University of Minho
School of Engineering

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Improving change management in large engineering projects: a case study

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Master's Thesis
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Thesis supervised by
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Agradecimentos

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Statement of Integrity

I hereby declare having conducted this academic work with integrity.

I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

University of Minho, Guimarães, september 2023

João Carlos Ferreira Santos

Abstract

Improving change management in large engineering projects: a case study

The present thesis was developed at Bosch Car Multimedia S.A., in Braga, in the project management team of the development department. This research was designed in the context of a large engineering project in the development phase of a new product. The main objective was to improve the engineering change management process by evaluating a possible reorganisation of activities and the creation of new procedures. The author integrated a pilot project that was already ongoing to study the possibilities for improvement in parallel. In this sense, the research methodology chosen was a case study, first analysing the Bosch standard process and the process followed by the pilot project, and then identifying and proposing opportunities for improvement.

The improvement opportunities can be divided into two main proposals. The first consists of a revised standard for the activities in each Engineering Change Request (ECR) phase, suggesting when each one of the activities should be started as well as the advisable way of action for the project manager. Then, the second proposal is related to the ECR deadlines compliance, being presented two possible approaches. Approach 1 suggests the dates tracking in an Excel file, while approach 2 suggests using Power BI dashboards. Both of the approaches could not be fully explored due to the limited data available to be exported from the Engineering Change Management (ECM) tool. For this reason, in both approaches, a prototype is presented, that could be implemented by the company, and the activities that the organisation should undertake to maximise the benefits of the proposal are also highlighted. The implementation of the second approach, combined with all the corresponding suggestions, would act as a framework where all ECR participants could see the overall status and pending tasks of the ECRs for which they are responsible. In addition, management could also use the tool to obtain the performance and statistics of all projects. It is expected that both proposals improve the normal flow of activities, resulting in higher compliance with the planned deadlines and ultimately reducing the cost and the implementation time of the change. However, for future work, these proposals should be extended to other projects and, if necessary, adapted to create a global standard.

Keywords

Engineering Change Management, Project Management, Large Engineering Projects

Resumo

Melhoria da gestão de alterações em grandes projetos de engenharia: um caso de estudo

A presente tese foi desenvolvida na Bosch Car Multimedia S.A., em Braga, na equipa de gestão de projetos do departamento de desenvolvimento. Esta investigação foi desenvolvida no contexto de um grande projeto de engenharia na fase de desenvolvimento de um novo produto. O principal objetivo foi melhorar o processo de gestão de alterações ao produto, avaliando uma possível reorganização das actividades e a criação de novos procedimentos. O autor integrou um projeto-piloto, que já estava em curso, para estudar em paralelo as oportunidades de melhoria. Neste sentido, a metodologia de investigação escolhida foi um estudo de caso, analisando primeiro o processo standard da Bosch e o processo seguido pelo projeto-piloto, e depois identificando e propondo oportunidades de melhoria.

As oportunidades de melhoria podem ser divididas em duas propostas. A primeira consiste numa revisão das actividades em cada fase da ECR, sugerindo quando se deve iniciar cada uma, bem como a forma como o gestor do projeto deve agir. De seguida, a segunda proposta está relacionada com o cumprimento dos prazos da ECR, sendo apresentadas duas abordagens possíveis. A abordagem 1 sugere o acompanhamento das datas num ficheiro Excel, enquanto a abordagem 2 sugere a utilização de dashboards no Power BI. Ambas as abordagens não puderam ser totalmente exploradas devido á limitação de exportação de dados da ferramenta. Por este motivo, em ambas as abordagens é apresentado um primeiro protótipo, que poderia ser implementado pela empresa, mas também são destacadas as actividades que a organização deve realizar para maximizar os benefícios da proposta. A implementação da segunda abordagem, combinada com todas as sugestões correspondentes, atuaria como uma *framework* onde todos os participantes da ECR poderiam ver o estado geral e as tarefas pendentes pelas quais são responsáveis. Além disso, a administração poderia também utilizar a ferramenta como forma de avaliar o desempenho e as estatísticas de todos os projetos. Espera-se que ambas as propostas melhorem o fluxo das actividades, resultando num maior cumprimento dos prazos planeados e, eventualmente, reduzindo o custo e o tempo de implementação da mudança. No entanto, futuramente, estas propostas devem ser alargadas a outros projetos e, se necessário, adaptadas para criar um *standard* global.

Palavras-chave

Gestão de Alterações ao Produto, Gestão de Projetos, Grandes Projetos de Engenharia

Contents

List of Figures

List of Tables

Abbreviations and Acronyms

AE Automotive Electronics.

APM Association for Project Management.

APMBOK APM Body of Knowledge.

BrgP Braga Plant.

CC Chassis Systems Control.

CO Correction.

EC Engineering Change.

ECM Engineering Change Management.

ECR Engineering Change Request.

FR Final Review.

ICB IPMA Competence Baseline.

IG Innovation Gate.

IPMA International Project Management Association.

KPI Key Performance Indicators.

NPD New Product Development.

PDM Product Data Management.

PDP Product Development Process.

PEP Product Engineering Process.

PM Project Manager.

PMBOK ® Project Management Body of Knowledge.

PMI Project Management Institute.

PN Part Number.

QG Quality Gate.

QGC Quality Gate Customer.

QGP Quality Gate Platform.

RQ Research Questions.

SAP Systems Applications and Products in data processing.

SC Steering Committee.

SF Simplified Flow.

TR Team Review.

XC Cross Domain Computing Solutions.

Chapter 1

Introduction

This chapter presents the research motivation behind the project, which was developed within the scope of the Master in Industrial Engineering and Management at the University of Minho. The project was carried out in the Development Department of Bosch Car Multimedia S.A., located in Braga, Portugal. Following the research motivation presented in section 1.1, the investigation objectives are detailed in section 1.2. Then, the chosen research methodology is outlined in section 1.3 and finally the structure of the dissertation is presented in section 1.4.

1.1 Background and research motivation

Project management has been practised since the beginning of human civilisation. Some examples of its presence over the years are the building of the pyramids of Giza, the construction of the Great Wall of China, the organisation of the Olympic Games, the voyages to the moon and many others (PMI, 2017). In all of these projects, someone had to manage a large number of workers, ensure that there was enough supply to sustain the project, make sure that the project stayed on track and that the results met the defined expectations (Seymour & Hussein, 2014).

In today's increasingly competitive world, competitiveness has become a key factor in an organisation's success. Factors such as the new context of economic globalisation, crisis phenomena, increased competition and the increased emphasis on time to market are forcing companies to change their attitude. Innovation and efficiency are seen as key factors to enable them to compete in such circumstances (Sousa et al., 2018; Hobbs et al., 2008). The automotive industry, in particular, faces all of the above challenges, as well as increased product portfolio diversification, increased features and complexity, and increased safety requirements (Heneric, Licht, & Sofka, 2006).

The use of project management processes, tools, and techniques builds a solid foundation for organisations to overcome difficulties and achieve their objectives (PMI, 2017). However, several industrial companies still need to improve their project management practices (Sousa et al., 2018).

The growth of market competitiveness, combined with the exceptional needs of consumers, contribute to a higher level of business renewal. For industries, this renewal usually means engineering changes to their products. In modern companies, all employees, suppliers and customers are involved in the decisions and opportunities for product development (Maceika & Toločka, 2021). Organisations need to be constantly prepared to improve and update existing products, and so engineering change management, which has always been important, is now an essential aspect (Jarratt, Clarkson, & Eckert, 2010).

Companies that design and manufacture complex products are well aware of the many possible changes that may be required to a product over time. These changes may be due to new product requirements requested by the customer, or due to new manufacturing requirements resulting from the company's investigation/identification (Perrotta, Faria, Araújo, Tereso, & Fernandes, 2017). A change may involve any modification to the form, fit and/or function of the product and may affect the interactions and dependencies of the different parts of the product (Jarratt, Eckert, Caldwell, & Clarkson, 2011).

Currently, the automotive industry is dealing with multiple Engineering Change Management (ECM) systems and processes to create and communicate changes. These systems include multiple formats and definitions, leading to increased confusion, cost and overall inefficiency in the system (Wasmer, Staub, & Vroom, 2011). In this context, project management practices are extremely relevant to ensure that the changes are managed effectively and efficiently with the primary objective of minimising disruption. Managing change is not an easy task and has a direct impact on the agility and cost of product production (Perrotta et al., 2017).

In manufacturing companies, the number of active changes can be so high that the conventional management is not enough (Perrotta et al., 2017). In this sense, organisations need to continually develop more effective and efficient processes to ensure that product design is clearly defined and carefully evaluated. An effective Engineering Change Management ensures that technical requirements are clearly defined, documented and their implementation is controlled throughout the product life cycle without interrupting the production of existing products (Wasmer et al., 2011).

1.2 Objectives

The main objective of this research was to analyse the possibility of improving project management processes in relation to engineering change management. In order to achieve this goal, the following objectives were defined:

- Analyse the current Engineering Change Management process in the company and pilot project context;

- Identify problems and possible improvement opportunities within the current activities;
- Define best practices and guidelines for the different stages and to be considered through the ECR process;

The aim is to study the current state of the ECM practices and to propose a detailed planning of the activities in each of the Engineering Change Request phases. This proposal will be followed by the study of a tool to track and monitor the process in order to ensure a better flow of activities and respect for deadlines.

Considering the objectives mentioned, the Research Questions (RQ) that this master thesis aims to answer are: RQ1: "How can the Engineering Change Management process be improved?"; and RQ2: "How can a tool be developed to track the activities and ECR status?"

1.3 Global research methodology

In order to achieve the objectives of this thesis, it was necessary to choose the most appropriate research methodology that would plan the necessary steps to achieve the desired results with this research. In this way, the case study was the research strategy adopted. This methodology allows the researcher to gain a deep understanding of the current state of the company and then be better prepared to formulate suggestions for improvement. The researcher was integrated into the project management team of a large engineering project and, as the project progressed, investigated how the engineering change management process could be improved to implement changes more effectively and efficiently. A deductive approach and multi-method qualitative research were used to develop this research. Information was collected in a number of ways including company documentation, unstructured interviews and direct and participant observation. All the data collected was critically analysed and the validity of the study was ensured through various tests.

1.4 Document structure

This thesis is divided into six different chapters. The first chapter is the introduction of the thesis and aims to present the background and motivation of the research, the objectives and the research methodology used.

The second chapter, which is the literature review, presents the concepts related to project management, an overview of the Project Management Body of Knowledge (PMBOK ®), the product development process and its reference models. It also clarifies the topics related to Engineering Change Management such as the standard process, the impact and the tools and techniques used.

The third chapter relates to the research methodology used, with a brief description of the method, all the data collection techniques and procedures, philosophy, approach, choices and time horizon.

The fourth chapter provides an analysis of the current state of the company, project management and engineering change management practices, as well as a presentation of the pilot project and improvement opportunities.

In the fifth chapter, the developed improvement proposals are presented, with the first proposal concerning the reorganisation of the project manager's activities and the second concerning the tracking of change requests.

Finally, in the sixth chapter, a general conclusion of the study is presented and suggestions for future work are made for the further development of the proposal.

Chapter 2

Literature Review

This chapter presents important concepts in the field of project management, based on published literature that provides a theoretical basis for the themes and concepts essential to the research. First, the definition of some project management concepts is provided. Then the standards for project management are presented, with particular emphasis on the PMBOK ® guide that is followed by the company. The third section covers the topic of product development, presenting some models provided by the literature. Finally, in the fourth section, it is explored the concepts associated with change management, including the change management process, practices, tools, and the impact that this topic has on project management.

2.1 Project management concepts

Project management is approached from different perspectives by different authors, resulting in some variations in concepts. This section presents the basic concepts that underpin project management and serve as the theoretical basis for the research that has been conducted.

2.1.1 Project

The definition of a project is very broad and can be interpreted differently depending on the author, reference guide, and book that describes what a project is. Each definition provides a slightly different perspective on what a project is and what it involves. Also, depending on the context and industry in which a project is undertaken, one definition may be more or less relevant than another. It is therefore important to explore some definitions, which are presented and explained below.

According to the Project Management Body of Knowledge (PMBOK ®), a project can be defined as a temporary endeavour undertaken with the goal of creating a unique product, service, or result. Projects are temporary and therefore always have a beginning and an end. The end can be reached either when the objectives of the project have been achieved, when the objectives can no longer be achieved and the project is cancelled, or when the project is no longer needed (PMI, 2021).

Similarly, the International Project Management Association (IPMA) defines a project as unique, time-bounded and undertaken with the intention of achieving pre-defined objectives, which may be expressed in terms of outputs, outcomes or benefits. The success of a project is usually measured by its ability to meet the acceptance criteria for the objectives, within the agreed time and budget (IPMA, 2021). Following the same line of thought of the Project Management Institute (PMI), the IPMA definition adds the concept of deliverables, stating that the project is conducted with the aim of producing one or more deliverables within the defined constraints (IPMA, 2021).

Another prestigious project management association is the Association for Project Management (APM). According to them, a project is a set of coordinated and interrelated activities, resources and tasks designed to achieve specific objectives or results. This may be creating a new product, service or process, improving an existing one, or resolving a particular problem or challenge. A project is guided by defined objectives, benefits, costs, risks and stakeholders involved in the project and serves as a basis for decision-making and evaluation of project success (APM, 2019).

Although there are small variations in project definitions, in a broad way, we can understand a project as a series of interrelated, complex and distinct activities, with a specific goal to be achieved within a given time frame, with a set budget and meeting certain requirements (Miguel, 2019). Thus, the following characteristics can be attributed to a project (Costa, 2017; Miguel, 2019):

- **Sequential:** a project has a series of activities that need to be carried out in a particular order.
- **Unique:** The activities and the circumstances of a project are always different from previous and future projects. Unique aspects may include the deliverables, stakeholder influence, resources, constraints, and the adaptation of processes to achieve the deliverables.
- **With a purpose:** a project may have a single purpose, however, the larger and more complex projects may be divided into sub-projects, each with a specific purpose.
- **Time-bound:** All projects have a start and finish date. The end date may be set by the client or internal management, so in most cases this date is not under the control of the team working on the project.
- **Collaborative:** a project must integrate different fields of knowledge capable of achieving the desired objective in an integrated way.
- **Constrained:** a project is limited in time, capital and resources, in particular people, money and equipment.

- **Follows specifications:** The client expects the project to meet a certain level of quality. There are many factors that can cause the specifications to change, even though the project manager treats them as static.

According to PMI (2021), a project can be managed as an individual project (outside of a portfolio or program), but it can also be integrated into a program or portfolio. A program is a group of related projects that are managed together to achieve benefits that could not be achieved if the projects were managed separately (PMI, 2021). On the other hand, portfolios can be understood as projects, programs, subsidiary portfolios and operations that are also managed as a group to achieve strategic objectives (PMI, 2021). For a better understanding, the relation between projects, programs, and portfolios is illustrated in the Figure 1.

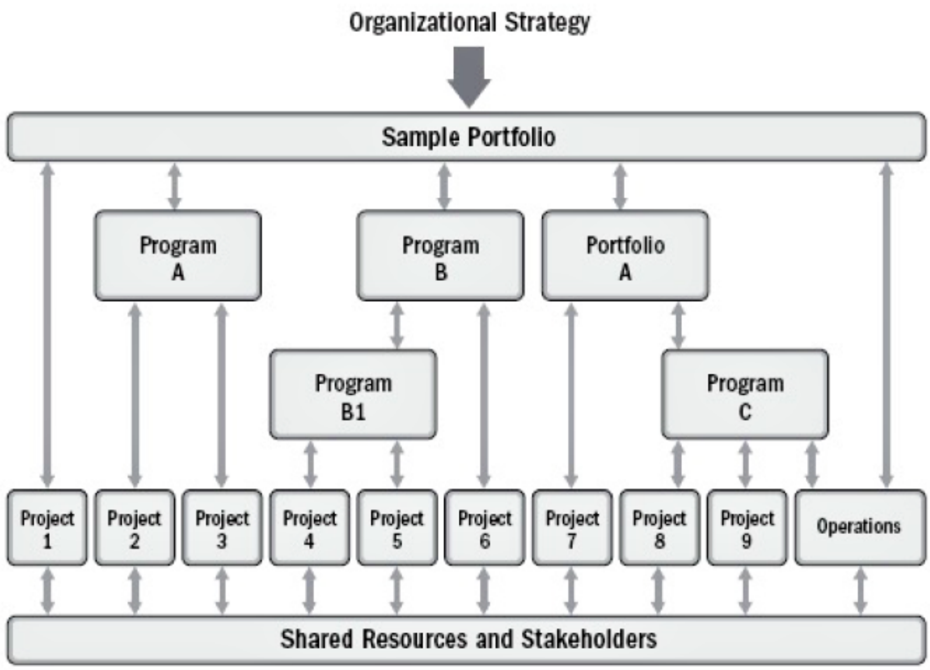


Figure 1: Relationship between projects, programs and portfolios
(PMI, 2017)

2.1.2 Project management

Project management can be a way for companies and industries to add more value to their products and services and make them more competitive, compared to their competitors (Jugdev & Müller, 2005). However, the company has to invest a significant amount of resources to create and manage a project, so it is extremely important that a project is successful in order to justify the investment (Sanchez, Terlizzi, & de

Oliveira Cesar de Moraes, 2017). Effective project management brings many benefits to the organisation and its stakeholders, ensuring that resources are used efficiently and that objectives are more likely to be achieved (IPMA, 2015).

Similar to the project concept, project management can be interpreted in different ways depending on the author or book. Therefore, to better understand the concept, it is good to have an overview of the different definitions.

According to PMI, project management can be defined as the application of knowledge, skills, tools and techniques to create activities that comply with the project requirements. In other words, project management is responsible for managing the project in such a way that the intended results can be achieved (PMI, 2021).

Similarly, IPMA (2015) and APM (2019) define project management as the application of methods, tools, techniques and skills to a project with the aim of achieving objectives. It can be seen as a set of processes and involves the integration of all phases of the project life cycle (IPMA, 2015). Finally, it can also be understood as the planning, organising, directing and controlling of resources with the aim of completing specific goals and objectives (Kerzner, 2009).

