIB as the organizer of all the ECs was confirmed by experts. Comments from the experts show that experts think the establishment of the CIB can benefit the coordinating and implementing stage of the ECs:

- *By including all the different functional departments in the CIB, the evaluation of the change impact will be more accurate and authentic especially when the ECs involve more than one functional department in the coordinating stage.*
- *The feedback (whether agree or not) from the functional departments in the coordinating stage can offer constructive comments for the further improvement of the EC which can help avoid unnecessary work in the implementation stage.*

The utilization and classification of implementation plan for EC was also confirmed by experts.

- *The process of EC implementation can be more efficient by classifying the implementation plan based on the EC classification. By including the task, estimated time and cost in the implementation plan, a solid foundation is created for the final implementation of the EC.*
- *Communication mechanism in the implementation stage can mitigate risk during the implementation of ECs. The share of information within the CIB can guarantee the correct conduction of the implementation plan.*

From the experts' point of view, the measurement of the performance of the ECM process can also provide benefits to the continuous improvement of ECM in the company.

- *Regular audit guarantees the conformity between the product and the documents. The feedback loop which links the auditing stage and the planning stage can create a continuous improvement mechanism for the ECM process in the company.*

The experts also pointed out a shortcoming of the framework for improvement which is shown below:

- *In the planning stage, the framework should allow the CIB to return the solution from the functional department if the solution could not fulfil the demand of time or cost the EC.*

The reason for this comment is that the experts pointed out that CIB can not only accept the solution proposed by the functional departments. The CIB should have the right to return the solution under some circumstance. For example, if some constraints of time or cost have been fixed by the management level of the company, the solution from the functional department may exceed the constraints of the time or cost. So the planning stage of the framework in section 6.1.3 was revised to accommodate the suggestion.

6.2.3 Summary

The development and validation procedure of the ECM framework were introduced in this chapter. The three experts were selected and the draft framework was demonstrated to the experts from the company. The positive comments from the experts showed that most of the practices proposed in the framework were confirmed by the experts. And shortcomings of the framework were also pointed out by experts and were addressed in the revision of the framework.

7 Discussion and Conclusion

The discussion and conclusion of this research is described in this chapter, showing the achievements gained during the research and the potential benefits for the aircraft manufacturing company.

The four objectives of this research project are reviewed in this chapter, summarizing the main findings of this research. The result of this research is discussed and concluded in this chapter.

In addition to this, the contribution to knowledge is abstracted from the research findings and achievements. Limitations of this research are also shown in this chapter. Finally, the recommendations for future study are provided.

7.1 Result Discussion

The aim of this research is to develop a framework for ECM to improve the performance of the current ECM process. The aim is achieved by the achievement of the four specific objectives of this research project.

Objective one: "*Perform a study of ECM practices via literature review. Identify the critical success factors which can affect the performance of ECM"*.

The first objective of the approach was achieved by the comprehensive literature review. This objective enables the author to obtain a clear view on the state of art ECM practice though literature. The literature review provides an adequate number of previous surveys on ECM and specific practices for case studies. Knowledge gap was identified in this stage. The necessity of developing the ECM framework for the manufacturing company is confirmed by the literature review. The identification of the critical success factors for ECM built a solid foundation for the questionnaire design in the later research stage.

The literature review mainly focused on the domain of ECM. The relationship between ECM and other activities such as project management and quality management were not included in the literature review. However, it would be noteworthy to consider the interconnection between ECM and other management practices.

Interview with ECM professionals was considered in the early stage of the research, but due to the lack of access to the qualified people in the UK, it has not been adopted in the research.

Objective two: "*Investigate and model the current practices in ECM in the aircraft manufacturing company"*.

The second objective was achieved by modelling the current ECM practice in the aircraft manufacturing company by using $IDEF_0$ approach. A profound understanding of the ECM activity in the selected aerospace company is gained.The actual ECM practice was understood and gaps were identified in this part. The model of the AS-IS ECM process also contributed to the design of survey for data collection.

The existing problem of the current ECM process in the company can be summarized as follows:

1. There is no feedback for continuous improvement of the ECM process.
2. There is no clear definition of who should be responsible for the whole lifecycle of the ECs.
3. The decision making process in the current ECM process brings risk to the implementation if these departments cannot fulfil the requirements of the new released ECs.
4. The classification of ECs is not fully implemented into the whole ECM process.
5. There is a lack of central governance of the ECM performance.

Objective three: "*Benchmark the current ECM practices in aerospace and automobile industries and identify the best ECM practice*".

This objective was achieved by conducting the survey to identify the best practices in ECM activities in aerospace and automobile industries. Based in the critical success factor identified in the literature review, questionnaire was designed to investigate the relation between the ECM performance and the actual ECM practices related with the critical success factors. The best ECM practices were identified by a qualitative analysis on the data obtained from the survey. The degree of satisfactory given by the respondents indicated that the performance of the ECM can be influenced by whether following a certain ECM practice. The identified best practices were used for the development of the ECM framework for the aircraft manufacturing company.

However, due to the limitation of time and resource, the survey only investigated 31 companies mainly in UK. If there are other available databases or networking, research could be done by enlarging the sample of the survey. Nevertheless, the survey has provided foundation for further investigation of the similar research topic in other countries.

The list of best practice could also be extended. Five best practices were identified by the survey in this research. In order to keep the questionnaire in a short and concise manner, there was a limitation of number of questions in one questionnaire. Further study can still be carried out to identify new best practice for ECM by launching new survey to examine more ECM practice.

Arguably, the criterion used to define the size of the company (more than 50 employees) could be considered relatively small in comparison to the top aerospace product manufacturers in the UK. Nevertheless the survey still provides some reasonable findings to draw some inferences from the current practices in these surveyed companies.

Objective four: “*Propose and validate a framework for ECM in the aircraft manufacturing company for further improvement”*.

In the last phase of the research, the framework was developed from the model of current ECM process in the company and validated through experts’ judgement. The best practices identified in the third part of the research were integrated into the model to refine the current ECM process in the aircraft manufacturing company. The recommended best practices were validated and confirmed by experts in the company. The comments from them show the new developed ECM framework is able to provide benefits and improvements for the ECM in the company.

It should be noted that the framework was developed and validated from a manufacturing perspective. The ECM can also affect other disciplines during the product life cycle including design, custom support and procurement etc. Further research would be necessary to integrate this framework with the whole lifecycle of ECM.

7.2 Research Limitation and Future Work

7.2.1 Research Limitation

As discussed in section 7.1, the limitation of this research can be summarized as follows:

1. The total number of the sample for the survey is not very large. And the survey mainly focuses on the companies in UK. The response rate of the survey is relatively low. The outcome of the survey would be more convincing if more companies have participated into the survey.
2. Although the literature review provided the basic foundation for the questionnaire development, the questionnaire can still be improved if interviews were held to capture the critical success factors for ECM.
3. The framework only considered the circumstance under a manufacturing environment. It is design for a manufacturing centre which is separated from the R&D centre which mostly serves as the origin of ECs.
4. In the survey only the satisfaction towards the ECM system was used to measure the ECM performance in the surveyed companies. Only the degree of satisfaction was used as the indicator for ECM performance. It

could be a complement for this research if the relation between satisfaction and performance was thoroughly investigated.

7.2.2 Future Work

Based on the limitation of the research, the following aspects can be considered for future work as a complement for the developed framework:

1. The number of survey samples can be enlarged by considering companies beyond UK. The outcome of the survey would be more convincing if more companies participate into the survey.
2. Due to the limitation of time and other resource, only aerospace and automobile industries were surveyed in this research. There are other fast developing industrial sectors such as the manufacturers of medical devices and electronic devices which also perform the similar new product development process. Their ECM practices can also be considered for future research. The list of best practices for ECM may be expanded if the survey is expanded to other industrial sectors.
3. Interview can be considered in the future research for further investigation of the identified best ECM practices.

7.3 Conclusion

Based on the discussion, it can be concluded that the aim and objectives of this research project is achieved. And the knowledge contribution of this research can also be concluded into two perspectives.

Frist, this thesis highlights the correlation between the performance of the ECM process and the actual ECM practices. The best ECM practices were identified by the benchmarking survey. The key recommendations which can be beneficial for ECM are presented below:

- Formal process for each stage of ECM

This survey reveals that the formal process should cover all stages of ECM in order to obtain a better performance. As can be seen from the survey, the respondent companies who have adopted a formal process in these four stages take up a higher percentage and also have a higher degree of satisfaction towards their ECM.

- The classification of ECs

The survey revealed that the performance of the ECM process can be improved by classifying the ECs into different categories. The implementation and audit should also be classified accordingly based on the classification of the EC.

- The measurement of the ECM performance

It is highlighted by this survey that improvement can be achieved by measuring the performances of ECM process. The measurement of the ECM performance provides feedback for the continuous improvement of the ECM practice.

- The utilization of the Change Committee/Team/Board

The importance of formally established Change Committee/Team/Board is identified in this research. The result of the survey shows that the companies following this strategy are benefited from this practice

- The utilization of implementation plan

It is confirmed by the research that the utilization of implementation plan can generate a higher ECM performance.

The second contribution of this research is the ECM framework developed for the targeted aircraft manufacturing company. The framework particularly focuses on helping the manufacturing companies which are usually in the downstream of the ECM process to cope with the impact from ECs initiated in the upstream. It is proved that the framework developed in this thesis can provide benefits for further improving the current ECM process in the aircraft manufacturing company. The framework also offers a benchmarking reference for other companies to examine their own ECM process and initiate improvement.

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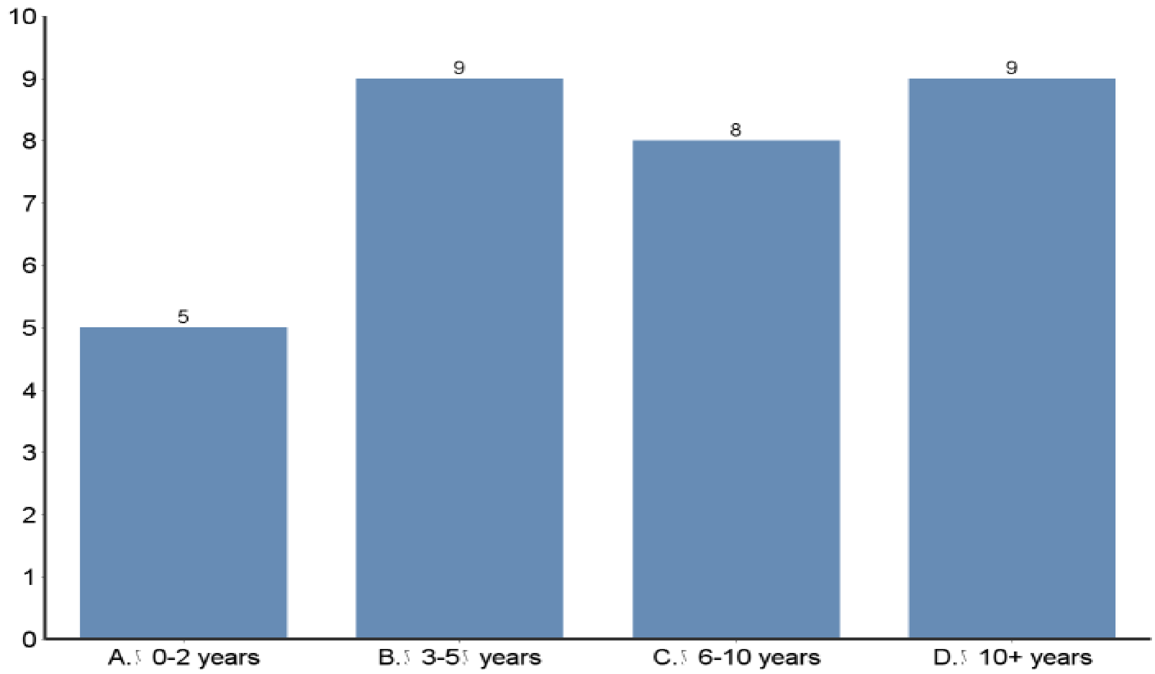
APPENDICES