The purpose of project management is to execute projects effectively and efficiently. When applied correctly, it can help organisations achieve business objectives, meet stakeholders' expectations, increase success, optimise the use of resources, manage change effectively, respond to risks, deliver the products on time, and other positive impacts (PMI, 2017). On the other hand, when project management is poorly executed or even when it doesn't exist at all, there are many negative results, such as the need for rework, poor quality, missed deadlines, and others (PMI, 2017). Therefore, Project management plays an important role in the success of the projects, in meeting all requirements and even in the success of the organisations.

2.1.3 Program management

As stated above, a program is defined as a group of related projects that are managed together to achieve benefits that could not be achieved if the projects were managed separately (PMI, 2021). In turn, APM (2012) states that program management is the coordinated management of projects and change management activities undertaken to deliver benefits. Nevertheless, it is important to note that not all projects are necessarily part of a program (Miguel, 2019).

A program is usually created when there is a change in the company's vision and therefore its goals. For an organisation to successfully change its processes and mindset, it needs to change the way it manages projects, so the use of programs can be very positive in this case (APM, 2012). However, programs should be initiated in an organisational environment where project management is already done in a consistent way and well managed. Nevertheless, it happens that some companies that do not manage projects in the best possible way collect the various projects and create a program (APM, 2012).

The main reasons to integrate different projects into a program are (Miguel, 2019):

- the need for a global report for all the projects;
- the need to understand the impact of each project in the others (dependencies between projects);
- the need to monitor the resource allocation between projects that share the same resources.

Once program management can bring benefits to the organisation, it is important to define these desired benefits and determine if the investment is justified. Therefore, a detailed specification of the desired end state of the program should be defined at an early stage. However, due to the dynamic nature of the business, the specifications may need to be redefined on a regular basis (APM, 2012).

According to APM (2012), program management can address the following activities:

- Project coordination: it is needed to identify, initiate, accelerate, decelerate, redefine and terminate the projects and also to manage the inter-dependencies between the different projects;
- Transformation: manage change and ensure that the outputs deliver outcomes;
- Benefits management: involves defining, quantifying, measuring and monitoring the benefits of projects;
- Communication: important to develop and maintain a good relationship between all stakeholders to enable productive and effective communication.

2.1.4 Portfolio management

As stated above, a portfolio can be understood as projects, programs and operations that are managed as a group to achieve strategic objectives (PMI, 2021). The projects and programs present in the portfolio are not necessarily interdependent or related to each other (Miguel, 2019). Kock, Schulz, Kopmann, and Gemünden (2020) note that in a portfolio, projects compete for common resources, so it is necessary to prioritise and allocate resources in a way that exploits synergies between different projects. Managing portfolios can be divided into four main different phases (Kock et al., 2020):

- **Portfolio structuring:** it is necessary to decide if the project idea should be selected and have the investment made. It is necessary to establish methods and tools to evaluate the projects, taking into account factors such as conflicting goals, economic benefits, complementary projects, risk, profitability and others;
- **Resource allocation:** it represents a major challenge for organisations and it is crucial for project and portfolio success. The resources assignment should reflect the project priorities;
- **Portfolio steering:** the project changes need to be done in a way that allows achieving the goals of the organisation and not only the goals of a single project. It is necessary to integrate the information from the different projects in order to take advantage of the benefits and synergies of project portfolio management;
- **Portfolio learning:** projects are temporary and therefore dissolved after completion. Thus, it is important to reuse the knowledge, experience and competencies gained from previous projects to facilitate the management of future projects.

Project portfolio management has a big challenge managing all the complexity, inter-dependencies and goals of the projects. It is really important to have transparency and resource allocation in the projects to be able to achieve the benefits of working with portfolios (Kock et al., 2020).

2.1.5 Project stakeholders

The definition of stakeholder has a wide range but can be understood as "individuals, groups, or organisations that may affect, be affected by, or perceive themselves to be affected by a decision, activity, or outcome of a portfolio, program, or project" (PMI, 2021, p. 31). Stakeholders can have a positive or negative influence on a project, its deliverables, performance, schedule, quality, success, benefits, cost, risk and team members (Miguel, 2019; PMI, 2021).

Stakeholders can be divided into three main groups that interact with each other. One is responsible for the organisation and execution of the project, another is responsible for the project governance and the last includes all the other parts involved in the project. The project manager may be part of the group that organises and carries out the project, but is an important link between the various stakeholders in the different groups. (Miguel, 2019)

The project manager is the person responsible for leading the project team in the organisation and execution of the project, performing various functions, such as facilitating the work of the project team to easily achieve the intended outcomes (PMI, 2021). The project manager role also has the responsibility of ensuring the success of the project by performing some crucial activities such as (Miguel, 2019):

- Develop the project plan;
- Maintain and control the budget, the quality and the time frame within the project limits;
- Identify, evaluate and mitigate the risks throughout the project lifetime;
- Provide information on project performance;
- Manage the communication between the different parties involved, in particular the client, the sponsor and the project team.

In addition, PMI (2017) states that a project manager must have three key skills, technical project management, leadership, and strategic and business management, which together form the PMI talent triangle, as shown in Figure 2.

Figure 2: Project manager talent triangle

(PMI, 2017)

2.1.6 Project life cycle

Project management is a really complex activity, and therefore, it is necessary to manage the entire life cycle and its different phases in order to ensure the success of the project (I. S. X. Fernandes, 2021). A project life cycle is a "series of phases that a project passes through from its start to its completion" (PMI, 2021, p. 33). A life cycle phase is defined by a group of related activities that culminate in the delivery of one or more outcomes. A good definition and understanding of these phases allows resources to be managed in an efficient way, thereby facilitating the achievement of the project objectives (PMI, 2017).

The phases are time bounded and between each one there is a review or control of the project's performance. There are different terms to define this control point, but basically, it is a comparison with the plan and a decision as to whether the project needs to be changed, terminated or continued as planned (PMI, 2021). The phases in the project life cycle are influenced by many factors depending on the project. However, it is possible to say that the generality of projects includes the Feasibility, Design, Build, Test, Deploy and Close phases (PMI, 2021).

The project life cycle and its phases are affected by the deliverable approach and by the delivery cadence (PMI, 2021). Since a project has phases related to the development of a product, service or result, it is also possible to define the development life cycle. These life cycles can be predictive, iterative, incremental, adaptive or even a hybrid model (PMI, 2017). Each project needs a different type of life cycle approach, with the project manager being responsible for choosing the most appropriate approach (PMI, 2017).

According to PMI (2021), the project life cycle can be divided into the following stages: **Start Up**; **Plan**; **Development**; **Test**; **Deploy**; and **Close**. In Figure 3 it is possible to see an example of the order and the timing of the different stages as well as the possible project control points (milestones) and deliverables.

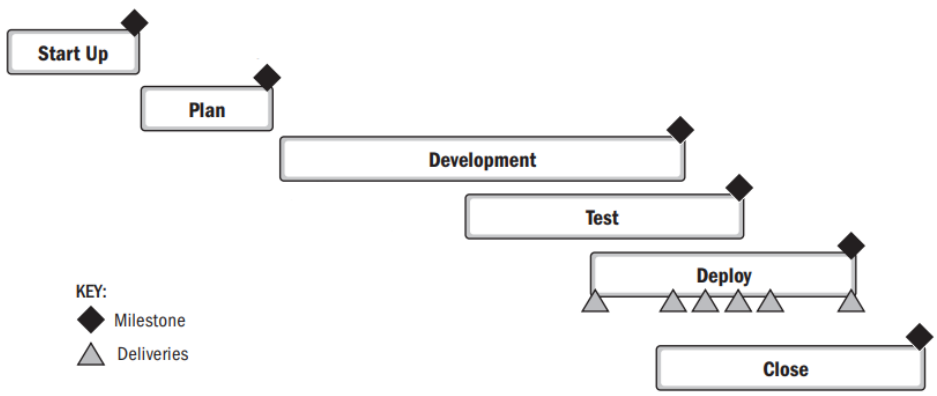


Figure 3: Project Life Cycle

Adapted from (PMI, 2021)

In the Start-Up phase, it is defined the project team, resources, budget, milestones and the project roadmap. This is followed by the Plan phase, where it is performed a decomposition of the initial high-level information into detailed plans. The Development phase overlaps with the Test and Deploy phases and includes the activities needed to achieve the proposed plan, with different delivery cadences and approaches for each deliverable. In the Test phase, a final quality review is performed and each deliverable goes through inspections and small-scale trials before moving on to the Deploy phase. The Deploy phase consists of putting the project deliverables into use. It is an iterative process that adapts as more deliverables become available. Finally, the Close phase involves evaluations and retrospectives, the release of project team members and the archiving of project knowledge.

2.2 Standards and project management methodologies

Although project management was already a common activity in organisations, it was not until the late 1960s or early 1970s that project management associations began to evolve. In the beginning, their activities were mainly related to the exchange of information, but soon there was a need to expand into the area of certification (Shepherd & Atkinson, 2011). Three different standards for project management are presented in subsection 2.2.1 and then in subsection 2.2.2 the PMBOK ® is explained in more detail.

2.2.1 Overview

As a result of the lack of standards, some associations saw the need and began to develop their own concepts and models. The first model to be created was the Project Management Body of Knowledge (PMBOK ®) by Project Management Institute (PMI), followed by the APM Body of Knowledge (APMBOK) by Association for Project Management (APM) (Shepherd & Atkinson, 2011). To this date, both PMI, based in the United States of America, and APM, based in the United Kingdom, have published seven editions of the Project Management Body of Knowledge (PMBOK ®) and APMBOK respectively. Over time, other associations have also developed their own guides to project management, being important to mention the International Project Management Association (IPMA), which is responsible for developing the IPMA Competence Baseline (ICB) (IPMA, 2015). The structure and topics of these three documents can be summarised as shown in Table 1.

Table 1: The organisation of the different standards

PMBOK	APMBOK	ICB
Project Management Principles: • Stewardship • Tailoring • Team • Quality • Stakeholders • Complexity • Value • Risk • Systems Thinking • Adaptability and Resiliency • Leadership • Change **Project Performance Domains:** • Stakeholders • Planning • Team • Project Work • Development Approach and Life Cycle • Delivery • Measurement • Uncertainty	**7 Categories:** • Project Management Context • Strategy Planning • Strategy Execution • Techniques • Business and Commerce • Organisation and Leadership • People and the Profession	**3 Areas of Competence:** • Perspective • People • Practice **29 Competence Elements:** • 5 Elements in Perspective Competence • 10 Elements in People Competence • 14 Elements in Practice Competence

The different standards for project management have become increasingly comparable in terms of their structure and content. Despite the differences, it is possible to say that they all include aspects such as terminologies, functions (so-called knowledge areas/main tasks), process descriptions and organisational models (Ahlemann, Teuteberg, & Vogelsang, 2009).

Standards are an important element that organisations need to have and use. This need can be mainly explained by two reasons (Grau, 2013). The first is to support the organisation, to provide guidelines for processes and methods, and to inform which application improves the quality of work and results. The second is to improve the trust between different parties, such as suppliers and customers, and even to consider potential partners.

The diversity of standards makes it difficult for organisations to select and implement the most appropriate standard for their context. Organisations should identify the standard that is recognised and used by the people involved in the project, that can be applied to the organisation's project context and that can provide benefits (Grau, 2013; Ahlemann et al., 2009).

Despite the important contributions of all the different standards, the PMBOK ® will be examined in more detail in the next subsection, as it is the standard and methodology followed by the company in which the case study was conducted.

2.2.2 Project Management Body of Knowledge - PMBOK ®

The purpose of the PMBOK ® is to identify the subset of project management knowledge that can be recognised as good practice (Miguel, 2019). The concept of good practice can be understood as the application of tools, skills and techniques that can increase the success of many projects (Miguel, 2019). There have been seven editions of the PMBOK ®, each with improvements and updates in response to the needs and feedback of the project management community (PMI, 2021). With project management evolving more than ever, the orientations of previous editions cannot be maintained forever and must reflect the current moment (PMI, 2021).

As an example, the sixth edition of the PMBOK ® presented ten knowledge areas and five groups of processes for successful project management. The sixth edition proposed a well-defined project life cycle with five phases (Figure 4) , associated with 49 processes (PMI, 2017). The processes had the primary objective of producing deliverables leaving to the background the opportunity of create value through the work done (Amaro & Domingues, 2023).

Figure 4: Project Management Process Groups

In the seventh edition, PMI defends that projects should not only produce outputs, but more importantly, deliver results that ultimately add value to the organisation and its stakeholders. Therefore, in this edition there is a shift to a principles-based standard and performance domains (PMI, 2021).

The project management principles have been developed to provide guidance on effective project management. These principles were defined and developed with input from many members of the project community. After several rounds of feedback, the following 12 principles were identified (PMI, 2021):

- **Be a diligent, respectful, and caring steward:** conduct activities with integrity, diligence and trustworthiness, while complying with internal and external guidelines. Should demonstrate a commitment to the financial, social and environmental impact of the projects.
- **Create a collaborative project team environment:** project teams are made up of people with

different skills, knowledge and experience. When project teams work together, they can achieve a common goal more effectively and efficiently.

- **Effectively engage with stakeholders:** stakeholders have an impact on projects, performance and results. It is, therefore, necessary to proactively engage stakeholders to enable opportunities, increase satisfaction, find solutions and contribute to project success.
- **Focus on value:** value is the primary indicator of project success. It is present during the project, at the end of the project, or after the project has been completed, and it can be quantitative and/or qualitative. Project teams need to assess and adjust the alignment of the project with the business objectives in order to maximise benefits and value.
- **Recognise, evaluate, and respond to system interactions:** a project can be seen as a system of interdependent and interacting domains of activity. It is necessary to have a holistic view of how the project parts interact with each other and with external systems (systems thinking) to enable project teams to achieve and maximise positive results.
- **Demonstrate leadership behaviours:** leadership is different from authority and can be demonstrated by any element of the project team. Effective leaders know their team members and are able to adapt their communication and actions to different situations. When applied well, leadership promotes project success and helps to achieve positive outcomes. A leader must have honesty, integrity and excellent ethical conduct.
- **Tailor based on context:** every project is unique. Tailoring is the art of designing the project approach based on its context, objectives, stakeholders, governance and environment, using only what is necessary to achieve the desired outcome, maximise value, manage costs and improve speed. It is an iterative process and therefore continuous throughout the project.
- **Build quality into processes and deliverables:** quality focuses on meeting acceptance criteria and requirements for deliverables. Project quality has the function of ensuring that the deliverables meet the project objectives and satisfy the needs, uses and acceptance requirements of the stakeholders. Project quality should also ensure that project processes are appropriate and as effective as possible.
- **Navigate complexity:** complexity is the result of human behaviour, system interactions, uncertainty and ambiguity. It is necessary to continually assess and manage project complexity so that approaches and plans enable the project team to reduce the amount or impact of complexity and successfully deliver the project.

- **Optimise risk responses:** risks can be positive (opportunities) or negative (threats). Risk exposure should be continually evaluated to maximise positive impacts and minimise negative impacts. Risk responses should be appropriate to the significance of the risk, cost-effective, realistic, agreed upon by stakeholders and owned by a responsible person.
- **Embrace adaptability and resiliency:** a project rarely goes exactly as originally planned and will eventually encounter challenges or obstacles. It is important to build adaptability and resilience into the organisation and the project team to help the project adapt to change, recover from setbacks and move forward.
- **Enable change to achieve the envisioned future state:** in order to remain competitive and relevant in the market, organisations need to respond quickly to change and act as change agents. However, this can be challenging as not all stakeholders will be receptive to change. To facilitate this process, a structured approach should be followed to help move from the current state to a desired future state.

Project Management Principles are fundamental truths, norms or values that influence and shape the work done in projects. These principles provide guidance on how to behave in the performance domains in order to achieve the intended results. It is possible to say that the project management principles provide behavioural guidance for activities in each of the performance domains (PMI, 2021).

PMI (2021) defines a project performance domain as a group of related activities that are critical to the effective delivery of project outcomes. Project performance domains are interactive, interconnected and interdependent areas that work together to achieve the desired project results. There are eight Project Performance Domains, as shown in the Figure 5.

Figure 5: Project Performance Domains

Adapted from PMI (2021)

The **Stakeholder** domain covers the activities of identifying, analysing and managing stakeholders throughout the project life cycle. It includes stakeholder engagement, communication and governance to promote positive relationships and satisfaction.

The **Team** domain focuses on developing, managing and leading the project team. It encompasses all activities related to project team members, with the aim of building team capability, managing team performance and resolving conflicts.

The **Development Approach and Life Cycle** domain addresses activities and functions related to the development approach, cadence and life cycle phases of the project. The aim is to create phases in the project life cycle that connect the delivery of value from the beginning to the end of the project and that facilitate the cadence and development approach required to produce the deliverables.

The **Planning** performance domain has a focus on creating the project plan and managing the overall project approach. It includes the initial ongoing activities of defining project objectives, selecting appropriate methodologies and creating the project schedule, with the aim of successfully delivering the project outcomes and deliverables.

The **Project Work** domain includes activities and functions associated with defining appropriate project processes, managing the physical resources efficiently, and fostering a learning environment.

The **Delivery** domain focuses on the actual execution and delivery of project work. Good execution of this domain enables the intended outcomes to be achieved, the project benefits to be realised in the defined time frame, and the stakeholders to be satisfied with the project deliverables.

The **Measurement** domain involves activities related to assessing project performance and taking appropriate actions to maintain acceptable performance. These activities can ensure that project targets are met and that additional value is created by making decisions based on forecasts and assessments.

The **Uncertainty** domain covers topics related to the management and reduction of risk and uncertainty. Uncertainty is present during all the phases of the project and is therefore necessary to continually minimise negative impacts and maximise positive impacts. All the resources, costs and schedule reserves should be used in an effective way to achieve the project objectives.

In parallel with the concepts of the 12 principles and the project performance areas, the concept of tailoring is introduced. The concept of tailoring can be understood as "the deliberate adaptation of the project management approach, governance, and processes to make them more suitable for the given environment and the work at hand" and should be driven by the project management principles, organisational values and organisational culture (PMI, 2021, p. 6).

Tailoring consists of adapting to the project context, objectives and environment. It involves the selection and application of processes, life cycle and development approach, engagement, methods and tools based on the characteristics of the project, such as its complexity, size, people involved and other factors (PMI, 2021). This selection is important because projects operate in complex environments and there is, for example, a need to deliver as quickly as possible, minimise project costs, meet the expectations of different stakeholders and continually adapt to change (PMI, 2021).

The tailoring process usually starts with the selection of the development approach, followed by the tailoring to the organisation, the tailoring to the project and finally the implementation of continuous improvements. The philosophy is to continuously adapt to the changing environment, of course within the limits of the organisational guidelines, but always with the aim of achieving the best performance and the best results (PMI, 2021).

2.3 New product development

A product (or concept) is considered new when it is completely new to the market, or new to the company, even though similar products may already exist in the market. As the market becomes increasingly competitive, the development of new products and services plays a critical role in the survival and success of organisations (Idrees, Xu, Haider, & Tehseen, 2023; A. Fernandes, Tereso, & Nunes, 2019). The importance of New Product Development (NPD) can be easily explained by the increasing internationalisation of the market, the increase in product variety and even the reduction of product life cycles (I. S. X. Fernandes, 2021). In subsection 2.3.1, the Product Development Process (PDP) and its importance are defined and then in subsection 2.3.2, some reference models used for a better performance of the PDP are presented.

2.3.1 Product development process

The development of a new product involves a range of process stages, from the product design to its delivery to the customer, and requires the involvement of people from many different areas, including design, testing, manufacturing and marketing (Cooper, 2019). The people and departments involved may differ from project to project, depending on the product characteristics, but as an example, it is possible to see in Figure 6 the development team for an electromechanical product.

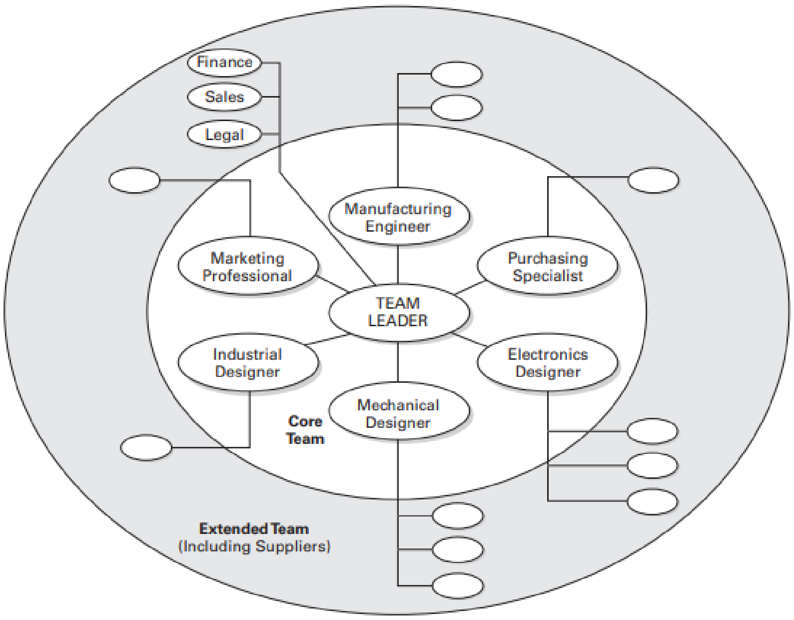


Figure 6: Product development team for an electromechanical product

(Ulrich & Eppinger, 2016)

Developing a brand-new product within the constraints of time and budget is a difficult task, therefore, project management is an essential part of the entire process of creating a new product (Costa, Fernandes, & Tereso, 2017). This process of creating a new product has to be clear, effective and have a strong articulation with the processes of creation, development and marketing. In this way, the creation of a new product will have influence over all the stages of the project and it is, therefore, necessary to plan and define all the phases from creation, continuing through production, and culminating in the delivery to the customer (A. Fernandes et al., 2019). A good definition of the Product Development Process (PDP) allows to ensure higher quality, improve the coordination between the different participants, maintain the plan up to date, manage the global performance and promote continuous improvement in the process (Ulrich & Eppinger, 2016).

PDP is a complex and unique process defined as a set of activities that have various marketing, financial and technical challenges and risks (Pons, 2008). It is a process that companies use in order to reduce production time and create more competitive products with a high pattern of quality and excellence (Rozenfeld et al., 2006). The creation of the PDP should be based on the knowledge, resources and capabilities of the organisation, always taking into account the products needed and/or desired by the customers. Furthermore, PDP has the ability to organise and structure the different phases of product development, reducing rework and costs, improving quality and ensuring easier time control (A. Fernandes et al., 2019).

However, in order to extract all the potential from the PDP, it is necessary to have reference models that help to standardise the activities and minimise uncertainties at the different phases of the process. The use of these reference models allows organisations to have better management of the PDP, ensuring also a better use of project management practices and a single language or way of acting for the organisation (Rozenfeld et al., 2006).

2.3.2 Reference models

Regarding the reference models for the PDP, there are a considerable number of different authors proposing different models. Nevertheless, it is possible to highlight the Stage-Gate model proposed by Cooper (2008), the model proposed by Ulrich and Eppinger (2016) and the model proposed by Rozenfeld et al. (2006). All of these models have small differences between them, but all follow the same pattern with a certain amount of phases and control points between them.

Stage-Gate Model

Cooper (2008) defines a product development model called Stage-Gate. In this model, PDP is a structured process with a series of stages separated by control and decision points. Between each stage, there is an evaluation and decision (gate) to continue, cancel or suspend and redefine the project, if it is not meeting its pre-defined objectives (Cooper, 2008). To do this, each gate is structured by the deliverables of each stage, criteria that allow the project to be evaluated, and the results of the gate reviewed. In this model, Cooper (2008) divided the PDP into five distinct phases, as shown in (Figure 7), which can be defined as:

- **Stage 1: Preliminary Investigation** - It defines the scope and assesses the market.
- **Stage 2: Detailed Investigation** - Includes concept and business impact investigation, leading to product and project definition.
- **Stage 3: Development** - The product and the necessary processes are developed.
- **Stage 4: Testing and Validation** - Technical and commercial tests are performed on the product to evaluate its compliance with the requirements.
- **Stage 5: Full Production and Market Launch** - Includes all production, marketing, distribution and commercialisation processes.

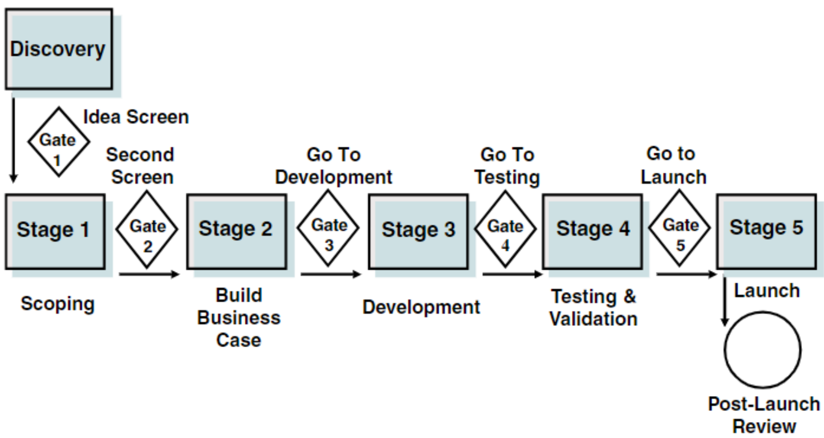


Figure 7: Stage-Gate Model Process

(Cooper, 2008)

Ulrich & Eppinger Model

PDP should follow a process adapted to the company context and take into account its needs and resources. With this aim, Ulrich and Eppinger (2016) propose a generic model for the product development process, inspired by the Stage-Gate Model, capable of being adapted to the context in which it is applied. This model also has control points and is defined by six phases:

- **Stage 0: Planning** - it precedes the approval of the project and the start of the actual product development process. The output of this phase is the project mission statement, which specifies the target market for the product, business objectives, key assumptions and constraints;
- **Stage 1: Concept development** - identifies the needs of the target market, generates and evaluates alternative product concepts, and selects one or more concepts for further development and testing;
- **Stage 2: System-level design** - involves defining the product architecture, decomposing the product into subsystems and components, designing key components and assigning detailed design responsibility to resources;
- **Stage 3: Detail design** - includes the complete specification of the geometry, materials, and tolerances of all of the unique components and the identification of all standard components to be purchased from suppliers;
- **Stage 4: Testing and refinement** - involves the construction and evaluation of several pre-production versions of the product;
- **Stage 5: Production ramp-up** - the product is manufactured using the intended production system. The product is launched and becomes available for sale.

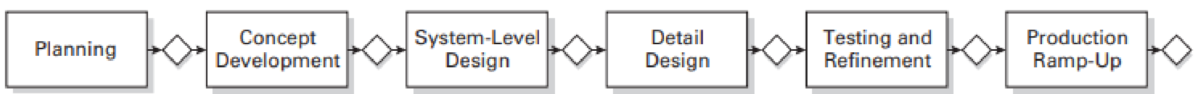


Figure 8: Generic product development process

(Ulrich & Eppinger, 2016)

Rozenfeld et al. Model

The model proposed by Rozenfeld et al. (2006) is defined as a unifying model of different models, practices and approaches of different authors. As shown in Figure 9, this model divides the development process into nine sequential phases, divided into three groups of phases:

- **Pre-development**: This group contains two phases (strategic product planning and project planning). It is extremely important because it contributes to the efficient use of resources, defining priorities and making the start of projects faster and more efficient. At the end of the group, there is the first gate, where the activities and results of these two phases are evaluated;
- **Development**: Within this macro-phase, there are five phases which are the informational design, the conceptual design, the detailed design, the production preparation and the product launch. These phases define all the characteristics of the product, its production process and its marketing. There are also five control gates, one after each phase, to check the work carried out in each of them;
- **Post-development**: This consists of two phases, product and process follow-up and product discontinuation. After each of the phases, there is also a control point (gate). During these phases, the data and lessons learned from the project are evaluated and recorded.

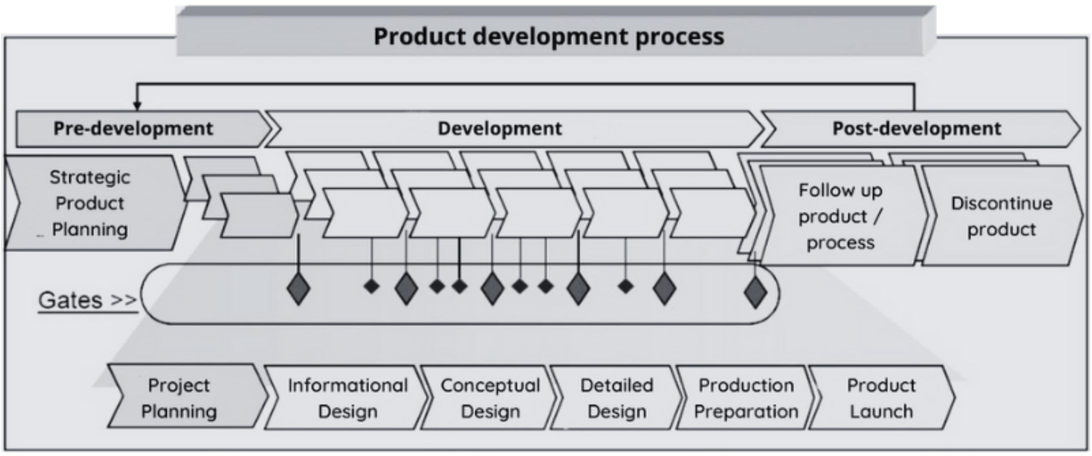


Figure 9: A reference model for PDP

Adapted from Rozenfeld et al. (2006)

2.4 Engineering change management

Engineering Change Management is the process of identifying, evaluating, approving and implementing changes to a product or system throughout its life cycle (Wilberg, Elezi, Tommelein, & Lindemann, 2015). It is critical to ensure that products meet customer requirements and regulatory standards and are delivered on time and within budget. The process involves many stakeholders and effective communication and collaboration are essential (PMI, 2013). The use of appropriate tools and technologies is also essential to manage the change management process efficiently and minimise the risk of errors or delays (Habib, Menhas, & McDermott, 2022).

This section is divided into four subsections. First, in subsection 2.4.1, an overview of the ECM is provided. Then, in subsection 2.4.2, a generic change process is defined, followed by the definition of potential impacts in subsection 2.4.3. Finally, in subsection 2.4.4, tools and techniques that support ECM are presented.

2.4.1 Overview

An Engineering Change (EC) can be defined as a change to parts, drawings or software that has been approved during the product design process. The size and nature of the change, and even the number of people and duration of the application, can vary depending on the project and the various factors involved (Wilberg et al., 2015) (Jarratt et al., 2011). Engineering Change can be understood as the activities carried out to make changes to a product. Therefore, Engineering Change Management is responsible for organising and controlling all the activities that make up the EC process (Jarratt et al., 2011).

ECM is a component of project management and its implementation is an important step to achieve success in the projects as it assumes a relevant role, being responsible for keeping all the ECs under control (Wilberg et al., 2015; Eckert, Clarkson, & Zanker, 2004). The activities of ECM include forecasting possible changes, identifying changes that have already occurred, planning preventive measures and also coordinating the changes (Wilberg et al., 2015). Overall, managing and controlling ECs in the project is a task with high complexity and that demand both time and money, so the goal of ECM is also to avoid or reduce the number of engineering change requests before they occur, select an efficient implementation when they occur and learn from the ECs implemented (Hwang & Low, 2012; Hamraz, Caldwell, & Clarkson, 2013).

The complexity and turbulence of the market lead to a low tolerance for failure, and therefore, it is necessary to continually evaluate the current situation and address all the aspects that need change (PMI, 2013). As a result of the need for continuous access to the need for change, there will be changes throughout the entire project and, consequently, throughout the product life cycle.

The changes can be triggered by the various stakeholders (internal and external), including customers, suppliers, internal company departments, government bodies, and even market drivers (Iakymenko et al., 2018). In fact, change can not only be triggered by, but can also affect all the major business functions, such as manufacturing, purchasing, marketing, and after-sales support, illustrating its relevance in the project context (Jarratt et al., 2011). Communication between all those involved in the change is of crucial importance to explore all the topics such as potential risks, benefits and requirements that the change may entail. Project team members and project managers can and should work with the stakeholders to create a two-way communication in which it is possible to stimulate acceptance and assimilation of the change, but also to identify valid concerns that have to be addressed (PMI, 2021).

There are several terms used by different authors and companies to describe the paperwork and activities that follow the engineering change process. These include Engineering Change Request (ECR), Engineering Change Notice (ECN), Engineering Change Order (ECO) and Engineering Change Proposal (ECP). Depending on the author or company, the terms may have slightly different meanings, and in most cases, ECRs and ECPs are synonymous, as are ECNs and ECOs. An ECR can be understood as a form used to describe a proposed change or problem that may exist in a given product, whereas an ECO can be defined as a document describing an approved engineering change to a product and the instructions for implementing the change into the product (Jarratt et al., 2010).

2.4.2 Engineering change process

Over the years, various authors have proposed different definitions of the EC processes, each of which divides the process into a different number of phases (Jarratt et al., 2011). For example, Lee, Ahn, Kim, and Park (2006) proposed a four-stage model for the change process, including the stages of (1) initiating the ECR, (2) evaluating the ECR, (3) issuing the change orders, and (4) storing and analysing the process for future changes. However, Jarratt et al. (2010) proposed a more comprehensive process including six steps (Hamraz et al., 2013).

Figure 10 shows a generic engineering change process based on the many models proposed by other authors (Jarratt et al., 2010). This generic process covers the complete life cycle of ECs, from the trigger given by the need for change to the review of the process (Hamraz et al., 2013).

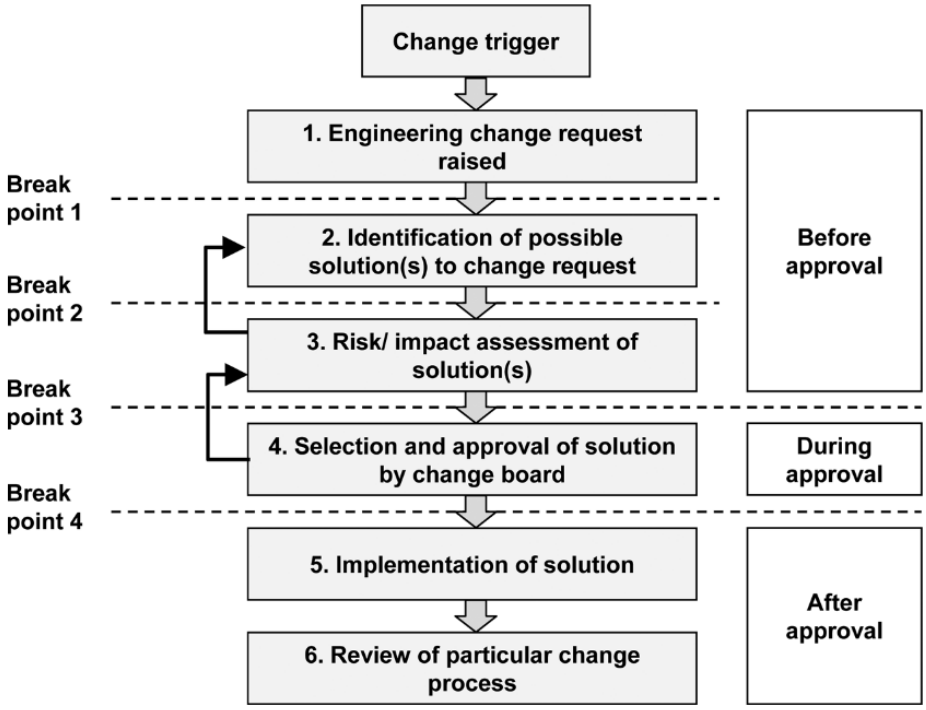


Figure 10: Generic Engineering Change Process
(Hamraz et al., 2013)

As shown in Figure 10, the EC process can be divided into three stages (Before approval; During approval; and After approval) and six steps (Jarratt et al., 2010):

1. An Engineering Change Request (ECR) must be made. Companies usually have standard forms (electronic or paper) that need to be filled in. It is necessary to outline the reason for the change, the priority of the change, the type of change, which components or systems are likely to be affected, etc. This form is then sent to a database and eventually to all those involved in the change for approval or other action.
2. After the request, it is necessary to identify potential solutions. However, in most cases, a single solution is investigated because of time pressure, because the solution is obvious or because the investigation is stopped once a solution has been found.
3. The risk or impact of implementing each solution must be assessed. Various factors need to be evaluated, such as the impact on design and production schedules, the impact on other products and components, the impact on supplier relationships and the cost of the change, and many others. The further in the design process a change is implemented, the more disruption there will be as a greater number of parameters need to be changed.