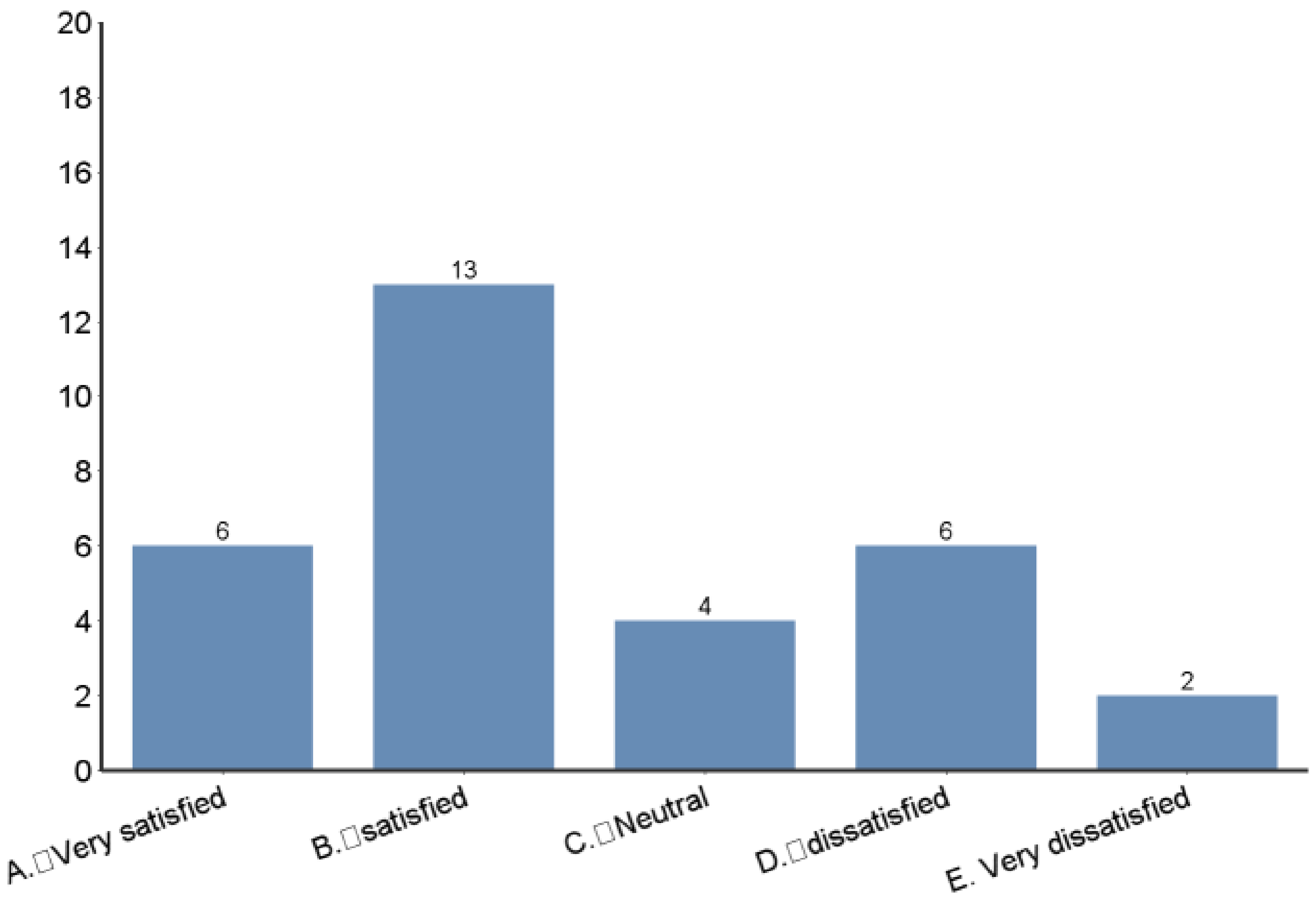
Appendix A Online Survey Template and Results

Q1 How long have you been in your current position?



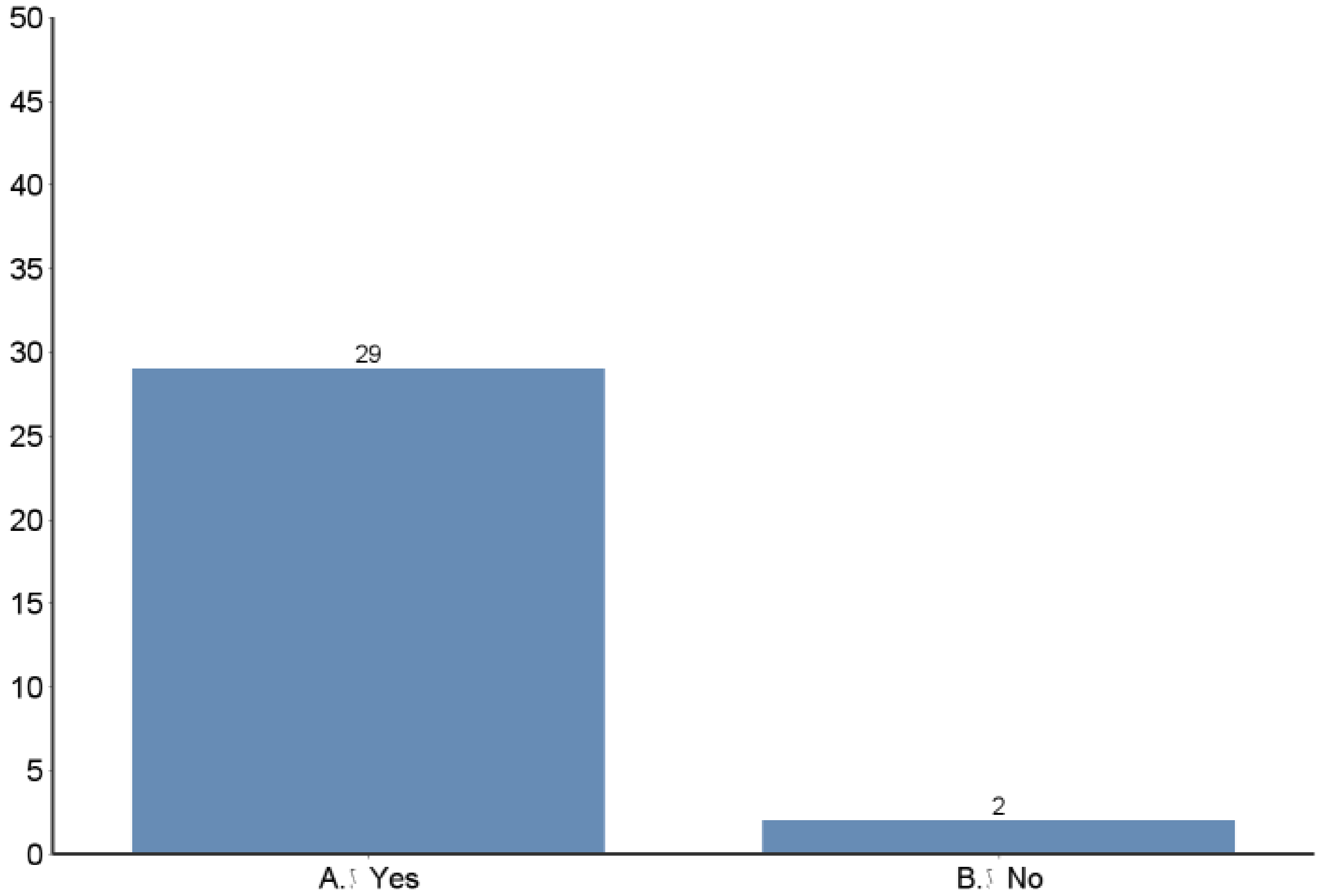
	Percent	Count	Percent
A. 0-2 years		5	16.1%
B. 3-5 years		9	29.0%
C. 6-10 years		8	25.8%
D. 10+ years		9	29.0%
Total		31	100.0%

Q2 How do you rate the performance of the Engineering Change Management practice in your company in general?



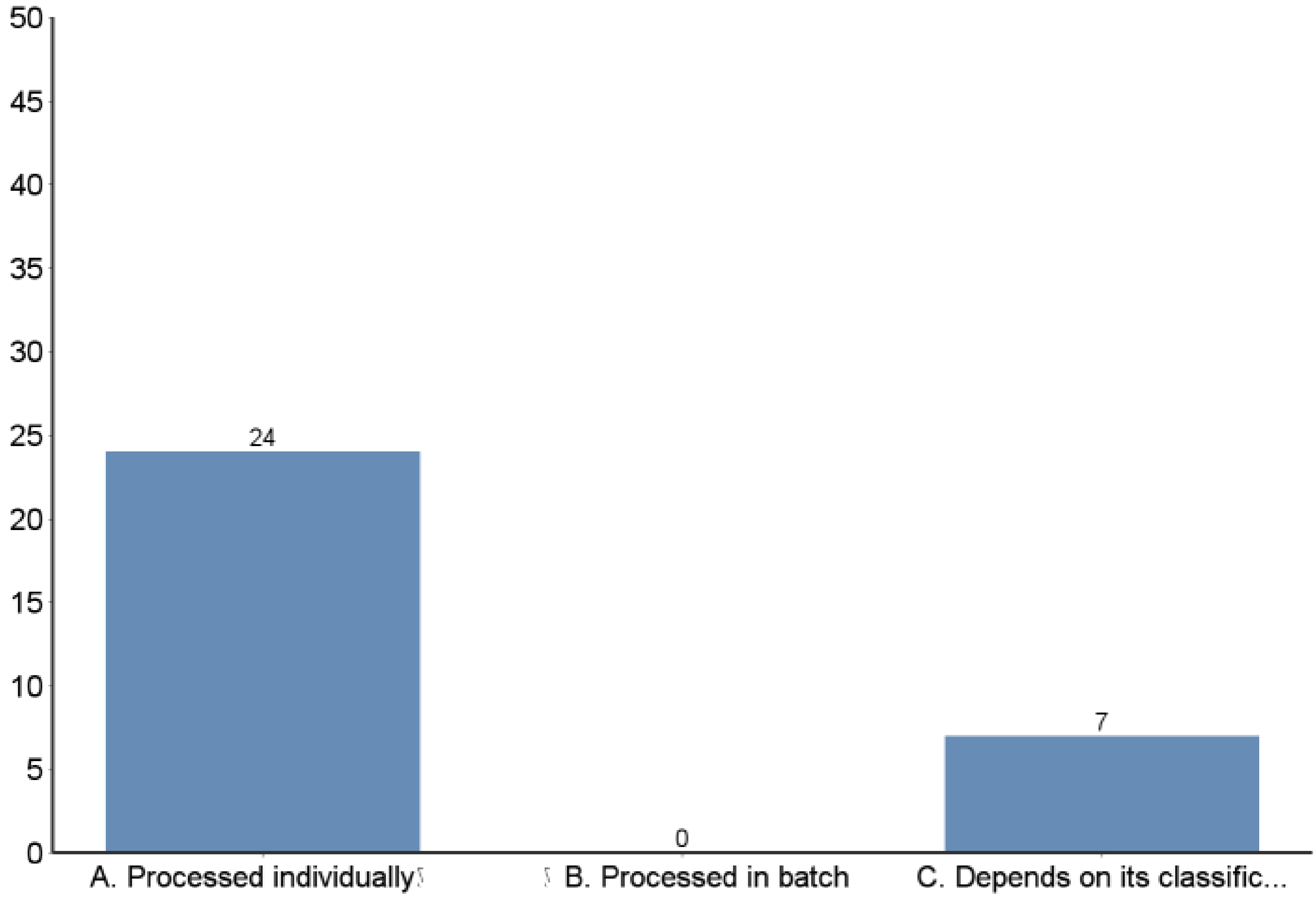
	Percent	Count	Percent
A. Very satisfied		6	19.4%
B. satisfied		13	41.9%
C. Neutral		4	12.9%
D. dissatisfied		6	19.4%
E. Very dissatisfied		2	6.5%
Total		31	100.0%

Q3 Does your company have a formal process for the Engineering Change Management?