4. After analysis, a particular solution is selected and approved. Companies have an engineering change board or committee that reviews and evaluates each change and then approves it for implementation. The engineering change board must include a range of people from all key functions associated with the product: for example, product design, manufacturing, marketing, supply, quality, finance, product support, etc.

5. Implementation can be immediate or phased, depending on a number of factors such as the nature of the change and when in the product life cycle it occurs. In addition, during implementation, it must be ensured that all documentation is up to date in the production area (Jarratt et al., 2011).

   Implementation is a stage where companies want to make the most efficient use of resources and often the least financial effort (Iakymenko et al., 2020). In order to implement Engineering Change (EC) efficiently, there are two main strategies: one realised by the EC urgency and the other realised by the EC batching (Iakymenko et al., 2020). For example, Barzizza, Caridi, and Cigolini (2001) suggest that the appropriate timing of the change can be determined by differentiating the change result between scrap, rework or use-as-is. On the other hand, Nadia, Gregory, and Vince (2006) suggests that the EC should be implemented in batches, rather than immediately after the occurrence.

6. Finally, the change should be reviewed to assess whether it has achieved what was originally intended and what lessons can be learned for future change processes. Despite the importance of this step, few companies carry out such a review process.

As can be seen in Figure 10, there may be iterations between steps. This can happen because the risk/impact assessment may determine that the solution is too risky and therefore it is advisable to find another solution, or it can happen in the approval phase because during the approval process, further assessments may be required and thus a return to the third phase. Although these are the only two loops shown, there may be others between other steps. In extreme cases, the review step may find that the solution is worse than the initial situation and a new change request must be initiated (Jarratt et al., 2010).

During the change process, there are four break points where the process can be stopped. These points can be compared to the stage-gate points used in product development projects. The different breakpoints are located between the different stages of the process and act as a way of evaluating the work done in that stage and deciding whether the process can proceed to the next stage or whether some adjustments or even a complete rework in the previous stage is required. The first breakpoint is after the change request. At this stage, it is important to filter the proposals and identify opportunities for improvement while avoiding unnecessary change costs. The second breakpoint comes after the identification of possible solutions. This breakpoint is justified because it is possible to conclude that there are no solutions and therefore the process cannot be carried out. The third breakpoint is immediately after the assessment phase, because it may be determined that the change is too risky to be approved. Finally, the fourth breakpoint is before the implementation step, because it is possible that the impact on other products or processes will be too great for the benefits to be gained from implementation (Jarratt et al., 2010, 2011).

It is important to note that all the information of the Engineering Change (EC) should be available in order to use the knowledge gained from the conducted process in future implementations. Furthermore, access to information is not only relevant after the implementation but also during the assessment and implementation phases. In fact, this is a major challenge for organisations that do not always ensure that updated documentation is available to all departments. Thus, it is important that all relevant information is properly documented and stored so that it can be accessed by all parties when required (Iakymenko et al., 2020; Morris, Halpern, Setchi, & Prickett, 2016).

In summary, although there is no universal best practice for the ECM, steps or guidelines should be followed to ensure the organisation of the process. In addition, there needs to be integration of all information and all stakeholders to better respond to the changing environment and organisations need to embrace change as part of their strategy to be able to compete and succeed in today's markets.

2.4.3 Impacts of change management

The identification of the impact of the change is extremely important for the engineering change process. In general, changes have an impact on planning, scheduling and project costs (Jarratt et al., 2010, 2011). It is, therefore, necessary to carry out a continuous assessment throughout the change process to ensure better use of resources and to reduce the costs associated with the change (PMI, 2013).

The organisation needs to ensure that the change is possible and that there is sufficient time, materials and resources to implement it (Iakymenko et al., 2018). The change impact assessment allows evaluation of the organisational capability to achieve the desired level of change and to move from the current state to the future state (PMI, 2013). The impact assessment includes the analysis of the gap between the current capability and the required future capability and the assessment of the organisation's readiness to implement the change (PMI, 2013).

It is important to note that the change will affect a large number of people, and this number will be even higher if the product is at a late stage in the design process or even in production (Jarratt et al., 2011). In addition, the scope of the change is usually greater than originally planned. For example, the impact of adding an isolated part or component to a product is relatively easy to determine at the beginning of the design process (Iakymenko et al., 2018). However, at a later stage, the insertion of a component may conflict with others or even be incompatible, requiring rework, material waste, more people involved, and resulting in higher costs and delays (Iakymenko et al., 2018; Jarratt et al., 2011).

An EC on one part of the product may spread to other parts and components (Iakymenko et al., 2018). The change may also affect other products (for example other products in the same product family), processes (for example the manufacturing process) and companies (for example products with the same suppliers or partners) (Jarratt et al., 2010). The change affects not only a product or component as it is directly implemented but also all products that are somehow related to that product or component. This propagation can create a snowball effect, and in the worst case, affect the whole system, increasing costs and delaying schedules (Hamraz & Clarkson, 2015).

The project manager is responsible for assessing the impact of the changes (PMI, 2013). In most cases, the assessment is based on the personal experience and expertise of the project manager and the project teams. It is expected that experienced managers will be better able to assess the impact of the EC. However, the assessments can still be incorrect and it is positive and recommended that the project team uses supporting tools and methods to make more accurate estimations (Iakymenko et al., 2018).

2.4.4 Tools and techniques

There are many change management tools available to help organisations overcome various challenges in the change process and make quick and informed decisions (Habib et al., 2022).

According to Jarratt et al. (2011), the tools and methods that support the EC process can be divided into two groups. The first refers to those that support the workflow or documentation of the process and the second refers to those that are capable of supporting decision-making on specific topics of the process. In terms of workflow and documentation, there are a large number of computer-based systems that integrate the whole process. These systems include several databases of engineering change activities, generate electronic change requests and notification forms for all stakeholders, and cover all stages of the product life cycle. On the other hand, the support of decision in the change process can be divided into two groups of tools/ techniques: (1) hard technologies including Computer-Aided Design, Materials Requirements Planning and other academic tools; and (2) soft techniques including Failure Mode and Effect Analysis, Design For Manufacture and Assembly and Value Analysis.

Therefore, the change process can really be facilitated if it uses tools and techniques (Habib et al., 2022). However, not all organisations have access to the recommended tools for various reasons, such as lack of awareness of their existence, failure to meet user requirements, high difficulty and time-consuming to use, and others. Furthermore, despite the importance of the tools, it is vital that the organisation clearly understands the process and how the changes are linked (Jarratt et al., 2011).

Chapter 3

Research Methodology

The purpose of this chapter is to explain the research methodology used in this thesis. In order to achieve the objectives of this project, it was necessary to choose the most appropriate working methodology to strategically plan the necessary steps to achieve the objectives of this research.

The research onion proposed by Saunders, Lewis, and Thornhill (2012) was followed to develop this research. As shown in Figure 11, it helps to define the research methodology, starting with philosophies and their implications, followed by approaches, strategy, decisions, time horizons, and ending with techniques and procedures for collecting and analysing the data.

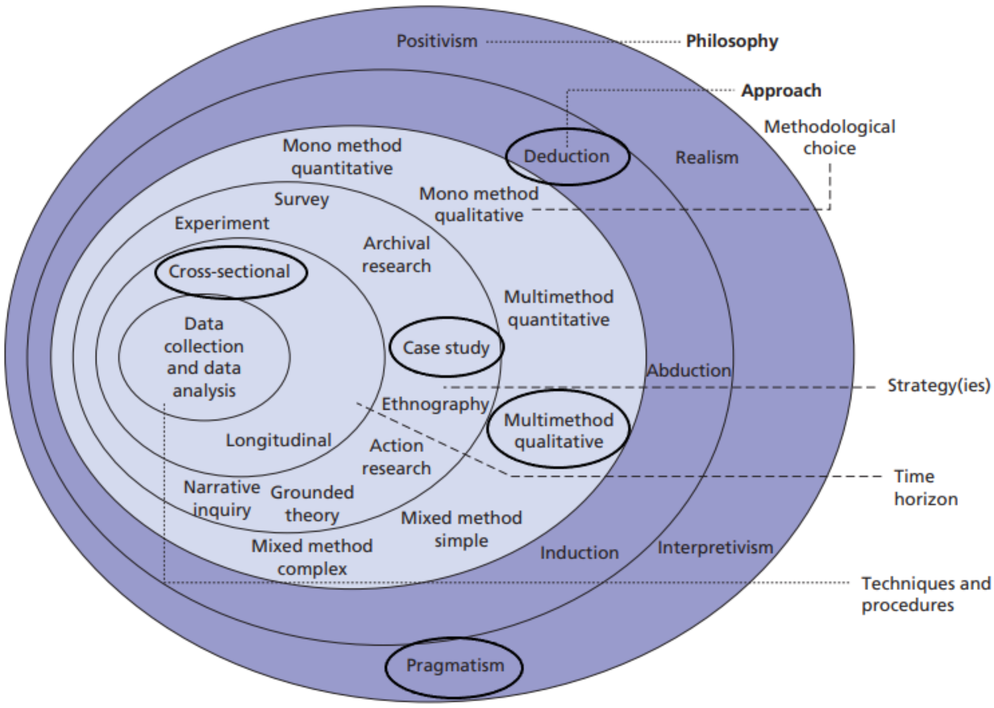


Figure 11: Research onion applied in this master thesis

Adapted from Saunders et al. (2012)

Philosophy

The research philosophy refers to a set of premises and beliefs about what knowledge will be developed. It can be understood as the assumptions that underpin the research strategy and the methods chosen. In this master's thesis, pragmatism was adopted as the research philosophy. Pragmatism defends that the research question is the most important determinant and that the real importance of an idea or a research finding lies in its practical consequences, adapting the methods to the situations in which they are used (Saunders et al., 2012).

Approach

In terms of research approach, this can be either deductive, inductive or abductive (the previous two combined). The main difference between the two is that, in the inductive approach, a theory is developed based on the knowledge gained from observations, whereas in the deductive approach, a hypothesis is developed based on existing theories (Saunders et al., 2012). Thus, the approach is defined as abductive because the research is based on both knowledge gained from observation and on an existing theory. This allows the data to be validated and correct assumptions to be formulated. The processes related to project management and engineering change management were studied with the aim of developing improvement proposals.

Methodological choice

In terms of research choices, a qualitative multi-method approach was adopted, using a variety of techniques and procedures to collect data for subsequent analysis. The research used information from the company's documentation, records and archives, conducted informal and unstructured interviews with people experienced in the engineering change management process, and made direct and participatory observations of the different stages of the process under study.

Strategy

The research strategy selected was the case study. This strategy involves an empirical investigation of a particular contemporary phenomenon (the case in question) within its real-world context and application. A case study is not only a way of obtaining data or identifying characteristics, but also a strategy that allows the formulation of theoretical propositions (Saunders et al., 2012; Yin, 2018). The elaboration of a case study is a variable process and should be revised and adapted as the project progresses (Yin, 2018).

A case study can be defined by four combinations. It can be holistic if it has only one unit of analysis, or embedded if it has several. It can also be a single case or an investigation with several cases. In this sense, this research can be defined as an embedded single case study, as different aspects and issues related to engineering change were analysed (embedded) in the same company (single case) in order to define some improvement proposals.

Time horizon

Regarding the time horizon, it is cross-sectional, since the study is momentary, situated in time. The improvement of engineering change management practices has been studied from February 2023 to August 2023.

Techniques and procedures

The collection of information to support the research may come from several sources to ensure greater reliability of the information, as each of the different sources has its strengths and weaknesses. The most common sources of evidence in a case study are (Yin, 2018):

- Documentation
- Archival records
- Interviews
- Direct observation
- Participant observation
- Physical artefacts

The different sources complement each other, and therefore a good case study will draw on as many sources as possible, as combining them will provide more accurate and reliable results (Yin, 2018). In this study, company documentation, unstructured interviews and direct and participant observation of the application of the methodology were used.

Data analysis refers to the set of actions required to develop critical thinking about the problem in question by examining, categorising, cataloguing and recombining the data collected in order to obtain answers to the questions. In order to carry out the analysis, it is necessary to start by defining the strategy and prioritising the information to be analysed, so that the evidence collected is properly processed. There are four general strategies "relying on theoretical propositions, working the data from the ground up, developing case descriptions, and examining rival explanations" (Yin, 2018). Any one of these strategies can be chosen, as can a strategy that combines more than one of them. However, the most common way of analysing the data is through the theoretical propositions that lead to the case study. The literature review acts as the driving element of the study and therefore helps to condition and shape the data collection and analysis plan, as well as guide the overall course of the case study (Yin, 2018).

There are then five analytical techniques: pattern matching, explanation building, time-series analysis, logic models, and cross-case synthesis, which are used to develop internal and external validity. However, pattern matching and explanation building are the two procedures applicable to qualitative analysis and the deductive perspective, and therefore to this study (Saunders et al., 2012). The first involves "predicting a pattern of outcomes based on theoretical propositions to explain what you expect to find from analysing your data" (Saunders et al., 2012, p. 579). The second, on the other hand, involves "an attempt to build an explanation while collecting data and analysing it" (Saunders et al., 2012, p. 580).

The validity of the study should be ensured through a series of tests. This logic can be ensured by checking four tests: Construct validity, internal validity, external validity and reliability (Yin, 2018). Construct validity is concerned with identifying the most appropriate measures for assessing the concepts under study. Internal validity seeks to establish a causal relationship between two variables and to examine the existence of patterns. External validity aims to show if and how case study findings can be generalised. Finally, reliability shows whether the operations of the study can be repeated and consistently produce the same results, even when replicated by a different researcher (Yin, 2018; Saunders et al., 2012).

In this project, construct validity was achieved through the use of multiple sources. Internal validity was ensured by identifying patterns between the different units of analysis and explanations for particular events. In terms of external validity, joint analyses of several changes were carried out. Finally, reliability was ensured by using the company database, which is common to all users.

Chapter 4

Case Study

After presenting the state of the art, the literature supporting this research and the research methodology used, it is crucial to describe the company, the current practices and other aspects related to the problem under analysis. This chapter begins with a brief contextualisation of the Bosch Group, Bosch Portugal and Bosch Car Multimedia Portugal (in Braga), where the research was conducted. Then, it is presented the company's vision regarding the product development process, followed by the change management process and its various activities, and the pilot project in which the researcher was involved. Finally, possible problems in the current change management practices are identified and possible opportunities for improvement are highlighted.

4.1 Company Presentation

This section focuses on the description of the automotive company in which the master thesis was developed. It begins with the presentation of the Bosch group on a global scale in subsection 4.1.1, and then it is presented the Bosch in Portugal in subsection 4.1.2 and in Braga in subsection 4.1.3.

4.1.1 Bosch group

The Bosch Group was founded in 1886 by Robert Bosch, who was only 25 years old at the time. At the start of its activities, the company presented itself as a precision mechanical and electrical engineering workshop, located in Stuttgart. In the same year, the company was recognised for the successful pioneering installation of a magnetic ignition device in an automobile engine. This milestone played a vital role in the structure and growth of the company and even served as the inspiration for the company's logo (Figure 12), which remained the same until today (Bosch, 2023a).

Figure 12: Bosch logo

The Bosch Group is currently headquartered in Schillerhöhe, located on the periphery of Stuttgart, and has a global presence, making it one of the largest companies based in Germany. In 2022, the company was present in more than 60 countries, with 440 subsidiaries and regional companies and employing approximately 420,000 employees. In that same year, the company reported 88.4 billion euros of sales revenue, representing an EBIT of 3.7 billion euros from all operations (Bosch, 2023a).

The company has been consistently recognised for its innovative solutions and commitment to social causes, while systematically pursuing sustainable and long-term financial success. This mindset has enabled and empowered the company to grow exponentially. Over the years, the company has diversified its products and services, always focusing on innovative technologies with the main objective of being a leader in the supply of technology and services. Currently, the Bosch Group has a wide range of products and services in a number of different business units. However, as shown in Figure 13, these products and services can be grouped into four main business sectors: Mobility Solutions, Industrial Technology, Consumer Goods, and Energy and Building Technology.

Figure 13: Bosch business sectors and business units

(Bosch, 2021)

In 2022, the Mobility Solutions sector was responsible for the higher revenue among all business sectors. As can be seen in Figure 14, Mobility Solutions was responsible for approximately 60% of the total sales, followed by Consumer Goods with 24% and finally Industrial Technology and Energy and Building Technology with 8% each (Bosch, 2023a).

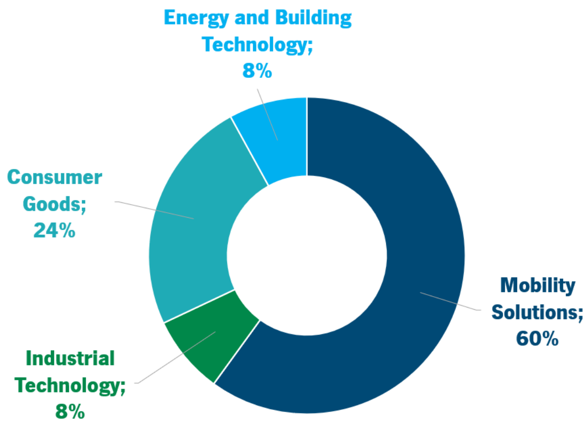


Figure 14: Revenue structure of the Bosch Group in 2022 by business sector

To inspire, motivate and create a valuable organisational culture, Bosch has adopted the mission statement "We are Bosch", always following the spirit of Robert Bosch and with the main objective of securing the company's future through strong and meaningful development and maintaining financial independence. The company's motivation is to be "invented for life", creating products that can inspire, improve the quality of life and at the same time conserve natural resources (Bosch, 2023b). The organisation is guided by its core values, which are presented in Figure 15. These values reflect the way the company deals with all its stakeholders, including business partners, investors, employees, and society. According to Robert Bosch, "In the long run, an honest and fair approach to business will always be the most profitable" (Bosch, 2023a).