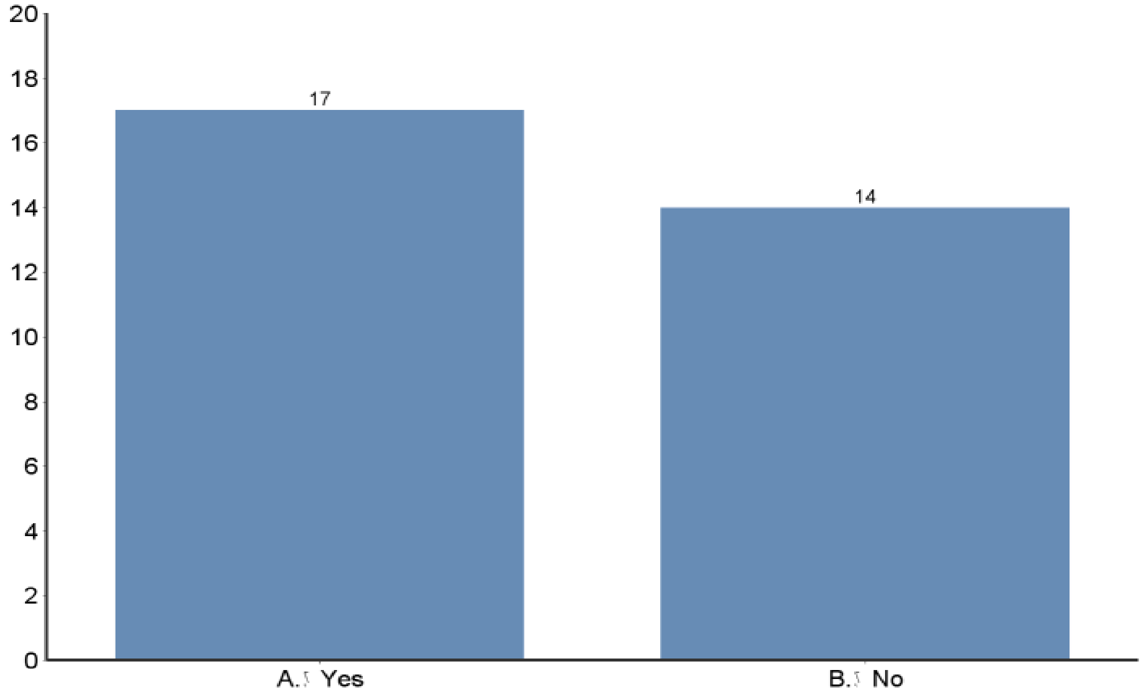
	Percent	Count	Percent
A. Yes		29	93.5%
B. No		2	6.5%
Total		31	100.0%

Q4 How are Engineering Changes processed in your company?



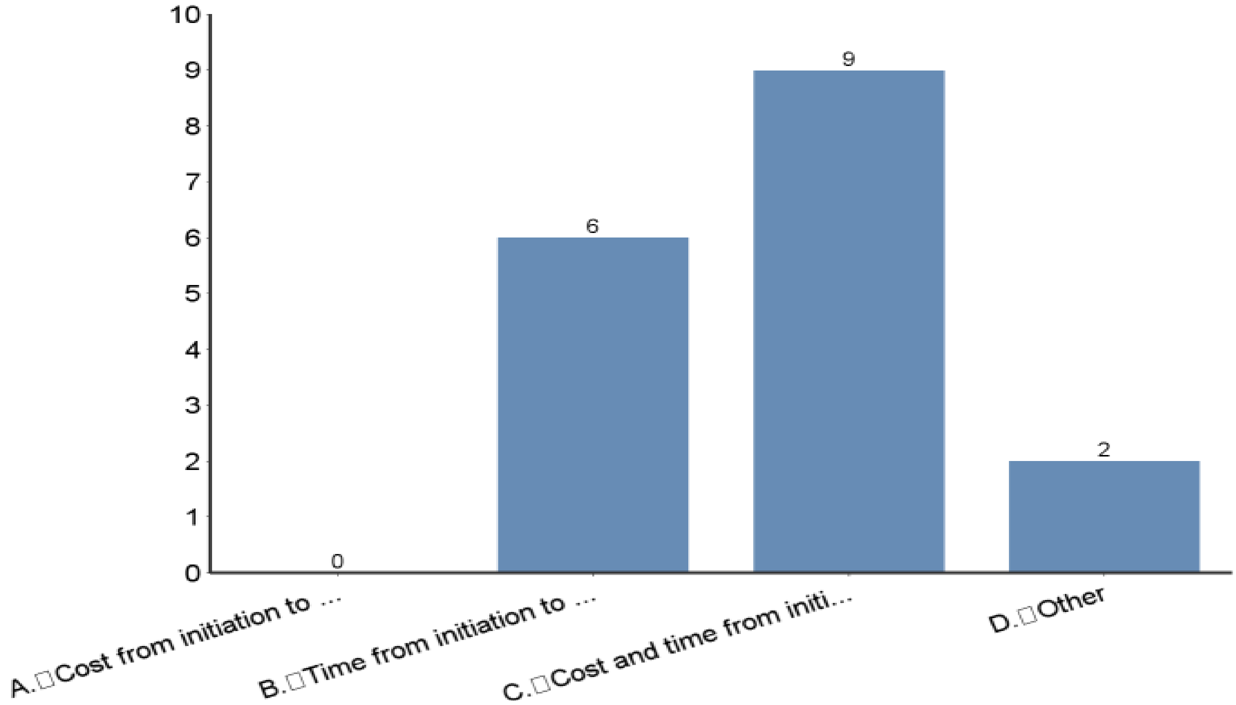
	Percent	Count	Percent
A. Processed individually		24	77.4%
B. Processed in batch		0	0.0%
C. Depends on its classification		7	22.6%
Total		31	100.0%

Q5 Does your company use any methods to measure the performance of the Engineering Change Management Process?



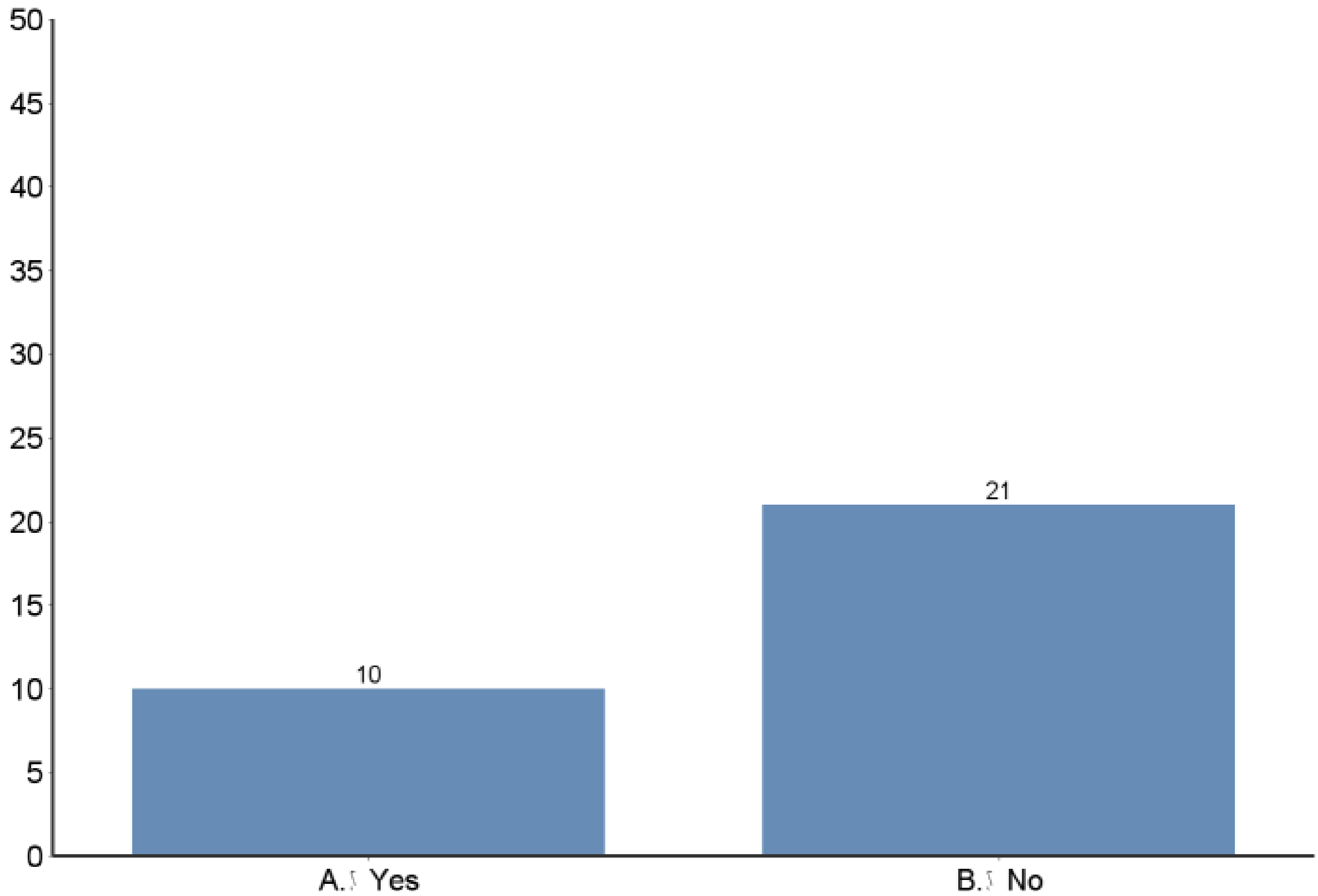
	Percent	Count	Percent
A. Yes		17	54.8%
B. No		14	45.2%
Total		31	100.0%

Q6 What is most important for measuring the performance of the ECM Process in your company?



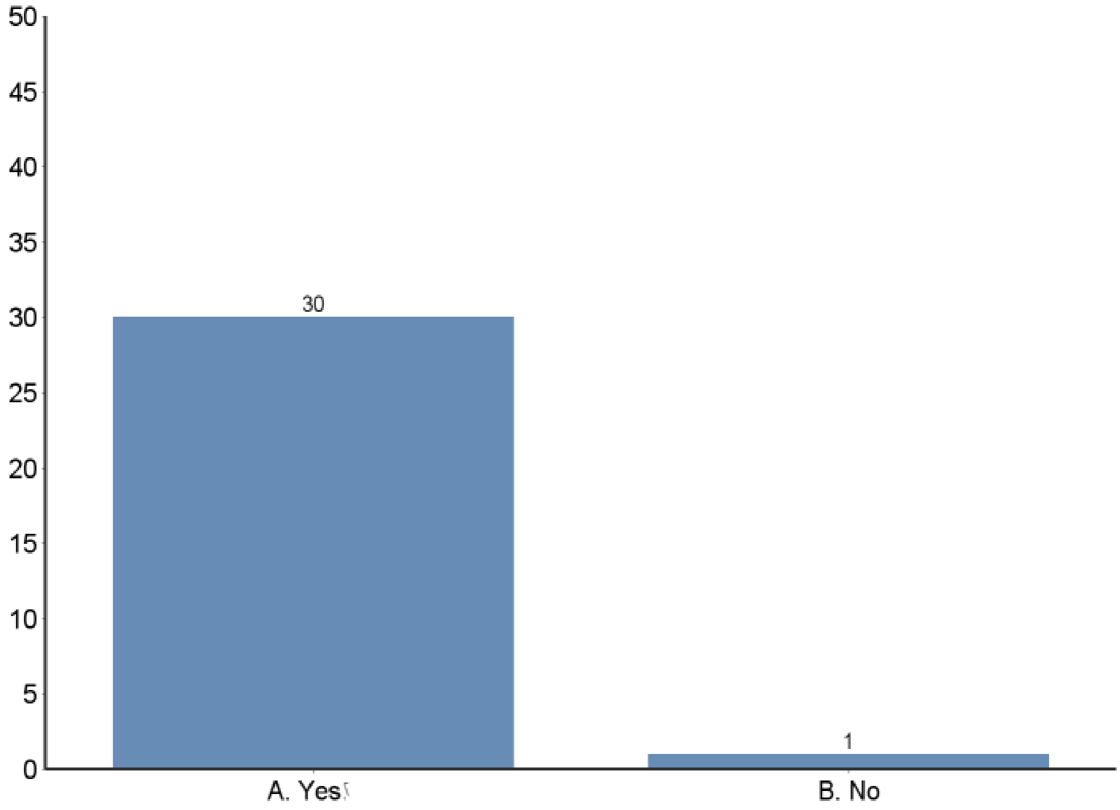
	Percent	Count	Percent
A. Cost from initiation to implementation		0	0.0%
B. Time from initiation to implementation		6	35.3%
C. Cost and time from initiation to implementation		9	52.9%
D. Other		2	11.8%
Total		17	100.0%

Q7 Does your company use any PLM (Product Life-cycle Management) software for Engineering Change Management?



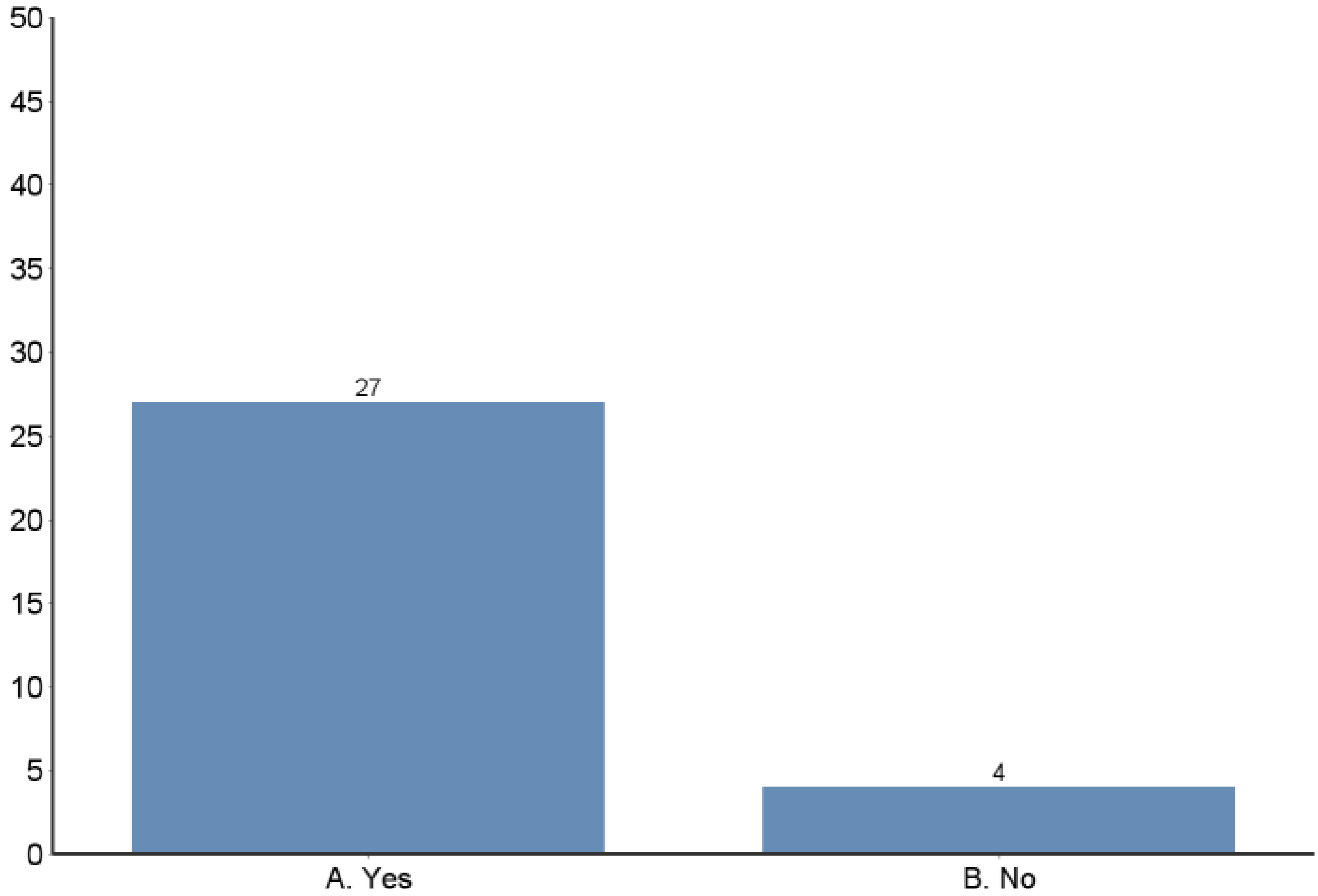
	Percent	Count	Percent
A. Yes		10	32.3%
B. No		21	67.7%
Total		31	100.0%

Q8 Does your company have a formal process for identifying the Engineering Change?



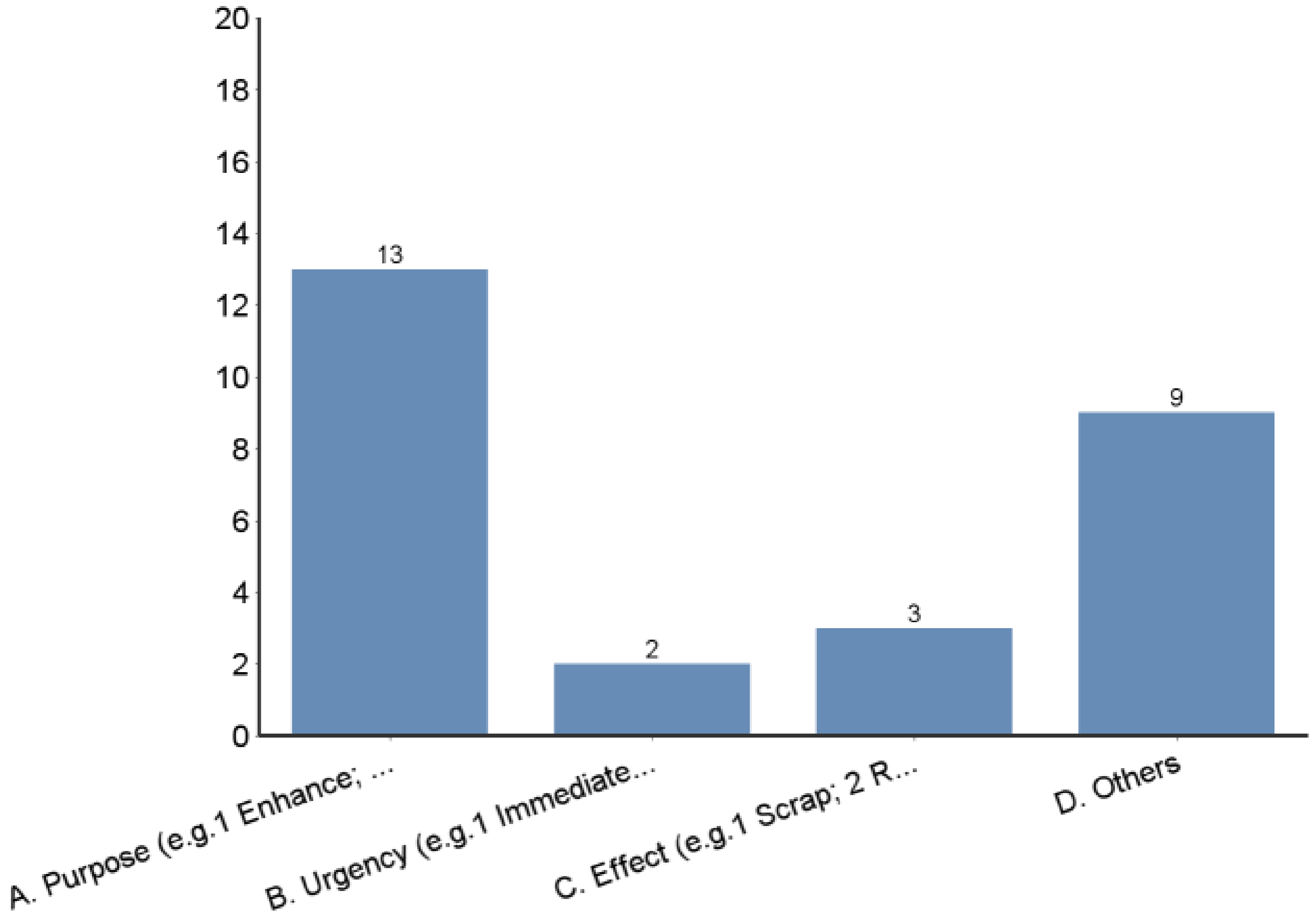
	Percent	Count	Percent
A. Yes		30	96.8%
B. No		1	3.2%
Total		31	100.0%

Q9 Does your company have certain criteria to classify the identified Engineering Change?