Figure 15: Bosch values

(Bosch, 2023a)

Of all the company's strengths (corporate culture, innovation, quality, global presence), innovation deserves to be highlighted. The company's commitment to this area can be demonstrated by the investment of 6.1 billion euros in research and development in 2021, assigning approximately 76,000 associates to this task. Bosch wants to lead the change in the areas of artificial intelligence, internet of things, future mobility, smart homes and industry 4.0. In all these areas, the goal is to take automation to a new level, making everyday life easier and to unlocking countless new benefits for people (Bosch, 2023a).

4.1.2 Bosch Portugal

The history of Bosch in Portugal began in 1911 when Gustavo Cudell established the first sales office in the country. Like the group in general, Bosch Portugal has grown exponentially over the years and is now one of the most recognised companies in Portugal. Nowadays, the company is present in 4 different locations, with each one having a different role or business sector (Figure 16). The Portuguese headquarters is located in Lisbon, where activities in the fields of marketing, communication, accounting, sales and human resources are performed. Bosch is also present in Aveiro, where hot water solutions are developed, in Braga, where automotive sensors and multimedia are produced, and in Ovar, where security and communication systems are manufactured (Bosch Braga, 2023).

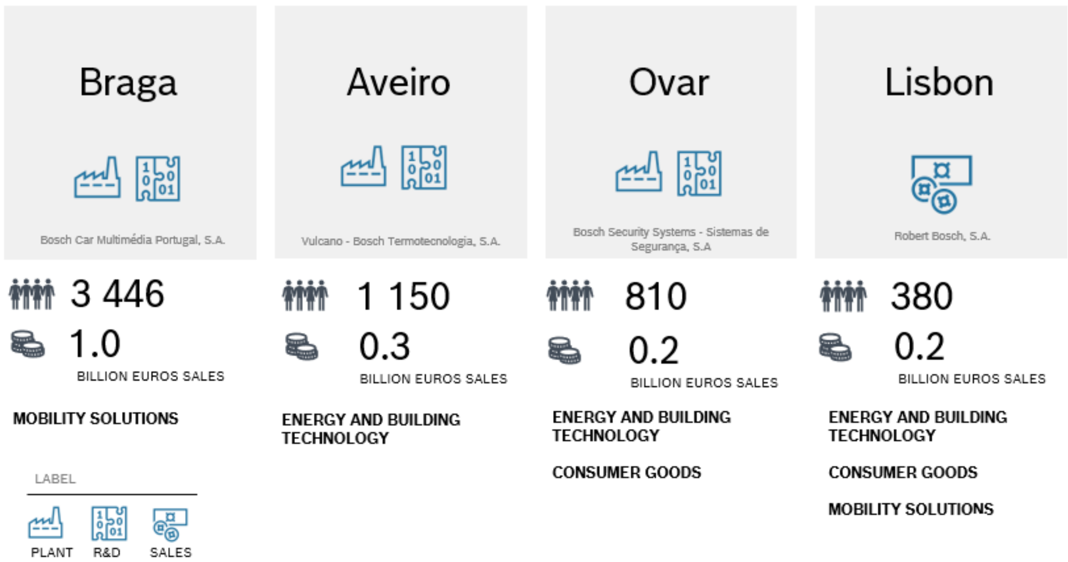


Figure 16: Bosch locations in Portugal

Adapted from Bosch Braga (2023)

With a total of around 5800 employees in the country, Bosch Portugal generated sales of 1.7 billion euros in

2021 and reported an export rate of 97% of its products (Figure 17). This amount of products represented 2.7% of the country's total exports, demonstrating its relevance and contribution to the country's economy.

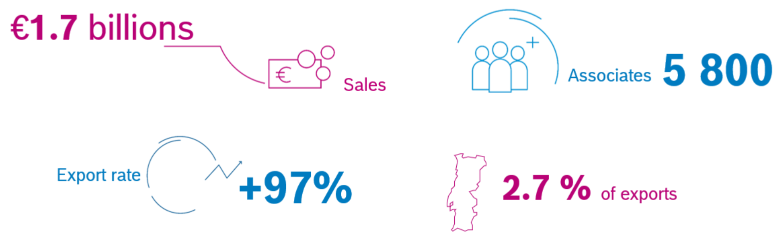


Figure 17: Economic results of Bosch Portugal in 2021

Adapted from Bosch Braga (2023)

4.1.3 Bosch Braga

Bosch Braga was founded in 1990 under the name Blaupunkt Auto-Radio factory and initially produced car radios with cassette mechanisms for the "Hamburg" model. From its origin until 2009, the Braga plant manufactured car radios and aftermarket accessories. In 2009, the Blaupunkt brand was sold, leading to a reorganisation of the Braga unit. At that time, the plant was renamed Bosch Car Multimedia Portugal, S.A., and shifted its focus to the development and production of various original components for the automotive industry (Bosch Braga, 2023). The Braga unit is the largest in Portugal, with 3446 employees and a turnover of 1 035 million of euros in 2021 (Figure 18).

Figure 18: Economic results of Bosch Braga in 2021

Adapted from Bosch Braga (2023)

At present, the Braga unit is responsible for the production of a wide range of products, including instrument clusters, infotainment and driver assistance, clusters for two-wheelers and motorsports, systems for professional vehicles, sensors and RADAR, and some other products. In terms of representativeness of all product types, instrument clusters account for 59% of all sales and infotainment and driver assistance for 26%. The remaining 15% is almost equally distributed among the other products (Bosch Braga, 2023).

All of the company's products and services are developed and produced to the highest quality standards, enabling it to work with a wide range of brands and companies, some of which are shown in Figure 19.

Figure 19: Main Bosch Braga customers

(Bosch Braga, 2023)

In the city of Braga, as shown in Figure 20, the company is present in 5 different locations, one of which is the plant (Building Brg104) where the production lines are located, and the rest are development offices, laboratories and warehouses.

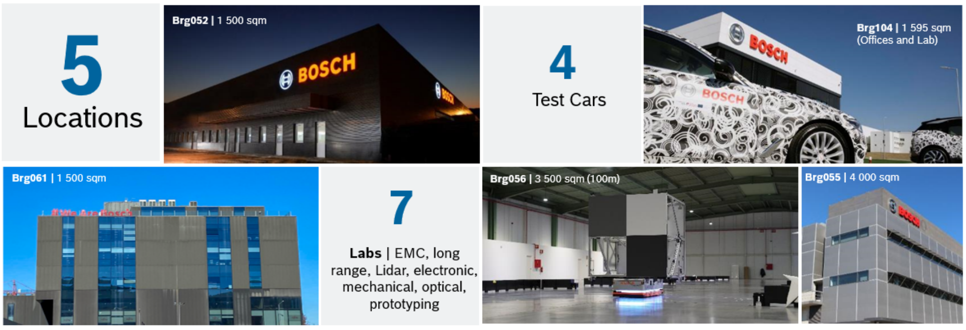


Figure 20: Bosch Braga Infrastructure

(Bosch Braga, 2023)

Following the company's innovation mindset, the Development department assumes a relevant position within the company. The department can be divided into 3 different business units: Cross Domain Computing Solutions (XC), Chassis Systems Control (CC) and Automotive Electronics (AE), covering the domains of mechanics, electronics, project management, system & testing optics and software (Bosch Braga, 2023). The innovation is so relevant that in the last 10 years, it has involved more than 1000 people and more than 190 million in investment, resulting in more than 90 patents. An important partnership and strength of Bosch is the partnership made in 2012 with the University of Minho, which allows sharing of information and collecting knowledge from specialised people in different fields (Bosch Braga, 2023).

4.2 Project management for product development at Bosch

The company has a project-oriented culture and considers project management as a core competence with high relevance in the product development process. In fact, more than 80% of Bosch sales are currently the result of successful projects. Since 2005, Bosch has become a benchmark for project management in the industry, with a broad and efficient application of the processes in line with the Bosch values and the focus on "striving for excellence" (Bosch, 2023a).

The company works closely with external partners to shape its approach in order to meet future challenges together and to keep aware of the latest trends and knowledge in project management. The project management definitions adopted by Bosch are closely aligned with those of PMI, particularly with regard to processes and methods. In order to ensure consistency and improve its practices, Bosch has created a central directive called "Project Management at Bosch", which is now applied to all projects, and a manual called "Bosch Project Management Handbook", both based on PMI's PMBOK (Bosch, 2023a).

Bosch has adopted the same process groups (Initiate; Plan; Execute; Monitor and Control; and Close) as PMI (2017). In order to provide a structured framework for managing specific types of projects, Bosch has established a project management life cycle that includes generic phases and milestones. Figure 21 illustrates Bosch's generic project life cycle, which project managers can use as a reference when developing their own processes.

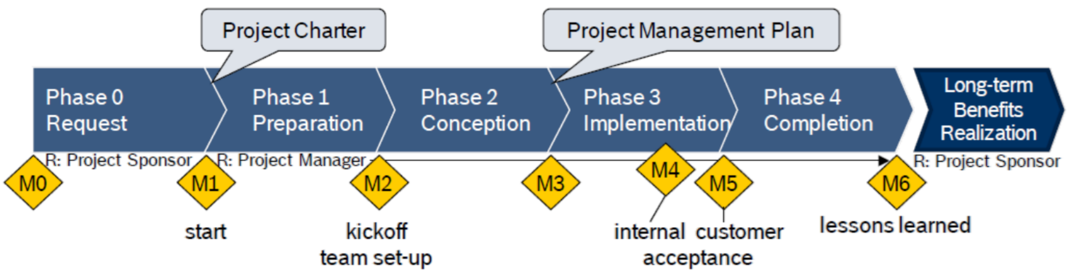


Figure 21: Phases of project life cycle

(Bosch, 2023a)

As shown in Figure 21, the phases are separated by milestones (M0-M6), which can also be defined as quality gates. A Quality Gate (QG) is a project maturity assessment that works alongside a project to identify and address deviations from project objectives at an early stage to avoid possible delays. In other words, it is a process of evaluating the work done so far or the level of maturity by comparing it with the defined criteria of the next steps (Bosch, 2023a). It can also be understood as an adaptation of the Stage Gate model proposed by Cooper, already explained in the literature review.

Depending on the type of the project, there are different QGs used. The Innovation Gate (IG) is used for innovation projects, the Quality Gate Platform (QGP) is used for platform projects (projects without a customer yet - the product is developed for more than one customer), and the Quality Gate Customer (QGC) is used for customer projects. The different processes and their respective gates are presented in Figure 22

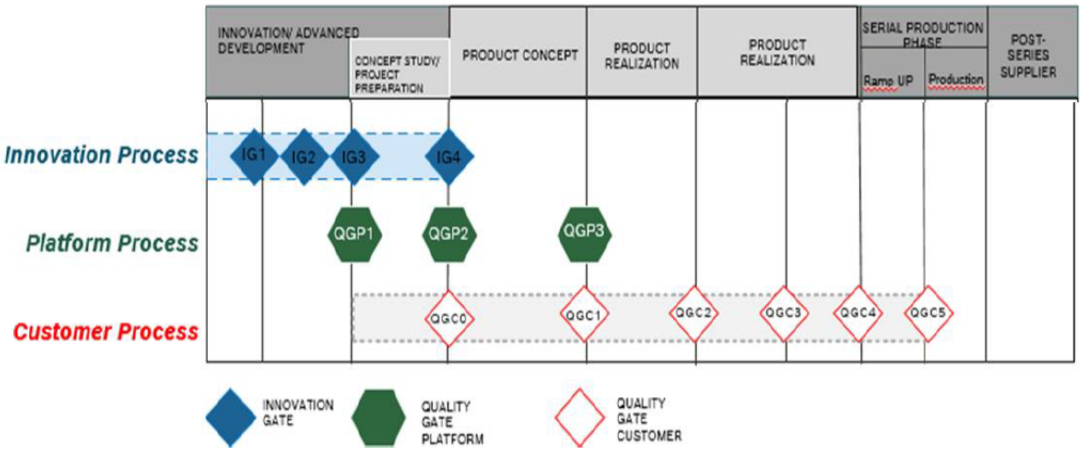


Figure 22: Quality gates for the different processes

(Bosch, 2023a)

Throughout all phases of the project, the project manager is responsible for leading the multidisciplinary teams to achieve the project objectives by creating and implementing a project management plan and working with the team and other resources. In addition, the project manager should establish the plan based on the project charter, integrate lessons learned from other projects, and apply all project management knowledge areas appropriately. In turn, the project team contributes with functional knowledge and experience to implement the project management plan in the most efficient way (Bosch, 2023a).

In the XC division, the projects can be divided into two different types: PEP and non-PEP. The Product Engineering Process (PEP) lead to tangible or intangible products while the non-PEP are projects created to manage organisational changes, mergers, and acquisitions, among other topics. At Bosch, a PEP can be started by two standard procedures:

1. a customer request for a product;
2. opportunity to expand and revolutionise the market through innovation.

In order to have a specific and standardised project life cycle for PEP projects, Bosch created the life cycle shown in Figure 23, where each phase can be understood and described by the five project management groups proposed by PMI: Initiating, Planning, Executing, Monitoring & Controlling and Closing.

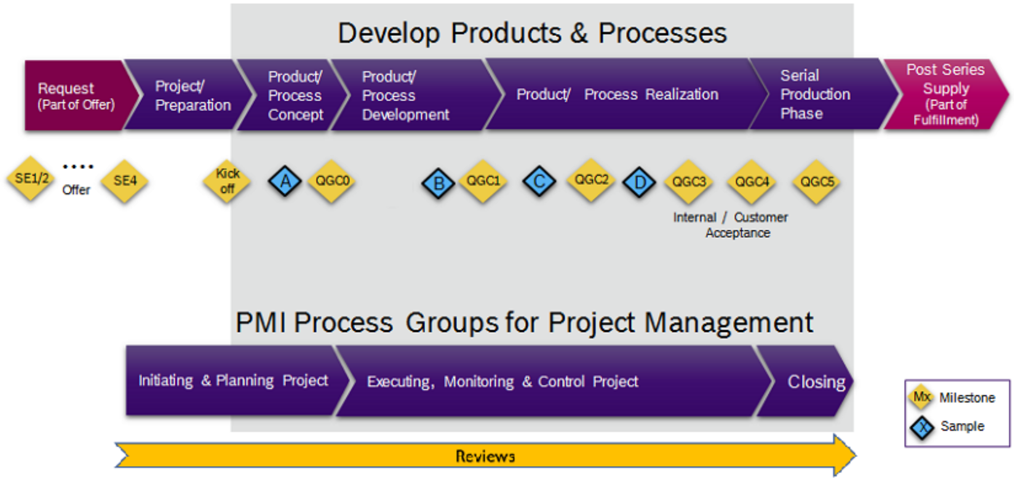


Figure 23: Product Development Life Cycle
(Bosch, 2023a)

In addition to the QGCs already explained before, it is also possible to see in Figure 23 the sample phases (A, B, C, D) that are considered in the development of a product. Each one of these phases has a target state of the product and the processes that are carried out. A short description of the sample maturity in each of the phases can be found in Table 2.

Table 2: Sample Phases

Adapted from Bosch Braga (2023)

Sample Phase	Sample Maturity
A	- Technical function largely assured; - Used for functional testing but not suitable for durability testing.
B	- Connection and mounting dimensions are standard; - Not all customer specifications may have been reliably met; - All functional requirements have been met; - Durability may be limited due to prototype manufacturing.
C	- Customer and Bosch specifications reliably met; - Design verification and validation completed.
D	- Initial sample with a test report for the customer as a basis for release of series production delivery; - Series nameplate with Bosch release part number and additional identification and/or numbering.

As shown in Table 2, each phase has conditions that need to be addressed to ensure the maturity of the product. In addition, each phase has specific objectives and contributions to the normal evolution of the product's development. For example, in the A sample phase, the product allows some preliminary tests to be carried out and packaging solutions to be studied. The samples in phase B are important for the customer to carry out preliminary tests and to ensure that the overall function and technical requirements are met. In phase C, the samples are mainly used for testing by the customer to obtain the "Technical Release" for Bosch as the supplier, confirming the release of the internal product and the end of the development phase. Finally, in phase D, the production process follows a series production approach to start the ramp-up to series production. During this last phase, Run Rates and Audits are carried out to assess the readiness and robustness for series production.

Once all these stages have been completed, the project moves on to series production, where large quantities of the already validated product are produced.

4.3 Engineering change management at Bosch

Engineering Change Management plays a crucial role in organisations, affecting areas such as customer satisfaction, competitiveness and quality. Therefore, Bosch wants to ensure that the organisation has a really detailed process in place that will benefit both employees and the organisation by saving time, maintaining a clear record of changes and easy access to relevant information about a change, avoiding unnecessary costs, ensuring quality, achieving customer satisfaction and ultimately strengthening the organisation's image and reputation.

This section is divided into four subsections, with subsection 4.3.1 exploring the process through the different phases of the PEP, subsection 4.3.2 presenting the roles and the people involved in the process, subsection 4.3.3 presenting the Bosch standard process and the different phases, and finally subsection 4.3.4 presenting the tool used to implement the changes and the different inputs required.

4.3.1 Relationship with PEP framework

Throughout all the development sample phases and then also during the series production, there are several changes to be performed to the product, the process, the suppliers, and possibly other aspects. Nevertheless, in a PEP framework, the ECR process is applied only after the QGC2, and so the whole process starts to be respected and followed only on the D samples. In the early stages of the project, in the A, B and C samples, the changes are made by creating a change notification, being agreed with the customer and the responsible parties and only being incorporated in the next sample phase. However, as mentioned before, the D sample phase is already a preparation and evaluation of the capacity for series production. Therefore, from the D phase onwards, the change process must be properly documented, taking into account all the defined criteria and steps.