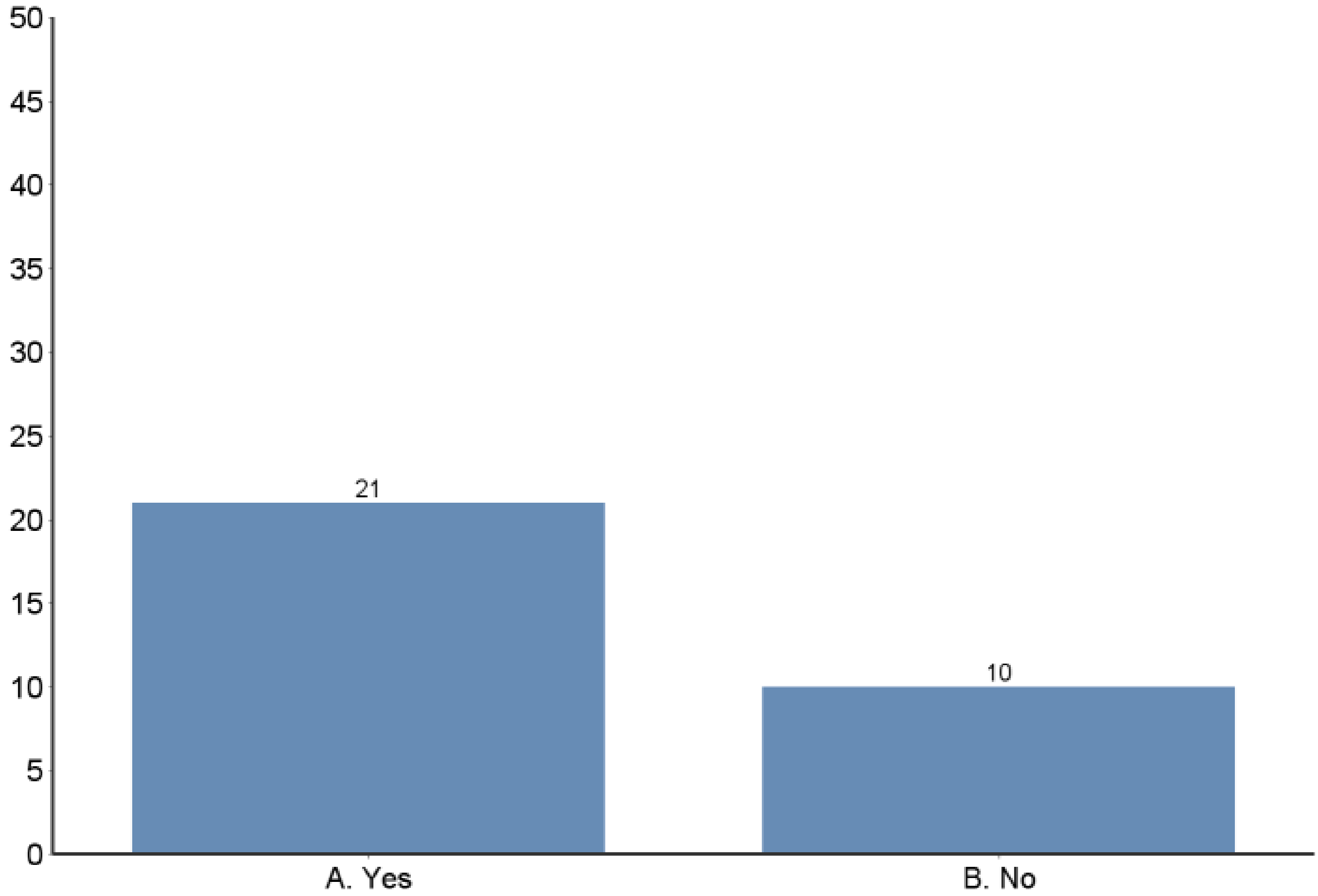
	Percent	Count	Percent
A. Yes		27	87.1%
B. No		4	12.9%
Total		31	100.0%

Q10 What is the criterion classifying the Engineering Change in your company?



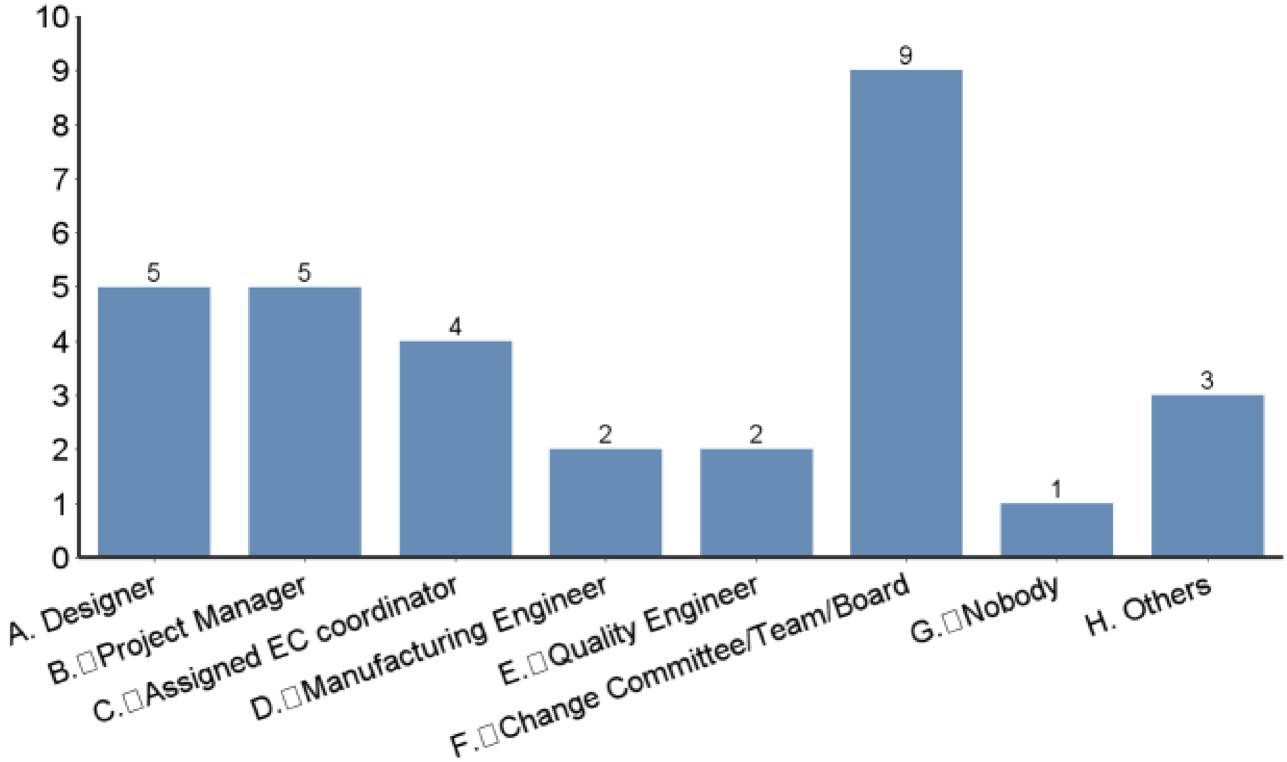
	Percent	Count	Percent
A. Purpose (e.g.1 Enhance; 2 Error Correction)		13	48.1%
B. Urgency (e.g.1 Immediate; 2 Convenience)		2	7.4%
C. Effect (e.g.1 Scrap; 2 Rework; 3 Us-as-is)		3	11.1%
D. Others		9	33.3%
Total		27	100.0%

Q11 Does your company have a formal process to evaluate the impact of Engineering Change?



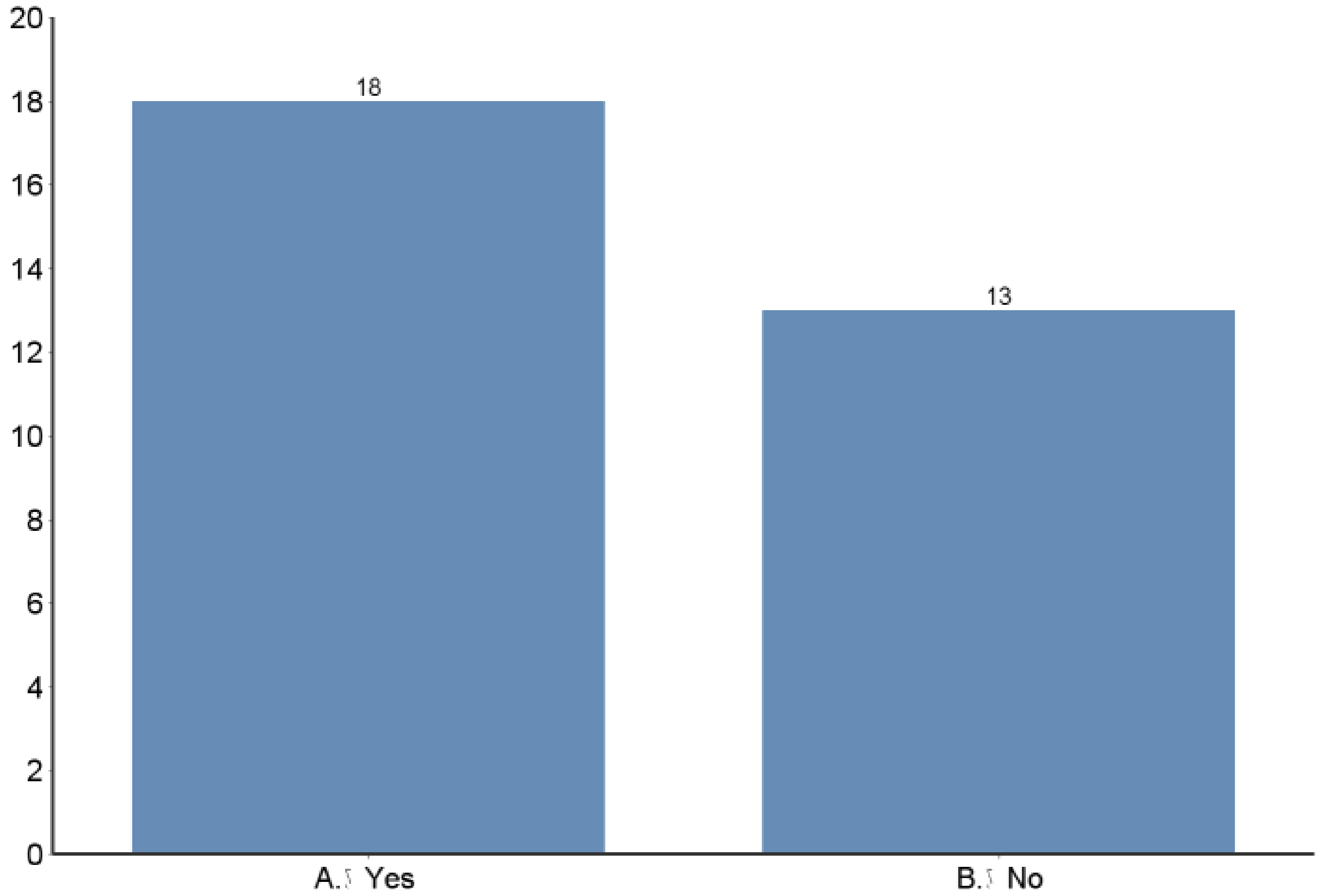
	Percent	Count	Percent
A. Yes		21	67.7%
B. No		10	32.3%
Total		31	100.0%

Q12 Who is responsible for evaluating of the impact of Engineering Change in your company?



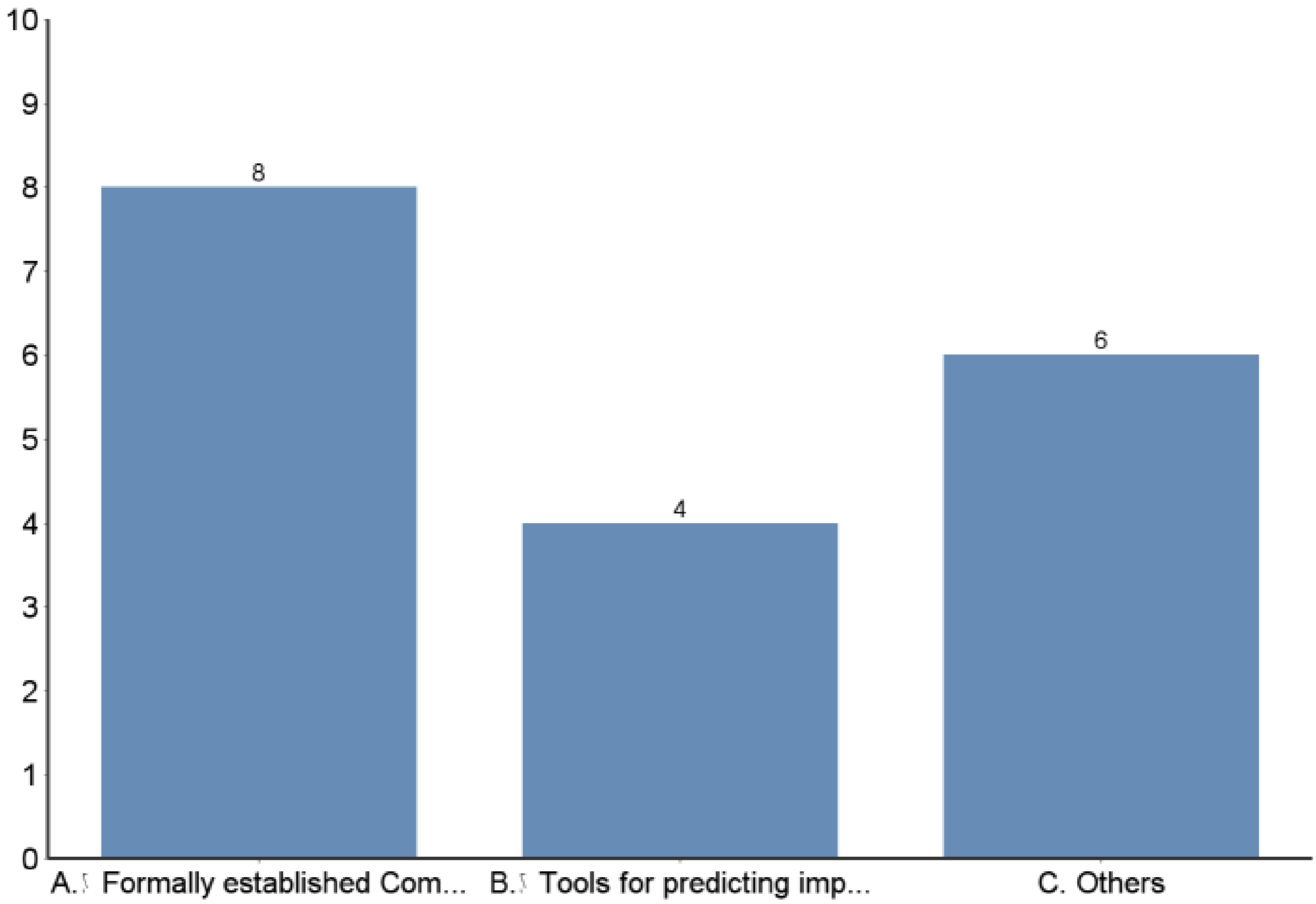
	Percent	Count	Percent
A. Designer		5	16.1%
B. Project Manager		5	16.1%
C. Assigned EC coordinator		4	12.9%
D. Manufacturing Engineer		2	6.5%
E. Quality Engineer		2	6.5%
F. Change Committee/Team/Board		9	29.0%
G. Nobody		1	3.2%
H. Others		3	9.7%
Total		31	100.0%

Q13 Does your company use any methods in evaluating the impact of Engineering Change?



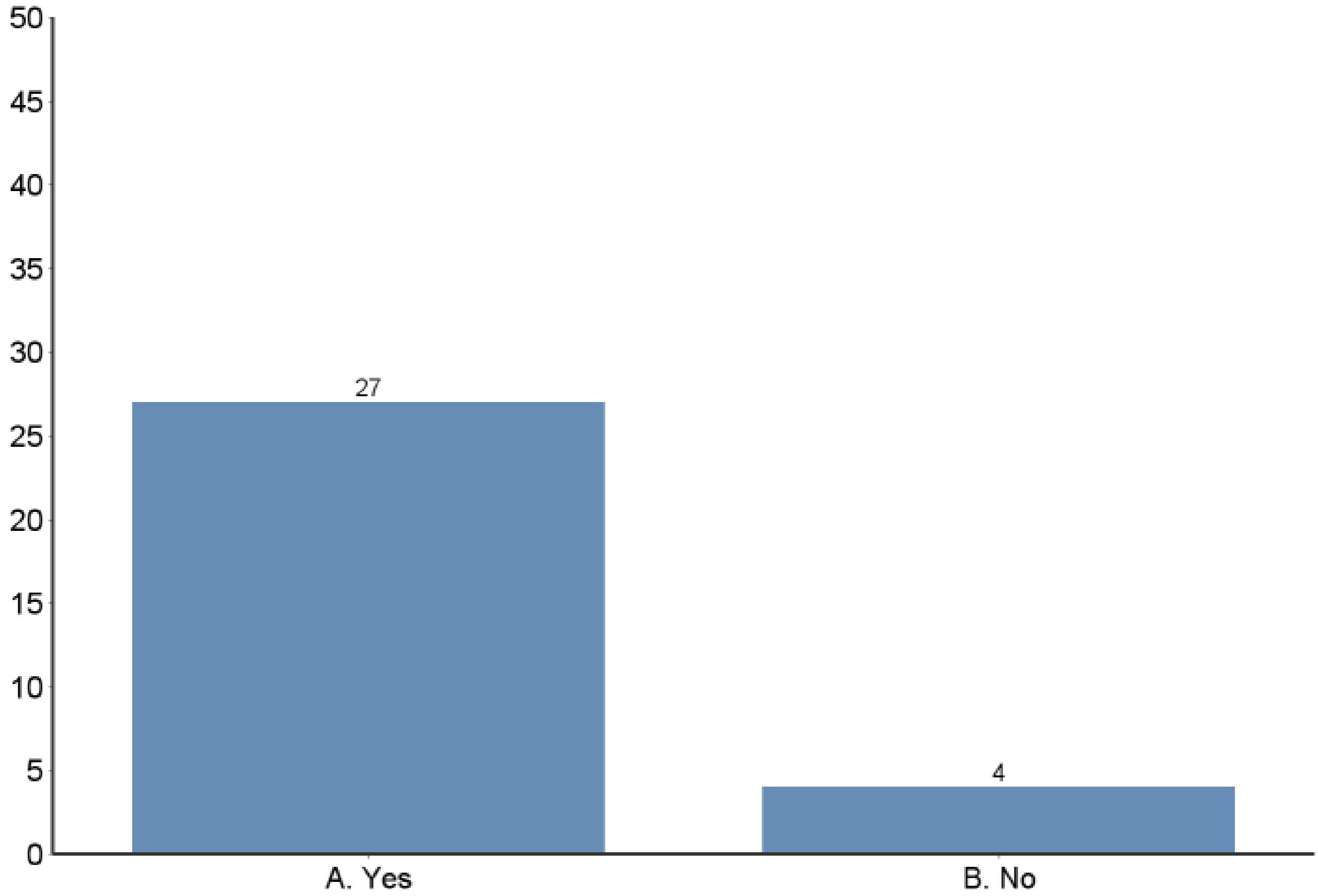
	Percent	Count	Percent
A. Yes		18	58.1%
B. No		13	41.9%
Total		31	100.0%

Q14 Which following method best describing the current practice of evaluating the impact of Engineering Change in your company?



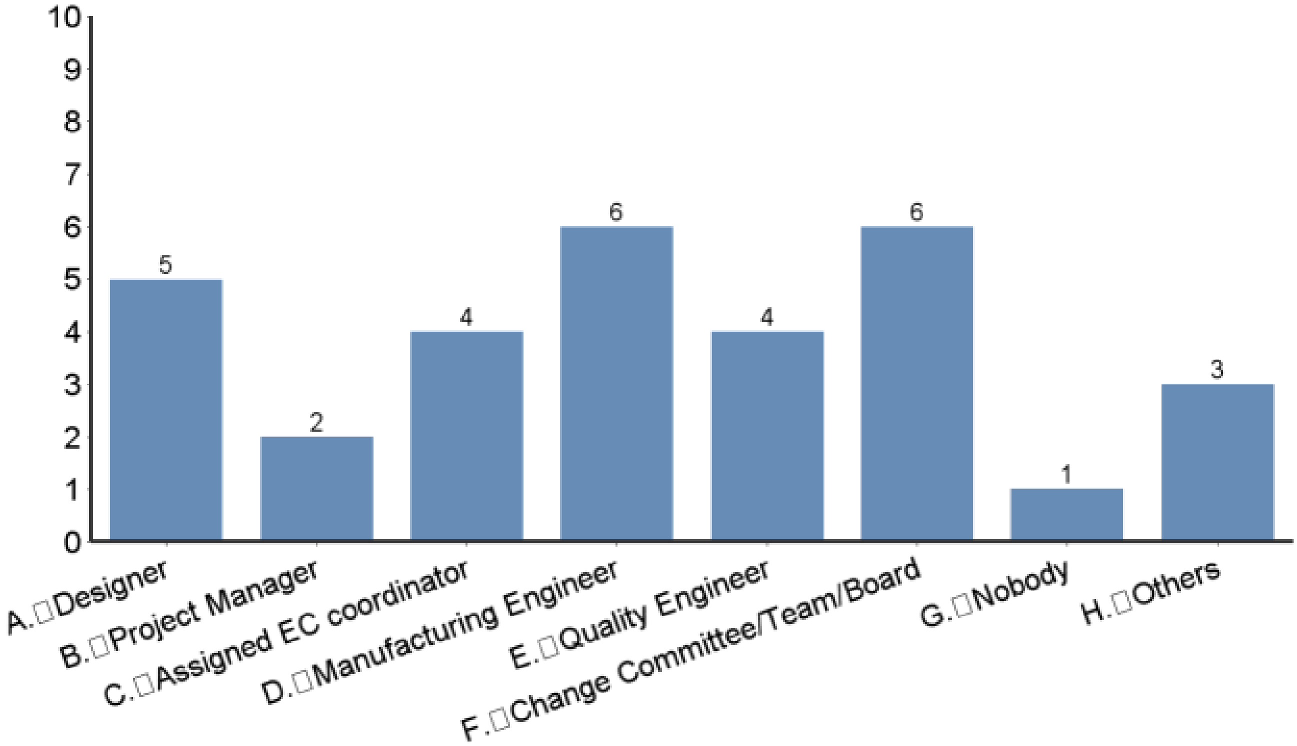
	Percent	Count	Percent
A. Formally established Committee/Team/Board for reviewing the Engineering Change		8	44.4%
B. Tools for predicting impact of the Engineering Change		4	22.2%
C. Others		6	33.3%
Total		18	100.0%

Q15 Does your company have a formal process for the implementation of Engineering Change?