This can be explained mainly by the fact that before QGC2 the development is very active, with changes being performed every time, which would mean a large number of documentation and the allocation of a significant amount of resources to control the whole process. Moreover, the production can be considered residual, with the production of a limited number of samples in the early sample phases. Therefore, the consequence of a change does not have the same impact as it would have if it was related to the series production, given the large quantities produced at this stage. Taking all of this into account, the normal procedure is simply to create a change notification that is visible to all stakeholders and needs to be approved by all the responsible parties and, if necessary, by the customer.

On the other hand, after the QGC2 and with the start of the D samples production, the goal is to ramp up, correct minor problems and stabilise the production process so that it is possible to enter in the series production stage. After that, the quantity of products produced is really significant and a mistake could mean the need to rework parts, the need to recall parts from the customer or even the need to stop the production, even for a short time. This would have major consequences, affecting the company's credibility and, of course, meaning a large amount of financial loss. It is therefore of the utmost importance that any change to the product and/or process, even if it appears to have no impact, is properly tracked and evaluated down to the smallest detail. For that, the ECR process is used to ensure that all information is reported to the appropriate people and that all data is documented. It is important to note that even though in the D sample phase, the quantity of products produced is not compared to series production, the ECR process starts to be used to simulate the series production phase and to familiarise the team and all those involved with the procedure.

4.3.2 Participants / roles

The standardised change process clearly defines the activities and roles phase of the process, involving several people with different roles and functions:

- **Change initiator** Associate who creates the engineering change as a change request;
- **Change representative** Associate responsible for the change from the planning phase to the start of the implementation phase. This is usually the same person as the change initiator;
- **Change coordinator** Responsible for the ECR implementation phase. Usually, it is the plant PM who is responsible for this role;
- **Manager of initiator** Responsible for the approval of the ECR;
- **Customer contact** May be development related, typically performed by sales or development managers, and/or quality related, usually performed by Quality Management & Methods (QMM);
- **Development Project Manager / Series Care Product Manager** The person responsible for following up the change with the team depends on the product phase. Before QGC5 the responsible person is the Development Project Manager. After that, the Series Care Product Manager is responsible. Both of them are responsible for following all changes from the beginning to the delivery to the customer, controlling the required budget, nominating the required resources and tracking all changes relevant to the project/product duration and delivery time;

- **ECR Team, Review Team (RT), Approver** The team is multidisciplinary and contains the responsible for each area. It can be dived into three subgroups: ECR Team; Review Team; and Approver. In Appendix A, a detailed overview of all ECR team participants and their respective tasks is presented;
- **ECR Steering Committee (SC)** If necessary, the Change Representative, the PM or the Series Care Product Manager can invite the ECR SC for support. The result of the escalation must be added to the ECR for documentation purposes;
- **ECR-Sales Coordinator** In the case of an ECR involving several customers, a sales coordinator may be appointed to help with customer contact.

4.3.3 Standard process

There are many factors that can change the process followed by the company. It is possible that the change is just a small correction to a previous ECR, where the change initiator only has to state the reason and the date of the change, and the manager has to approve the change. It is also possible, depending on the budget, the risk or even the project category, that the change is carried out and studied almost as a small project itself. In these cases, the change follows a process of QGs, just like the main project. However, the most common procedure is to use the ECR to implement the change. Even this process can have small variations, for example, customer involvement or not, but mostly it is a pattern procedure that can always be followed with the same thinking.

Despite the fact that, as explained, the ECM process may include other procedures, the ECR was the procedure studied and will therefore be explained in more detail, as it is also the normal procedure adopted for all engineering changes carried out within the projects.

As shown in Figure 24, the ECR process is defined by five phases (Preliminary clarification, Planning, Processing and Validation, Customer, and Implementation) with a review at the end of each. However, depending on the change, the customer may not necessarily be involved in the change and then the process has only the remaining four phases.

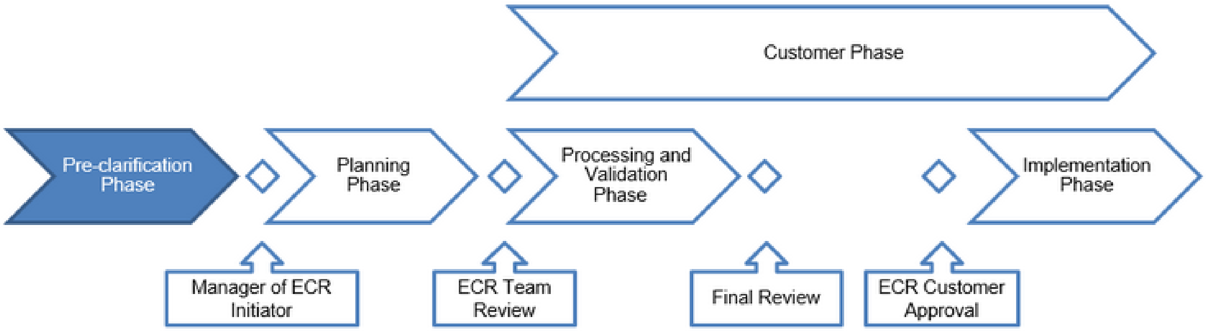


Figure 24: ECR Process Overview

The ECM process consists of several phases, each with its tasks and requirements. The Preliminary clarification phase, also known as the Preliminary agreement phase, is the first stage. In this phase, the initiator collects all the information, fills in the ECR with all the information including the reason for the change and nominates a change representative. The manager of initiator also plays an active role, helping to select the change representative if necessary, evaluating the work done and approving the ECR for further processing.

In the planning phase, the change representative is responsible for analysing the ECR and for planning/scheduling the activities for further processing. All the necessary documents are attached (risk assessments, impact checklist, security checklist, homologation checklist and many others depending on the characteristics of the change). In addition, the change representative clarifies the correct customer involvement, starts economic considerations (which cost centre will bear the costs) and analyses inventory details, including the parts and factories affected by the change. To define the correct level of customer involvement, a Bosch standard, that assigns an index to different types of change, should be used. This and the other tasks can and should always be supported by the project team, with the sales department playing a really relevant role in the process. This phase concludes with the team's approval in the final review.

The next phase is the processing and validation phase, during which the change is implemented in prototypes, which are then validated. At the end of the phase, a final review is carried out with the participation of the various departments (Development, Manufacturing, Quality, Logistics, Purchasing, Sales, ...) to assess the feasibility and quality assurance of the change, as well as the availability of all the information and documentation required for the change.

The customer phase can vary in length depending on the level of customer involvement but usually starts immediately after the final review. Prior to this, the change manager, in contact with the sales department, must prepare the presentation of the change to be explained to the customer. During this phase, the change is then presented, accompanied by all the documentation required by the customer. This phase ends when it is confirmed that the change can be implemented.

Finally, once the customer has approved the change and the change has been released internally, the implementation phase begins. The change coordinator is responsible for implementing the approved changes according to the timeline and controlling the cross-factory and cross-divisional implementation of the change to ensure customer demand. The Product Data Management (PDM) team is also present in this phase, mainly to ensure that all ECR documentation is correct and to document the implementation process, including date and time, for possible traceability. This phase ends with the release of the internal production process and the product updated with the given change.

After the implementation phase, future changes to the ongoing change process (e.g. technical upgrades) will require the ECR Review Team to decide how to proceed. However, changes to the content of the ECR are only allowed until the start of the implementation phase. Therefore, if it is decided to make further changes, it is expected that a new ECR will be initiated.

Overall, each stage has its own tasks and requirements and it is important to follow the process throughout to ensure that changes are implemented effectively and efficiently. The change management process is a complex, multi-stage process that requires good planning, documentation and evaluation. The process is iterative, so at each assessment, review or approval, there may be feedback on the need to make changes, improve a particular document or correct some information. There should be teamwork to ensure that the change is well documented and defined and that the process is followed correctly.

During the process, and taking into account each one of the phases already explained, there are different statuses of the ECR. In each one of the statuses there are many tasks that need to be performed and it works as a support and guidance to the project manager to define for each status what should be presented in the ECR and the work to be done. As shown in Figure 25 there are many statuses in the different phases of the process, each of which has a certain required maturity and contains a certain type of documents or information. As shown in Figure 25, the process has several statuses to describe each ECR phase.

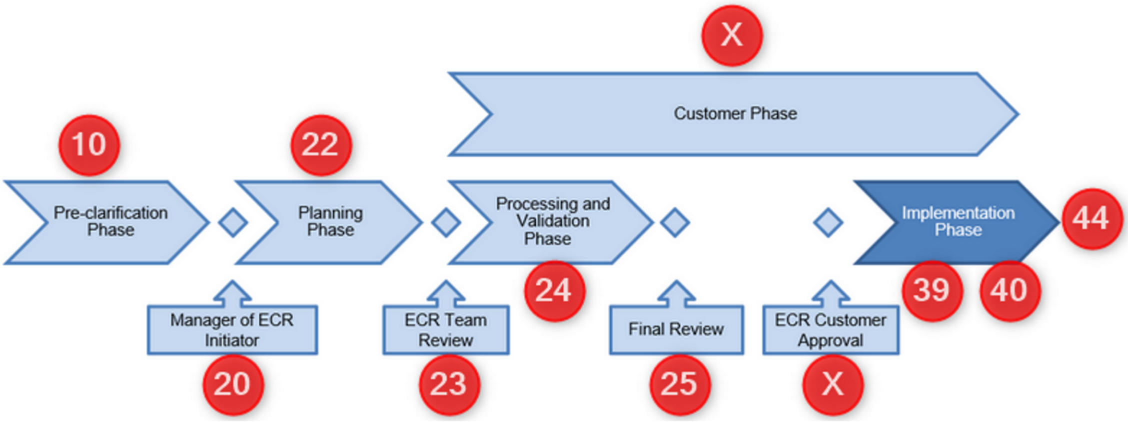


Figure 25: Status of an ECR

Regardless of the type, all ECRs start with status 10. Status 10 consists of the initiator issuing the ECR and can be understood as the first moment when the initiator officially creates the ECR on the ECM-Future platform. Before moving on to the next status, the initiator's manager must be selected, the type of ECR (Engineering Change (EC), Simplified Flow (SF), Correction (CO)) must be selected, the reason and description for the change must be specified, and the selection of the change representative must be studied with the help of the manager. Once these tasks have been completed, the initiator sends the ECR to the manager to evaluate and check that the reason for the change and all the information is correct. While there is no response from the manager initiator, the ECR remains at status 20. It is important to note that the manager could reject the proposal and request to change the information. In this case, there would be a step back to the pre-clarification phase so that the initiator could make the intended changes and then resubmit it for approval.

After the manager's approval, the ECR goes to change the representative's responsibility. At this point, the ECR goes to status 22 and remains there for the duration of the planning phase. In this state, all the information and documentation should be entered. This includes the schedule of activities agreed with the team, the documents relating to security, homologation and impact analysis, the documents representing the change (for example, if the change is mechanical, the drawing must be added), all the parts and plants affected must be indicated, the costs must be defined according to the activities of the change, and all the participants must be entered in order to be able to carry out the team review.

Once again, after planning all the factors, the representative sends the ECR to the team to perform the review and everyone approves. Along the team review the status is 23. At this stage, all the participants involved must approve the ECR. It is common for the change representative to push for approval and/or to give some more details to a particular participant. This phase is really important for meeting the expected implementation dates, so it is important to actively track these approvals to make this phase as efficient as possible.

The next status is 24 which corresponds to the possessing and validation phase. In this status, the tests previously planned must be fulfilled with positive results and properly validated. After the validation, the ECR goes to a sub-status (24D) where a formal check is done by the Product Data Management (PDM) department.

The following status is 25 corresponding to the final review where the team checks if the validation was fulfilled and with positive results. It also works as a confirmation if the plan proposed in status 22 is done.

In parallel with the two previous statuses, there is the customer phase that even though there isn't an actual number to define is taken also as a status that could be referred to as "X" just for tracking. This only happens of course when there is customer involvement. The reason this phase does not have an official number is that it happens parallel to another status and also because it is a phase that usually starts right after the Team Review (Status 23) but can be finished during Final Review (Status 25) or even after that. This stage can take several weeks so that the customer team can present the ECR to the customer. However, even if the customer team presents it on time, approval from the customer comes only when the validation results are available. Furthermore, the ECR does not go to the implementation phase (status 39) if the approval is still not available.

After both the approval from the team and the customer, the ECR enters the implementation phase and therefore in status 39. This status is the first step of implementation, with the ECR being sent again to PDM responsibility so that the affected documents are updated and it is created the change number in Systems Applications and Products in data processing (SAP) software. Next is status 40, still in the implementation phase. In 40 status, the goal is to have the change coordinator approve when the change is properly implemented in the plant. Important to mention that normally if the change is related to the product or process the only responsible for this is the change coordinator, however, it can happen if the change is for example on a purchase part that the purchase specialist is also included in this phase and it is necessary also its approval in this status.

Finally, at the end of the implementation phase, there is status 44 where the global change coordinator is responsible for the final approval. The responsibility is to ensure that all documentation is available so that all plants implement the change as proposed, and also to set the date for effective implementation into the normal production process.

It is important to note that the process is, as already said, every changing and depending on the type of change there is a status that will not be used for the ECR process.

4.3.4 ECM tool

The process in the company context is applied and supported by an ECM tool developed by Bosch, which not only documents the entire process but also integrates the change with all participants and makes the change visible to all in one place.

The ECM tool is just a means of applying the concepts of the process to reality. The tool acts as a framework within which the project manager should carry out all the tasks and steps described in the previous subsection.

In the framework, there is a section, presented in Figure 26, where the change initiator can fill in the roles of each responsible person, namely the change initiator, the change representative, the initiator's manager, the change coordinator and even the purchasing specialist if the change concerns a purchased part. In the same section, there is also a field to fill in with the customer involvement. This customer involvement must be studied to understand the impact of the change and what it means to the customer. To know that there is a table, presented in Appendix B, that supports the decision of the change initiator who, by answering each of the above questions, can determine how the classification should be defined.

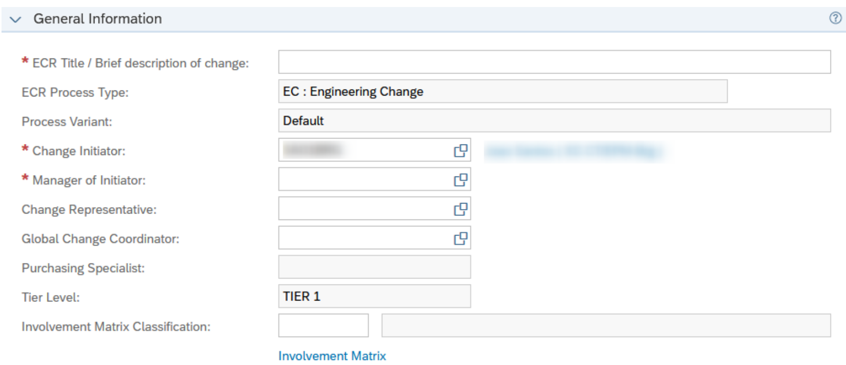


Figure 26: ECM tool general information section

The next section to fill in is the reason for the change. In this section, as shown in Figure 27, some of the normal changes in the projects are already present, it is only necessary to select the one that is more suitable. However, sometimes there is a reason that is not stated, so in that case, it should be selected

"Others" and write a really small statement summarising the change.

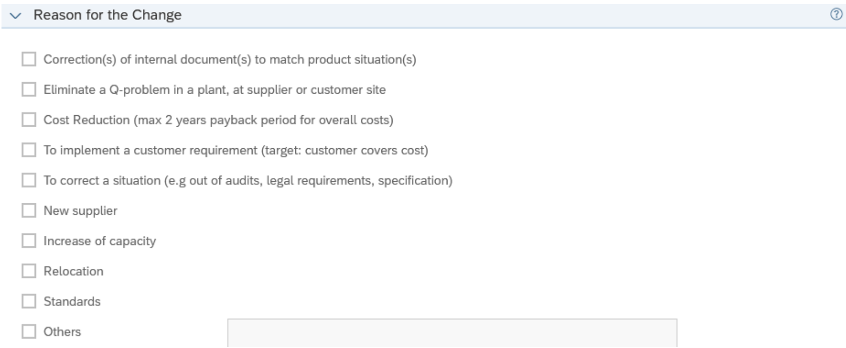


Figure 27: ECM tool reason for the change section

Then there is a section where the user can write the description of the change. Information such as the project affected, the project status, the plant(s) affected, the type of change, the cost of the change, etc., must be entered in this field. In Figure 28, it is shown an example of a template description. The description is supported by an Excel file present in Appendix C. To do so, the user has to select the phase that will include, the type of the change, the change costs category and the location affected. Depending on the choices inputted the participants are included or not as well as the description provided. After the selection of all the fields, the user has to click on "Report" and then it can just paste the information automatically generated that has a format as the one shown in Figure 28.

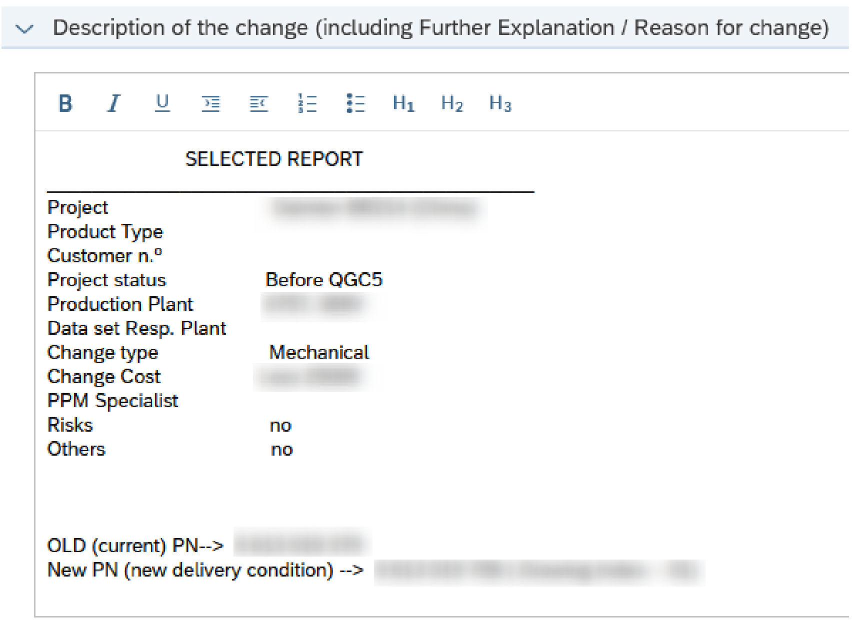


Figure 28: ECM tool description section - example

In the ECM platform, there is also a section where all the necessary and supporting documents can be uploaded. These documents can range from risk analysis, impact checklists, homologation checklists, drawings if it is a mechanical change, agreements with the customer, schedules and many others depending on the type of change. As mentioned above, this section allows all parties to see the documents, confirm their accuracy and evaluate the change. The most common documents are the checklists (homologation, security and impact) and the timeline. The checklists are usually requested from the team responsible person for each one of the topics, and the timeline is created by the change representative in Microsoft Project. The creation of the timeline is also supported by the team, namely the people who can answer questions such as when the new parts will be available, if there is a need to perform a test phase, and if there are any other events that could delay the implementation.