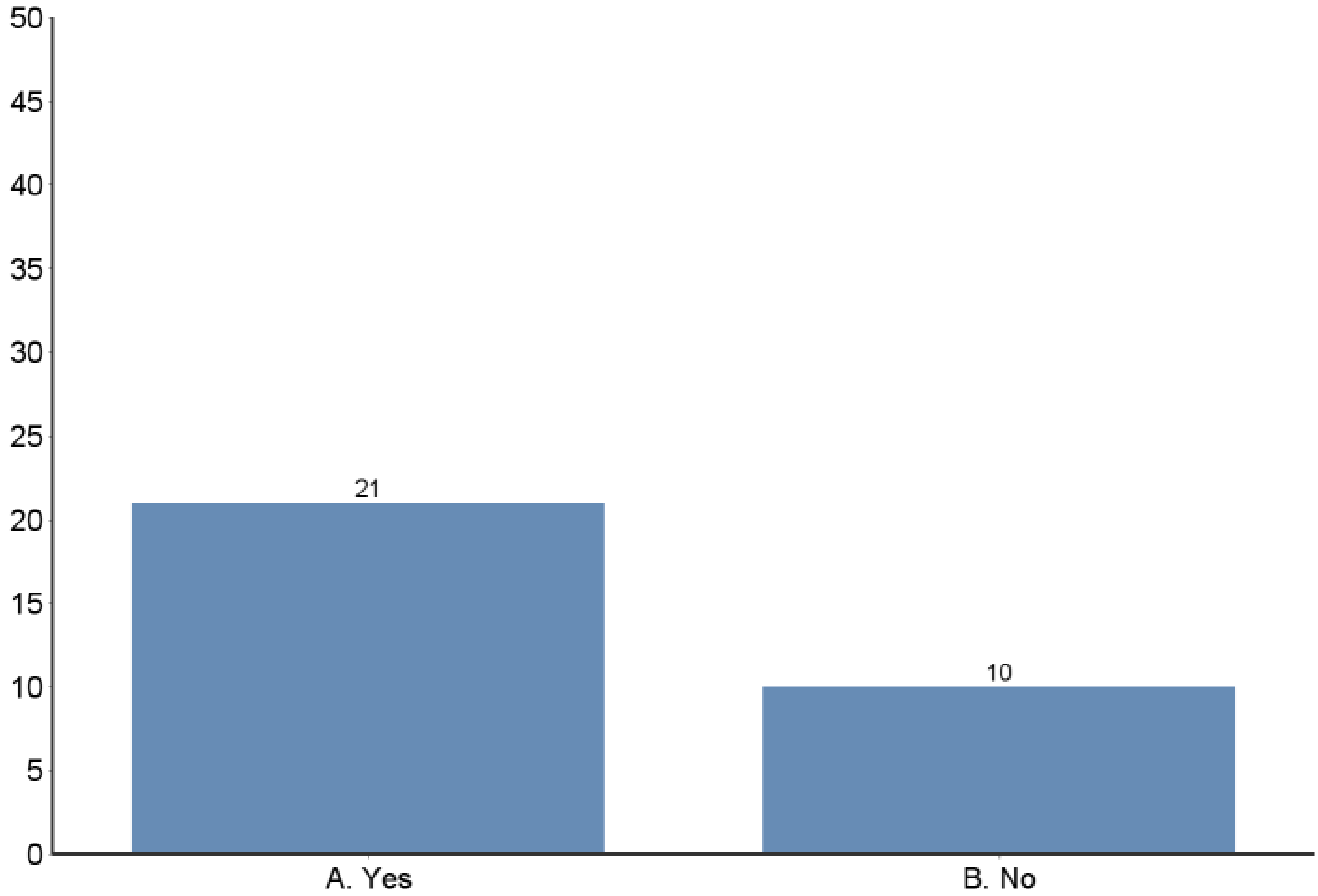
	Percent	Count	Percent
A. Yes		27	87.1%
B. No		4	12.9%
Total		31	100.0%

Q16 Who is responsible for the implementation of Engineering Change in your company? [Multiple answers]



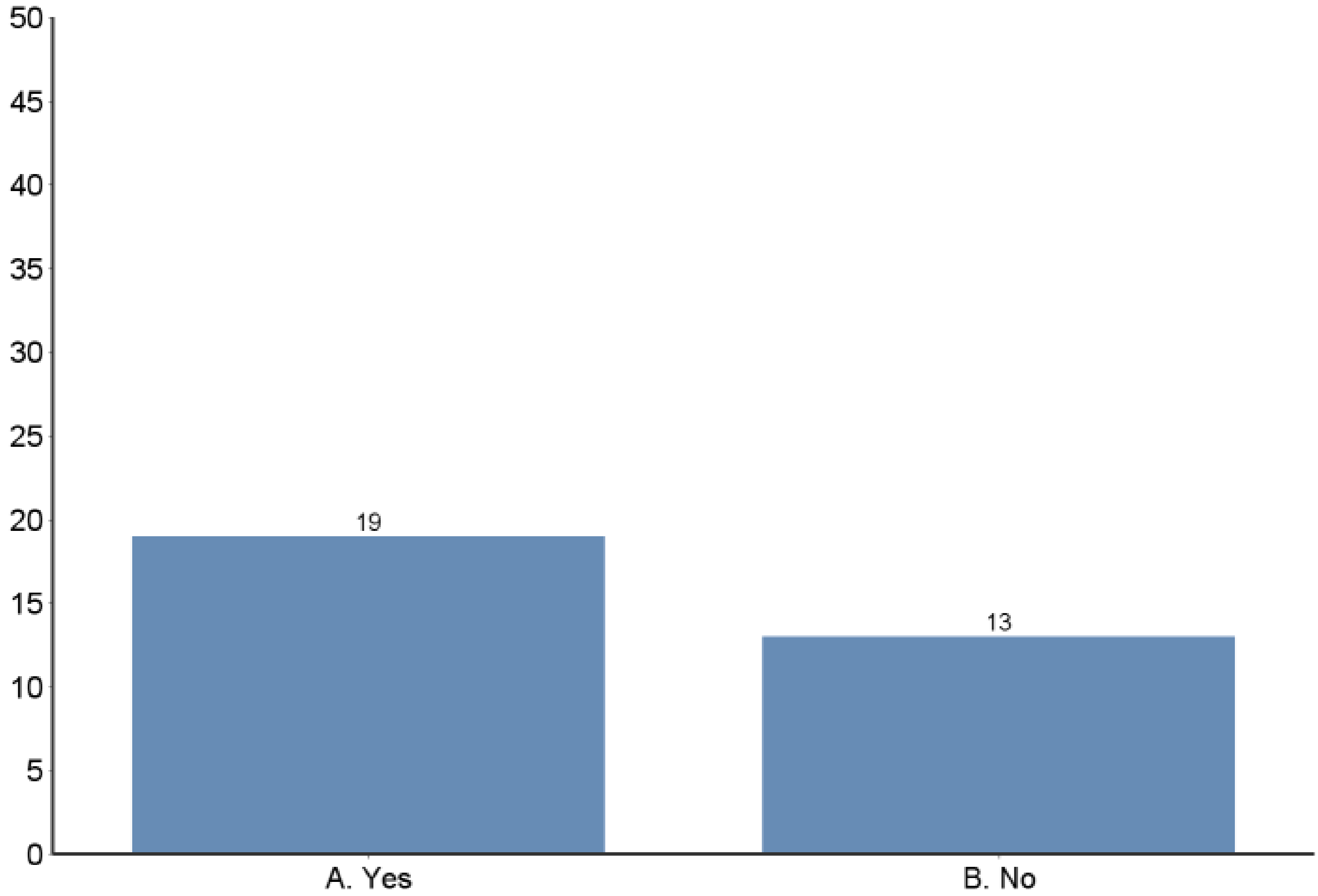
	Percent	Count	Percent
A. Designer		5	16.1%
B. Project Manager		2	6.5%
C. Assigned EC coordinator		4	12.9%
D. Manufacturing Engineer		6	19.4%
E. Quality Engineer		4	12.9%
F. Change Committee/Team/Board		6	19.4%
G. Nobody		1	3.2%
H. Others		3	9.7%
Total		31	100.0%

Q17 Does your company use implementation plan to control the implementation of Engineering Change?



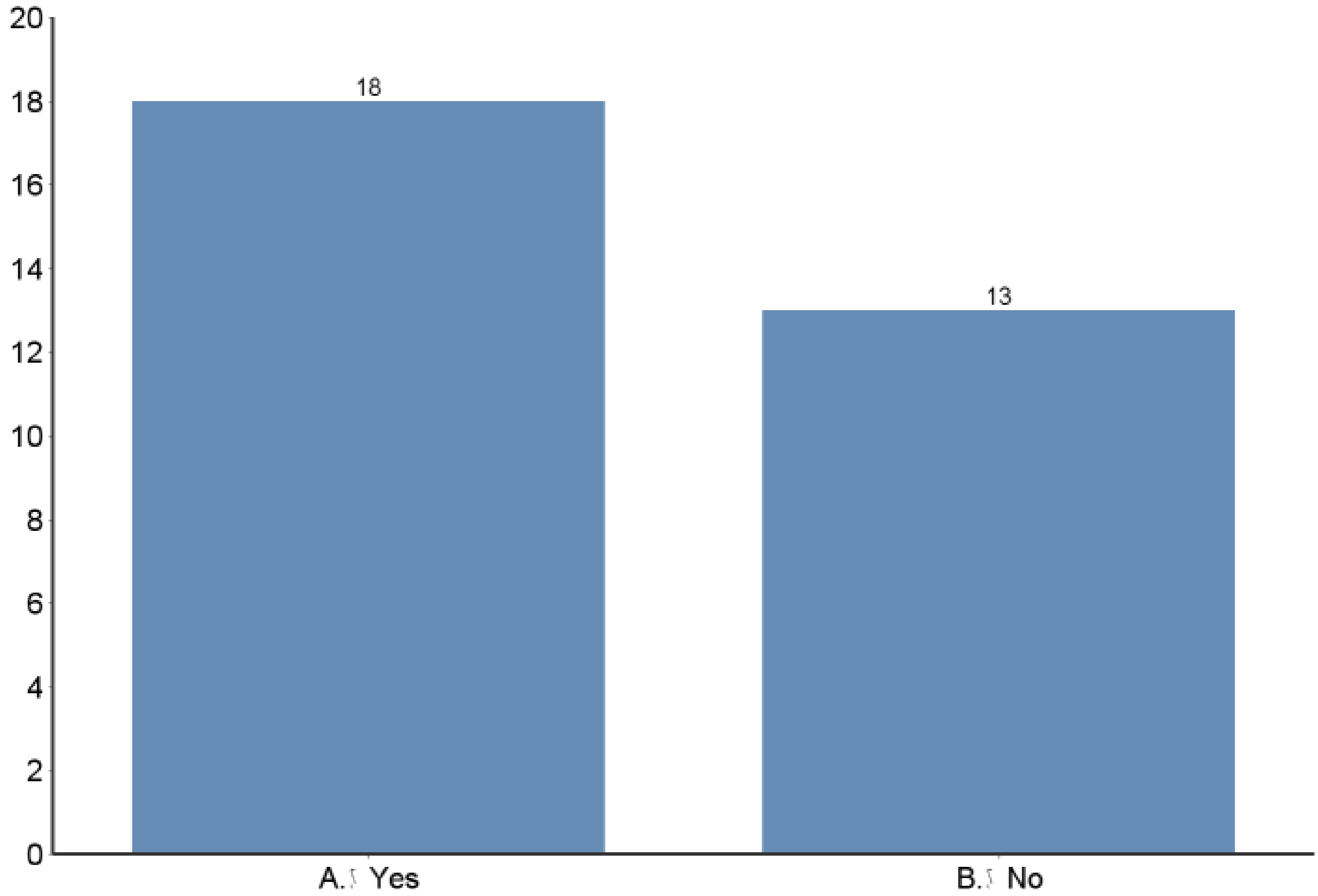
	Percent	Count	Percent
A. Yes		21	67.7%
B. No		10	32.3%
Total		31	100.0%

Q18 Does your company use any ERP software to implement or help to implement the Engineering Change?