Another important group of sections are the "Objects to be Changed", "Affected Plants" and "Affected Products and Customers". In the "Objects to be Changed" section, the change representative must enter the information about the object to be changed, and then the "Affected Plants" and "Affected Products and Customers" sections are automatically filled in, depending on the object(s) to be changed. As shown in Figure 29, it is normal that a change in a single Part Number (PN) will have an impact on several products, because the given component that will suffer the change is included in several products, for example. The same can happen with plants, in the case presented only one plant (Braga Plant (BrgP)) is affected, but it can happen that more than one is affected if the product is manufactured in more than one location. It can also happen that, in the case of the need to replicate a process, one plant is only responsible for the data set and the other, where the change is applied, is responsible for production.

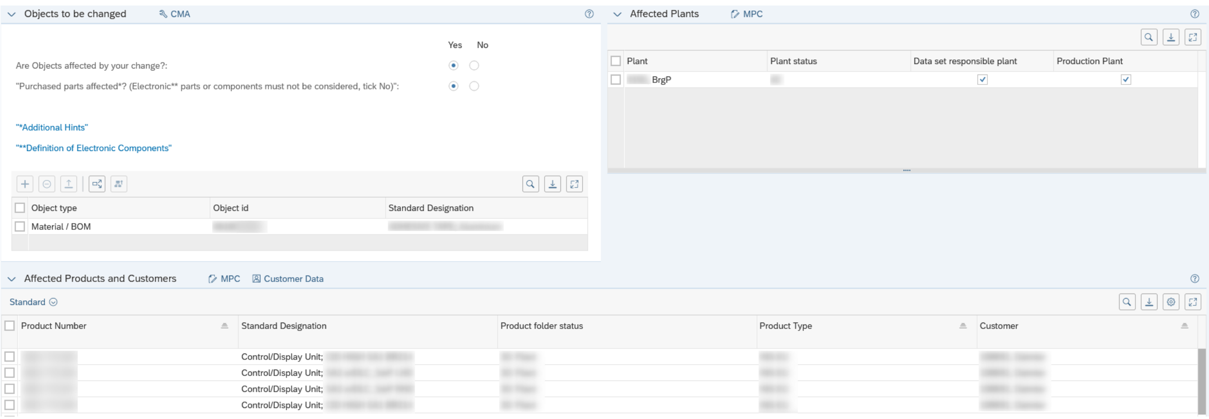


Figure 29: ECM tool objects to be changed and the affected plants, products and customers

Although, as already mentioned, a timeline with a detailed definition of all activities is uploaded, there is a section in the ECM tool where the change representative has to enter the planned date for the end of the

Team Review (TR), the end of the Final Review (FR) and the earliest and latest dates for implementation in the Bosch plant. These dates need to be defined in the planning phase and reflect the dates aligned in the timeline. This is an important point because it will not be possible to change them in a later phase.

Another important section of the ECR is the validation. This section is a series of questions about the need for certain actions and documents. The answers are in the form of yes or no and should be answered by each responsible person. There are also fields to enter the decision date, the person responsible for this answer and some comments.

There is also a section on the costs associated with the change, namely those related to administration, sampling, scrap/rework and others. In this section, it is also necessary to enter a cost centre that will support the stated costs.

If the change will somehow affect a component, it is necessary to determine what to do with the stock. In this situation, it is required to decide whether the old component should be used up, scraped, reworked or not affected by the change at all. This decision will depend on many factors, and although a solution such as a scrap may appear to have a greater negative economic impact, the change itself may be much more beneficial and therefore compensating to implement immediately rather than using the materials in stock first.

Finally, it is necessary to enter the list of participants, which can be entered either manually for each of the phases or using the support Excel file presented in Appendix C. To do this, it is necessary to select the project concerned, the phases, the type of change and the plant concerned, it is possible to generate an Excel file with the list of participants for these selected points and that can be uploaded in the framework to automatically fill in the participants' field.

4.4 Pilot project

In order to gain a better understanding of the day-to-day project management activities within the study organisation, the researcher joined a project management team responsible for a product development project. This pilot initiative was a large engineering project involving a core team of approximately 40 people, including both the project management team members and those responsible for each sub-project. The team was spread across five different countries, namely Portugal, Germany, Hungary, China and India, as shown in Figure 30.

Figure 30: Geographical distribution of the pilot project team

(Bosch, 2023a)

The pilot project team comprises the project management team (PMs) and eleven sub-project teams, each of which has a sub-PM responsible for coordinating and reporting on the work developed for their team. In Figure 31, the simplified project organigram is shown for a better understanding of the pilot project's organisational structure.

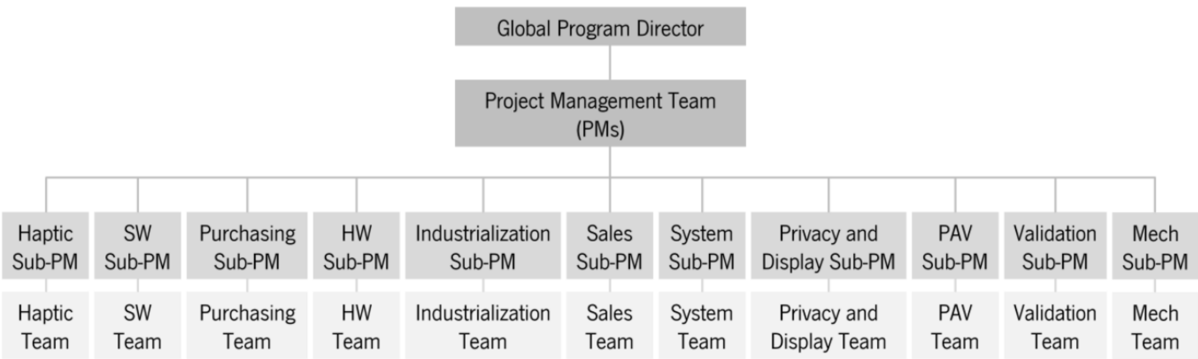


Figure 31: Simplified pilot project organigram

(Bosch, 2023a)

The project team is distributed across the five different countries mentioned above. Figure 32 provides a simplified representation of all the pilot project teams and the corresponding locations of each team. It is possible to see that the project management team is present in both Portugal and Germany, and then each one of the eleven sub-projects (Haptic, Software, Purchasing, Hardware, Industrialisation, System, Sales, Privacy and Display, Mechanics, Production Test, and Validation) is located in one or more of the five locations. It is important to mention that production is located in Portugal and China, which justifies, for example, the need for the industrialisation team to be both Portuguese and Chinese. The remaining teams were allocated to different locations mainly on the basis of the availability of company resources.

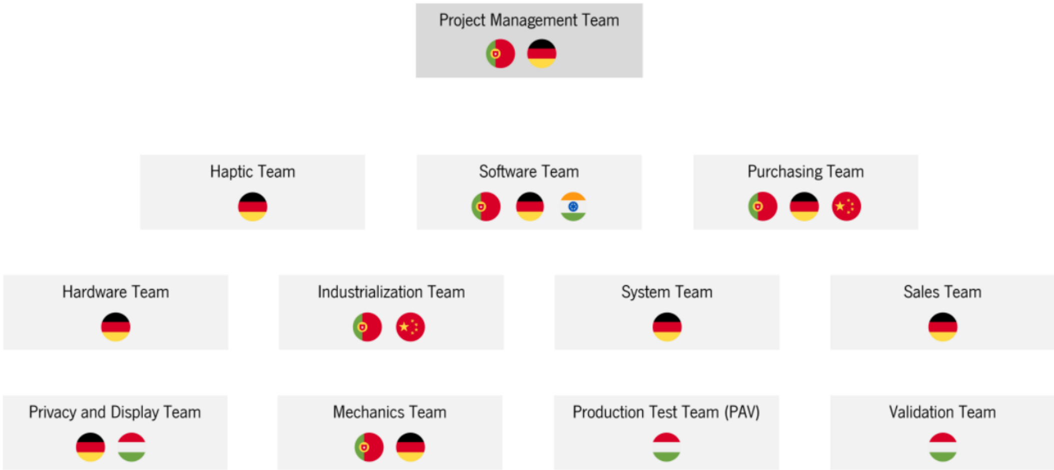


Figure 32: Geographical distribution of the project management team and the eleven sub-projects

Due to the project's dimension and the complexity and ever-changing environment, there is a need for a large number of ECs. Moreover, it is the responsibility of the project management team present in Portugal to create, track and push for approvals for the ECs of the different teams. The change initiator and change representative are both roles normally held by the project manager based in Braga, Portugal. Therefore, the Portuguese PM is responsible for the activities of both roles. In turn, the manager of initiator is usually the project manager in Germany, and the change coordinator is either the plant PM in Braga or in Wujin (China), depending on where the change is going to be implemented.

In the pilot project that the researcher integrated, the current development phase was the D sample phase, so the formal change management process had only recently started. The project followed the normal standard provided by Bosch, but there was sometimes evidence that the process was not the most appropriate for the project.

Similar to the other projects and as established by the company, the ECR process is carried out in the Bosch ECM tool, an interface created with association to SAP in order to support, document and connect all the participants in the change process and that it was already briefly explained in subsection 4.3.4. The goal of the platform is to document all the data but also to connect all the participants so that they can analyse the change request. Depending on the change and on its implications, different team members will be involved and so it is important to coordinate all of that.

The various approvers are informed of the change, either by email or in a meeting, and the change is explained in detail so that they fully understand the change and all its implications, and can approve the change with confidence. After this explanation, they evaluate all the issues and documentation and then approve the change. Several people are involved in this process, so the project manager needs to be constantly aware of who needs to approve and push for approval.

The documents uploaded to the ECR are in most cases the security, homologation and impact checklists, the change timeline and a document representing the change (for example a mechanical drawing). The checklists are an Excel file that is half-filled by the project manager itself and then sent to the person responsible for assessing each aspect. On the other hand, the schedule is developed in Microsoft Project and it is the responsibility of the project manager to carry out this task. However, the PM can and should, of course, trigger each of the team elements that can support and provide input on, for example, the date of parts availability (purchasing team), the timing of the production test (industrialisation team), and/or many other aspects. It may also be necessary to have other documents related to mechanical, quality, customer and other topics, but in this case, the PM has a role more of communication, explanation and work with the respective teams to have these documents available. All these documents are not only included in the ECR, but are also shared in a Sharepoint folder so that the team can see the documents and possibly modify them with their input.

As mentioned before, due to the complexity of the product, there are a large number of ECRs that are always in progress and that are sometimes even duplicated because of the two different production locations. In this sense, the project manager must be constantly updated on the status of each of the ECRs in order to minimise delays and even prejudice the implementation of other ECRs because of existing dependencies between them. To do this, the project manager must regularly open the ECRs under control to track their evolution.

4.5 Problems identification / Improvement opportunities

Following the presentation of the ECM process, which is currently the Bosch standard and therefore the process mainly followed in the pilot project, it is clear how important and relevant this topic is in a project context. It is necessary to use resources and time in a really efficient and effective way and to find ways to even potentiate possible solutions.

Reviewing the literature and comparing it with the Bosch process, it is possible to see that it is similar and that the process followed includes all the steps that the literature identifies as important for a successful engineering change. It is also important to emphasise the company's commitment to having the standard and following it as closely as possible. In a large company environment such as the one presented, it is crucial to follow the procedures to ensure a correct step-by-step of all activities and the documentation of all activities carried out for future traceability.

Even though this process is already defined, there are some points that are essentially left to the project manager to decide if it is necessary or not, at what time it should be done and who should be involved to help or even perform some of the activities. Therefore, using the Bosch procedure already created and applied, it is necessary to create a more detailed plan and improve it with some changes and indications in some of the topics.

Considering the whole process, it is possible to see that there is a definition of the required documents or activities in each milestone. However, there are no guidelines regarding the time of the activities, the people that should be involved and supported in the activities and so on. This means that the project manager has to make up his own mind about what is more advisable and take decisions about when, how, who, where,..., to do the required tasks. This, of course, usually leads to mistakes, delays and, in the end, the need for more resources and time to ensure the required status of the activities. In this sense, the first point to highlight is the need to define the recommended start of activities and also to define which activities are more suitable for each requirement and even the people who should be involved to support the project manager. This includes, for example, defining when the project manager should start developing the schedule and/or other documents or when the project manager should arrange a meeting with the rest of the participants, for how long, and with whom.

Another important issue that needs to be improved is the relationship between the participants and the ECR. On one hand, the participants often do not have the necessary knowledge to carry out some tasks or to approve and allow the process to move forward. It is, therefore, necessary to explain and inform the participants about the change so that they are up to date and can approve the ECR with all the necessary knowledge and confidence. In order to do this, it is also necessary to define the means and the timing of contact, for example, whether to hold a meeting with everyone or whether it is easier to contact each participant individually. In the end, whatever procedure is recommended, the most important thing is to inform the participants in a timely manner and before the time for approvals is reached, because this is what is currently being done and the result is a lot of delays in approvals, while the approvers do not have the full knowledge they feel they need. On the other hand, there is also a real problem with the time it takes people, even those who are well-informed about the change, to approve it. In these cases, the project manager has to constantly check which participants have not yet approved the change and ask them to do so. This may seem to have a small impact on the normal process of the ECR, but depending on the change, even one day can make the difference and have a huge impact on the planned schedule. It is therefore important that participants have an alert to remind them to complete the task.

As far as documentation is concerned, as has already been said, all relevant and necessary documentation must be added to the ECR. Nevertheless, and taking the pilot project as an example, it is necessary to share the documents with team members who are not necessarily involved in the ECR process. This may happen during the creation of some of the documents, as it requires input or feedback from the right people. Therefore, all documents should be made available to all team members so that they can access them. It should also be decided where and at what stage of the process they should be shared.

In parallel with the problems and opportunities for improvement already presented, the tracking of ECRs is also problematic. The tracking of ECRs can be understood as the controlling and monitoring of the status, the required activities and the next steps of all ECRs under the responsibility of the project manager. There is no process, template or file that can help the project manager in this task. This means that the project manager does not know how many ECRs are, for example, in status 23 and awaiting team approvals. The project manager has to open each of the ECRs to know which step they are in. Of course, this problem increases with the number of ECRs the project manager has to monitor. Depending on the phase of the project(s) and the characteristics of the product(s), the number of changes that a project manager has to follow can even reach hundreds. In such a situation, it is obviously very difficult for a single person to check the status and decide on the next steps one by one. And even if this were to be done, it would have to be done with a high degree of frequency, since the process is constantly moving, and in a matter of minutes, a ECR that was in a given status could move to the next step (for example, the last approver has approved it). To answer this problem, it should be used a tool, file or dashboard that allows the project manager with significantly less work to have one overview of all the ECRs. The project manager is then able to quickly know which ones need some kind of action, and which ones are just in the normal flow and also have a quick look at which were even already completely finalised and implemented. With this, the project manager will not only reduce substantially the time spent to have the information but also be much more informed and up to date on the ECR information.

In summary, the opportunities for improvement can be divided into two main groups: 1) the improvement of the activities and processes already carried out, and 2) the creation of a method to have an overview to facilitate the project manager in tracking the ECRs.

Chapter 5

Improvement Proposals

This chapter has the main goal of presenting and explaining the proposals developed during the study. The proposals are divided into two main groups with the first being a standard for ECM activities in each of the ECR process phases, and the second being the application of a control mechanism for tracking the ECRs.

5.1 Standard activities review

Although the activities are defined for each phase, there are some tasks that can be improved and reallocated in terms of the timing of a particular activity. For example, an activity required in a particular phase may take a long time to complete. Therefore it is necessary for the project manager to know when it is actually advisable to start the task, otherwise, the task will only be started to be developed only when the need appears and then depending on the lead time of the task it can lead to unnecessary delays in the execution of the ECR.

In order to respond to this problem, and taking into account the experience gained by the researcher during the project, it is necessary to adapt the timing as well as the way of working in order to ensure that the project manager is better supported in the correct respect of deadlines. With a well-defined process of when to start each task, how to contact the participants, how to explain the topics and others, the project manager will be better able to create a good organisation of the topics and be more efficient in the ECR implementation. With this in mind, it makes sense to define this standard according to the different and already defined phases of the Bosch change process as well as the different ECR statuses. Therefore, the activities in each phase are described separately in the following subsections.

5.1.1 Preliminary agreement phase

As the first phase of the ECR, it can be understood as a phase of definition and a short explanation of the change. As mentioned before, the main aim of this phase is to enable the manager of the initiator to assess the reason and the eligibility of the change. At this stage, the Bosch process only requires that the change title, change initiator, manager of initiator and change description are filled in. However, as the planning phase starts immediately after the manager of initiator's approval, and as there are many other activities to be performed in this phase, there are many tasks that should be initiated right away in this first phase, given the lead time that may exist for these tasks, and others that can already be done.

Given that in the pilot project in which the researcher was involved, the roles of change initiator and change representative are frequently played by the same person, there are many activities that, according to the process, would only be carried out in the planning phase (status 22), can be tailored to actually be carried out immediately when the ECR is created. It is also important to be clear that this is happening in the current phase of the project, with the change opportunity being well discussed before the formal creation of the ECR. Furthermore, this discussion is usually between the initiator's manager and the person who will take on the role of initiator and representative. However, in later stages of the project, namely when it is running in series production, it is expected that opportunities for change will be identified by different team members, so this also needs to be taken into account. In this case, it is necessary to effectively confirm the eligibility of the change before proceeding with any further activities in the ECR. In this way, when a team member identifies a change opportunity, it should be held a meeting with the manager of the initiator and the person who normally assumes the role of change representative in the project. This meeting will bring the initiator's manager up to speed on the issue and secure and accelerate approval in the subsequent stages.