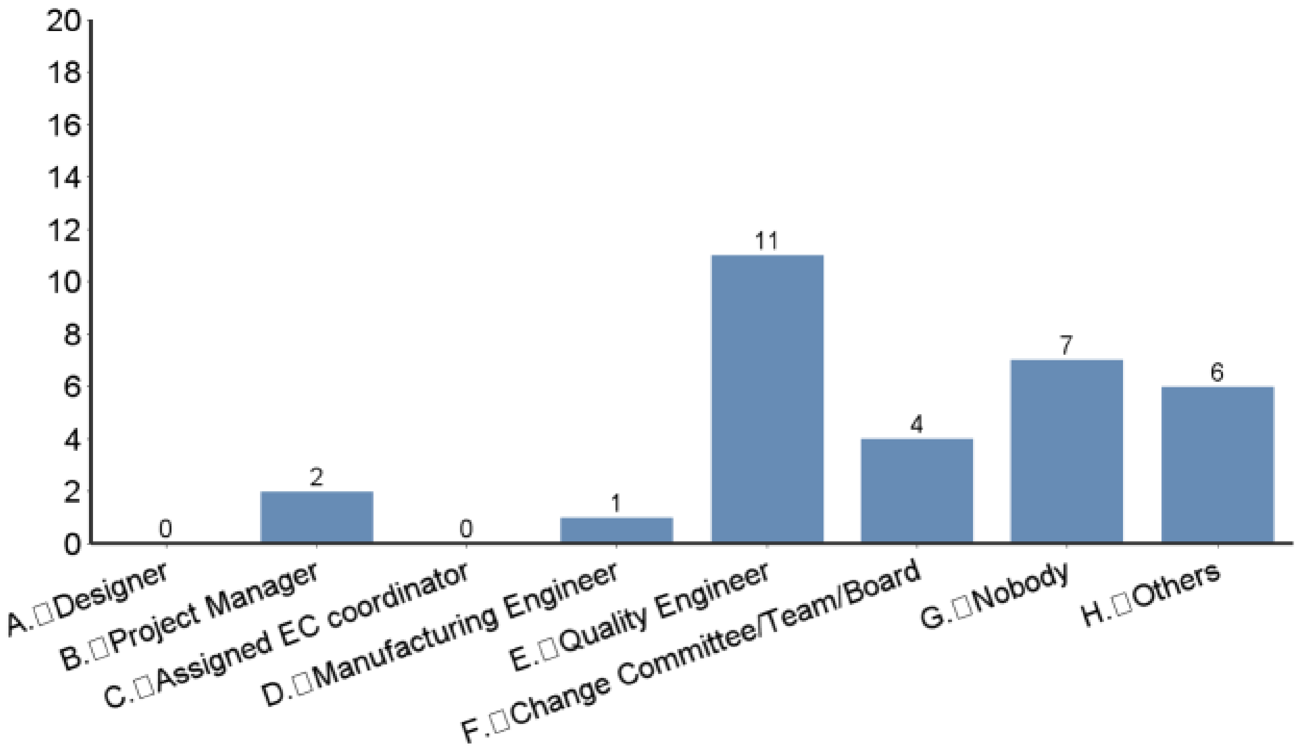
	Percent	Count	Percent
A. Yes		19	61.3%
B. No		13	41.9%
Total		32	103.2%

Q19 Does your company have a formal process to audit the implementation of the Engineering Change?



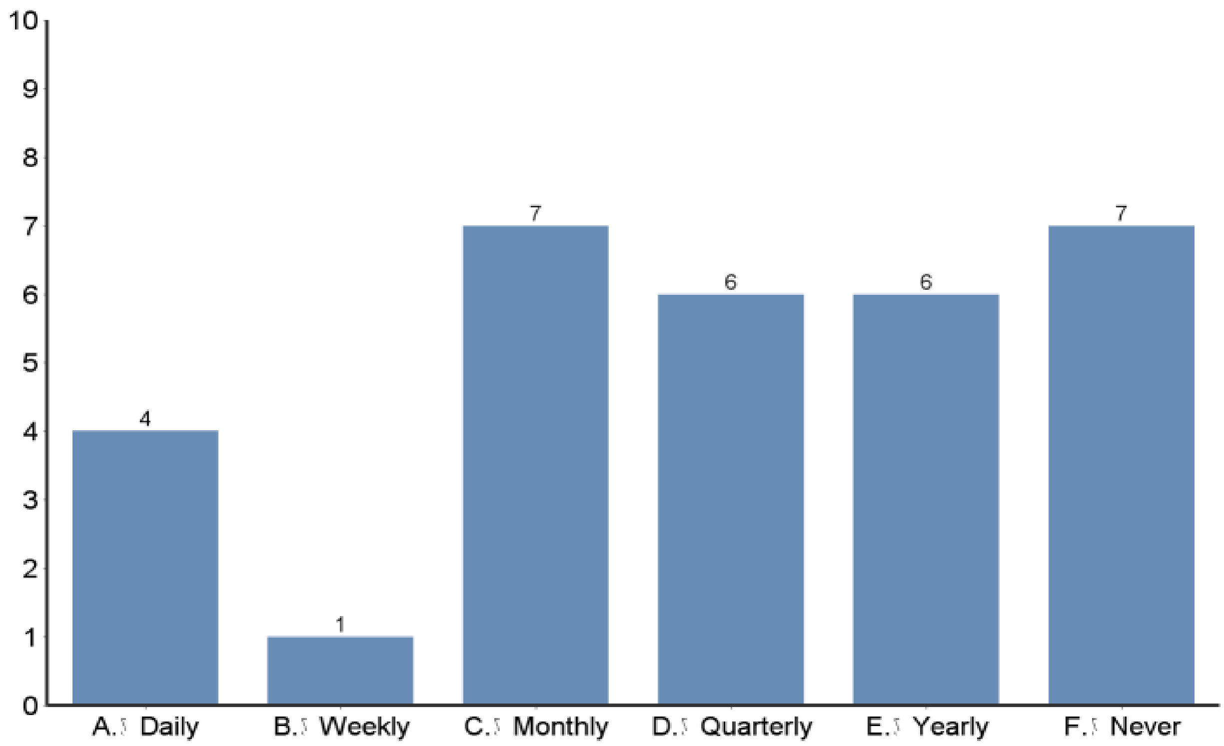
	Percent	Count	Percent
A. Yes		18	58.1%
B. No		13	41.9%
Total		31	100.0%

Q20 Who is responsible for the audit of the Engineering Change to ensure corrective implementation in your company?



	Percent	Count	Percent
A. Designer		0	0.0%
B. Project Manager		2	6.5%
C. Assigned EC coordinator		0	0.0%
D. Manufacturing Engineer		1	3.2%
E. Quality Engineer		11	35.5%
F. Change Committee/Team/Board		4	12.9%
G. Nobody		7	22.6%
H. Others		6	19.4%
Total		31	100.0%

Q21 Which one is the closest to the frequency of the audit in your company?



	Percent	Count	Percent
A. Daily		4	12.9%
B. Weekly		1	3.2%
C. Monthly		7	22.6%
D. Quarterly		6	19.4%
E. Yearly		6	19.4%
F. Never		7	22.6%
Total		31	100.0%

Appendix B

Search Strategy for aerospace and automobile manufacturers

Product name	Fame		
Update number	300		
Software version	54.00		
Data update	04/06/2014 (n° 7668)		
Username	Cranfield University-14869		
Export date	04/06/2014		
Cut off date	31/03		
		Step result	Search result
1.	Active/Inactive: Active	3,071,787	3,071,787
2.	Number of Employees: Last available year, min=50	61,090	43,564
3.	Trade description, UK SIC classification, Overview (All sections): AnyWords("aircraft" , "airplane" , "aerospace" , "aeroengine") AND AllWords("manufactur*")	2,865	668
	Boolean search : 1 And 2 And 3		
		TOTAL	668

Product name	Fame		
Update number	300		
Software version	54.00		
Data update	04/06/2014 (n° 7668)		
Username	Cranfield University-14869		
Export date	04/06/2014		
Cut off date	31/03		
		Step result	Search result
1.	Active/Inactive: Active	3,071,787	3,071,787
2.	UK SIC (2007): All codes: 29 - Manufacture of motor vehicles, trailers and semi-trailers	5,406	2,297
3.	Number of Employees: Last available year, min=50	61,090	288
	Boolean search : 1 And 2 And 3		
		TOTAL	288

Appendix C Definition of the terms used in Chapter 4

Term	Description
Configuration Control Board (CCB)	A board composed of technical and administrative representatives, which is responsible for review and approval of Class I change.
Configuration Control Team (CCT)	The design centre has established a couple of CCTs to participate in the configuration management process. CCT is responsible for transmitting ECP to the correct people for disposal upon completion of checking.
Configuration Control Office (CCO)	Configuration Control Office (CCO) is responsible for initiating the process of ECO implementation and tracking the state of all ECOs in process. ECO is subordinate to the Manufacturing and Engineering Department in Manufacturing Centre.
Engineering Change Request (ECR)	The function of ECR is to collect all the requests for engineering change from design department, manufacturing centre, suppliers and customs. The motivations of ECR include improving the performance of the product, reducing the cost, increasing the productivity, or reporting the discovered design problem. ECR can be used as the input for the Engineering Change Proposal (ECP) after approved by CCT.

Engineering Change Proposal (ECP)	A proposed engineering change and the documentation, by which the change is described, justified and submitted to CMB, CCB, CCT for approval.
Engineering Change Order (ECO)	ECO is released with drawing by the design department to give a detailed description of the engineering change.
Manufacturing Bill of Materials （MBOM）	MBOM is a bill of material used to manufacture the products of a single aircraft prepared by process planner. It indicates the general manufacturing demand of the products and lists each part number, quantity and the process data. It also indicates the relations between part number and subassembly.