The first topic that should suffer a change in the philosophy and timing is the selection of the change representative. Even though there is a pattern of the same person being both initiator and representative, this choice must be agreed upon with the initiator's manager. If both parties are in agreement, the choice can be made now, rather than waiting for the next phase, which is the phase until this task can be performed.

In addition, in most cases, the change representative should be a defined person in the project, so that there is one person in the project who is responsible for this function and therefore has a good knowledge of the procedures and the tasks to be performed. If the project is still in the development stage (before the start of production), it would be advisable to maintain the pattern of selecting the same person for both roles, even if this is not the normal Bosch standard. This would essentially ensure a high level of knowledge of the change by the manager of initiator and the change representative, who would follow the change from the beginning to the end. However, when the project goes into series production, it should be possible for there to be different change initiators, with the change representative remaining the defined person for the vast majority of the project ECRs. As mentioned before, in these cases there must be good communication between the change initiator and both the initiator's manager and the change representative so that the change proposal is well aligned and defined.

After that, there are many other tasks that are only required in the planning phase, but can also be completed earlier. These tasks include the list of participants/approvers, the material to be changed and the materials and plants affected. In order to do this, the responsible project manager needs information about the PN to be changed, the type of change and the location of the change. The PN will provide all the information about the parts and plants affected and, on the other hand, with the type of change and the location, it is possible, supported by the Excel file (Appendix C), to upload the list of participants. This task should be done with the support of the Excel file, as it saves a lot of time instead of entering the participants one by one, and also reduces the possibility of errors and missing approvers.

At this phase, it should be arranged a 30 minutes meeting, moderated by the change representative, with all the relevant participants for the change definition, taking into account the type and characteristics of the change. It must always include the project manager, the team leader that is responsible for the change domain (for example, if it is a mechanical change, involve the mechanical sub-PM), the plant PM, the purchasing specialist if it is regarding a purchased part, and any other relevant participant. In this meeting it should be confirmed the description, shared any necessary information for the change description (for example the new PN for the product/material) if the change representative doesn't already have access to it, and answered the validation questions. The aim of this meeting is to complete a series of tasks in a defined time, rather than communicating with each participant individually to obtain the information required. This allows the tasks to be condensed and the questions to be answered more quickly. Nevertheless, at the end of the meeting, the representative must send an email with all the topics discussed as well as address to the responsible members possible open topics.

On the other hand, there are also some activities that, even if they don't necessarily have to be completed at this stage, it is still important to start them. This is important because there are topics that require feedback from the team and that usually take some time to be completed. Therefore, the documents such as the checklists and the timeline should be initiated. In order to do this, the templates for the given project should be used, as they already contain the sample topics and the predetermined values for each field. A folder should also be created in the team SharePoint repository for each ECR, using an incremental index and clearly identifying the number and title of the ECR. This folder should contain all documents related to that change so that the project team can access the files, perform activities and provide feedback on the topics.

At the end of this phase, there is an approval by the manager of initiator, so if there are more tasks already performed in this phase, the manager can also evaluate more aspects than those required and defined in the current process. This is also very useful in the end, as it allows the other topics to be evaluated and, if necessary, corrected in the next phase for those topics that were not mandatory in this phase but were already completed.

5.1.2 Planning phase

The planning phase is a stage where all the fields and documentation of the ECR need to be filled in and completed. Since, according to this proposal, a lot of activities have been initiated/completed in the previous phase, this phase is more of a review of the work done so far and the completion of open tasks that were initiated early on.

At this phase, a meeting should also be arranged to review the timeline created by the change representative based on the template for the project. During this meeting, several topics should be discussed such as the time for parts availability, the need for test production, the duration of each activity, the existence of dependencies between activities and, ultimately, the setting of an implementation date taking all the factors into account. All those involved in the change must be included in this meeting. As mentioned earlier, this may vary slightly depending on the characteristics of the change being defined. However, it should always include the project manager, the global change coordinator (represented by the plant PM of one location if the change is only applicable to that location or represented by the global plant PM if the change is applicable to more than one location), the purchasing specialist, and possibly agree with the change coordinator on the need to involve others.

The same meeting can also be used to explore and confirm the validation questions if there are any open questions or even if the topic has changed since the last evaluation.

After the meeting, the representative must carry out a review of all the ECR, including the definition of the costs, now that there is a definition of all the activities. For example, in the case of sample production, the quantity required must be agreed with the plant PM so that it is possible to define the exact cost of these parts. The same procedure must be followed for other cost reasons, such as administrative costs, tooling/machine costs, scrap/rework of parts and/or many others. In addition, it is necessary to transfer the information from the timeline to the ECM tool, referring to the dates for the end of the Team Review

(TR), the end of the Final Review (FR) and the earliest and latest dates for the introduction of the change in the Bosch plant. These dates must be taken into account from this moment onwards by the change representative, who must ensure that each of them is met.

At the end of this phase, there is the TR where the different participants have the task of approving the ECR. As mentioned in the problems identification (section 4.5), there are always some delays and the participants take much time to approve, even being necessary to remember more than once the person to approve. With this in mind, the project should start using a new functionality of creating tasks for the participants. With this, it is even possible to create a request for documents or an answer to a given question, but in this context, it would work as a solution to send a notification to each approver alerting them to the need to perform the task. The new procedure would imply an effort for the change representative to create the tasks and for the affected team member to close the task and mark it as done. However, despite that, the actions would be better defined and tracked, ensuring a better overview of the team's collaboration on the ECR. This topic will also be discussed in more detail in subsection 5.2.3, where a Power BI integration is proposed to know the open tasks for each ECR.

5.1.3 Processing and Validation phase

At this phase, the responsibility shifts more to the change coordinator and to manufacturing topics, with the change proposal being tested and validated through a test production and possibly a reliability test, to assess whether it is a good option to implement or if there are any further implications. However, the change representative still needs to play an active role in the topics, as it is crucial that the various actions are monitored to ensure that the defined schedule is actually met.

There should be a regular exchange of information between the change coordinator and the representative to ensure that there is a clear understanding of all the developments in the matter.

After the documentation review, there is also final approval by some approvers, but with the exception of the manufacturing approvers, the validation does not need to be completed for the rest of the approvers to perform their tasks. This is really important because it means that all the other necessary approvals, such as quality, purchasing, product responsible quality and product responsible engineer, can be triggered earlier so that when the validation is complete, only the manufacturing responsible needs to approve. For example, the quality approver only needs to open the homologation checklist and assess if Bosch is or not the type approver owner, which is independent of the outcome of the validation phase. The duration of this step can then be reduced from several days to just one day if there is the recommended continuous communication between the change coordinator and the representative.

For this phase, it would then be important to set up the approval workflow in parallel with the validation, rather than waiting for the end of the validation. Of course, if this is done, it has to be ensured that the manufacturing responsible only approves when the results are actually available and doesn't feel pressured to approve before the end of the validation. Given this fact, an alternative solution would also be to split the current final review (current status 25) into two different statuses. The first would represent the approvals that could be carried out when the validation phase is still ongoing and the second would be the one where only the manufacturing related approvers take the action properly informed and based on the results.

5.1.4 Implementation phase

In the final phase of the ECR, the change coordinator again has a greater responsibility for carrying out the activities. However, as in the previous phase, it is necessary for the representative to keep close control of the dates and the introduction of the implementations.

It's really critical that the deadlines are met correctly, so that the implementations are all synchronised and the implementation of one change does not negatively affect the implementation of the following changes, thus creating a chain reaction of delays.

5.2 Tracking of ECR status

Organisations are constantly striving to analyse data and information in the most practical and intuitive way possible to enable quick and accurate decisions and responses. The current status analysis and tracking of ECRs is very time-consuming and requires a lot of effort for the change representative to evaluate the status of each ECR and to perform the necessary activities given its status. This creates a need for the creation of some procedure or tool that could help and facilitate the work of the change representative. In this way, two different approaches will be presented so that the change representatives can have a really quick analysis and can know immediately what their actions should be regarding each one of the ECRs for which they are responsible.

First, in subsection 5.2.1 the procedure to export the data is presented, followed by the Excel proposal in subsection 5.2.2 and finally the Power BI proposal in subsection 5.2.3.

5.2.1 Preliminary arrangements

Having identified this point of improvement, it was necessary to carry out a study on the possibility of performing an analysis on all the ECRs at once. This led the researcher to carry out a study and, in contact with the Bosch tool experts, it was found that it would be possible for the user to do an export of all the ECRs given the filters selected for that. In order to do this, the user has to click on the Search ECRs button, which opens a new page where the different search criteria can be selected.

As shown in Figure 33, there are some default fields that can be used to search for a specific ECR number, ECR status, who created it and the date of creation.

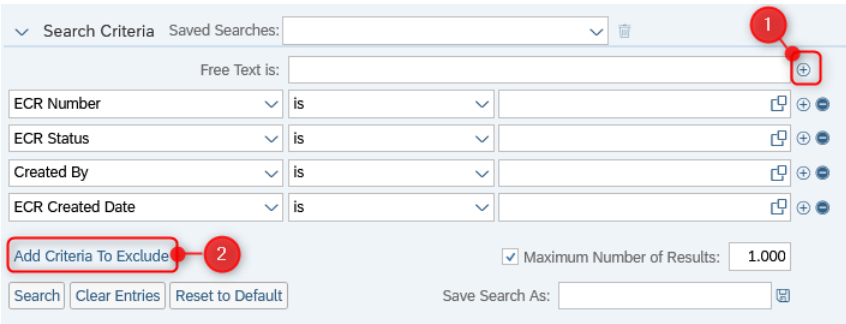


Figure 33: Screenshot of the search criteria fields

The use of these fields allows the user to search for a specific ECR or group of ECRs. However, there are many other fields and variables that can be added to perform the desired search. To do this, the user has to click on the plus sign (shown in Figure 33 with the number 1) and then select the variable to be taken into account and its value. On the other hand, it is also possible to exclude data from the search by clicking on "Add Criteria To Exclude" (shown in Figure 33 with the number 2) and filling in the data to be excluded from the filter.

It is important to mention that this search does not need to follow a strict way, however, and given that the objective is to track all the open ECRs for a given person, it would make sense to make the search only of the ECRs that are in that conditions. As the example shown in Figure 34, the search could be performed by the change representative(s) and could also exclude the ECRs that have already been completed (currently in status 48) or cancelled (status 11). Once all the intended fields have been defined, the user can even save the filter as a template for future use by naming the filter setup and clicking save.

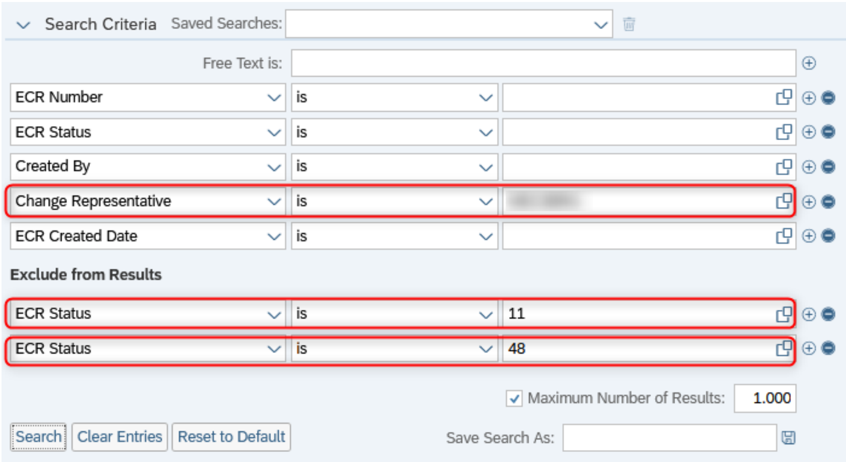


Figure 34: Screenshot of a search example

After applying the filters and clicking on "Search", it is possible to see at the bottom of the page the list of all the ECRs related to the intended search. Even though, by default, for each ECR it is given the information about the variables shown in Figure 35, it is possible to select other information to be displayed. For example, relevant information that is not immediately displayed is the planned dates for each phase. With this information, the change representative or project manager would be able to assess whether or not each of the deadlines was met. To do this, it is necessary to go to the gear icon in the top right corner, where all the variables entered in the ECR creation are displayed. Of all the columns that can be added, the most important ones are the planned date of the team review and the planned date of the final review.

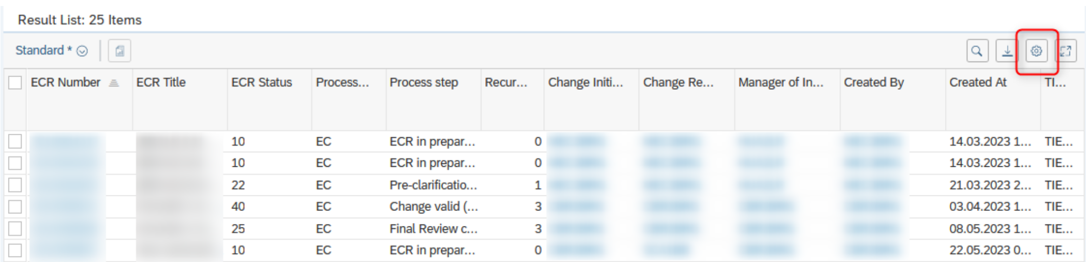


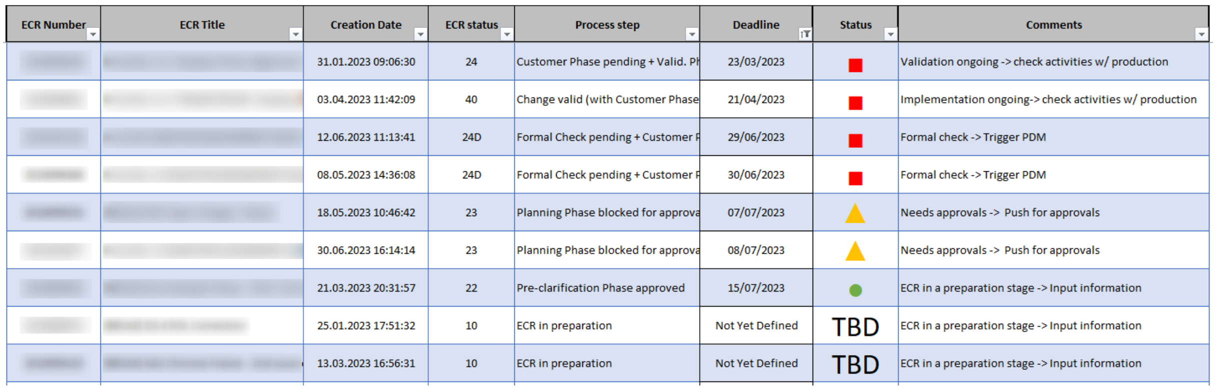
Figure 35: Screenshot of the search results

Finally, it is possible to download the selected information in Excel format with all the columns displayed on the platform.

5.2.2 Approach 1

As a first approach, the researcher decided to explore the use of Microsoft Excel to generate a report on the status of the selected ECRs. The main objective would be to quickly use the report generated by ECMFuture to be informed about the current state of each ECR and to know what the next steps should be. To do this, the user must first have all the data exported as explained in the previous subsection, including all the predefined information, but it is also really important to include the planned dates for the different stages (TR completed, FR completed and the last expected date of implementation). Only then it would be possible to compare the planned dates with the current date of the evaluation and see which ECRs are already delayed and need urgent action, and which are close to the deadline and therefore also need more attention to be met.

The analysis could be, for example, as the one shown in Figure 36. The report would be generated automatically, taking into account the ECR number and then confirming all the other fields in the dataset downloaded from the ECMFuture platform. The aim would be to summarise the information in such a way that the data shown is only an example of the total and that the user can adapt the fields to be considered in the report, according to their needs.



ECR Number	ECR Title	Creation Date	ECR status	Process step	Deadline	Status	Comments
[illegible]	[illegible]	31.01.2023 09:06:30	24	Customer Phase pending + Valid. Pl	23/03/2023		Validation ongoing -> check activities w/ production
[illegible]	[illegible]	03.04.2023 11:42:09	40	Change valid (with Customer Phase	21/04/2023		Implementation ongoing-> check activities w/ production
[illegible]	[illegible]	12.06.2023 11:13:41	24D	Formal Check pending + Customer F	29/06/2023		Formal check -> Trigger PDM
[illegible]	[illegible]	08.05.2023 14:36:08	24D	Formal Check pending + Customer F	30/06/2023		Formal check -> Trigger PDM
[illegible]	[illegible]	18.05.2023 10:46:42	23	Planning Phase blocked for approva	07/07/2023		Needs approvals -> Push for approvals
[illegible]	[illegible]	30.06.2023 16:14:14	23	Planning Phase blocked for approva	08/07/2023		Needs approvals -> Push for approvals
[illegible]	[illegible]	21.03.2023 20:31:57	22	Pre-clarification Phase approved	15/07/2023		ECR in a preparation stage -> Input information
[illegible]	[illegible]	25.01.2023 17:51:32	10	ECR in preparation	Not Yet Defined	TBD	ECR in a preparation stage -> Input information
[illegible]	[illegible]	13.03.2023 16:56:31	10	ECR in preparation	Not Yet Defined	TBD	ECR in a preparation stage -> Input information

Figure 36: Screenshot of the Excel ECR tracking overview proposal

The deadline shown is based on the current status and therefore the next deadline. For example, if the status is 22, this would mean that the next planned date is the end of the Team Review (end of status 23) and so the deadline will assume that value. On the other hand, if the status is for example 24, the next planned date would be the planned date of the end of Final Review (end of status 25) and so the deadline would assume that date. All statuses after the Final Review will then be based on the planned date for the implementation. This creates a more step-by-step approach than just looking at the final target implementation date because the various activities can take a considerable amount of time, and so if only the final result is taken into account, by the time those responsible find out about the delay it would be too late, as they would still have to wait for the ECR to pass for the various phases.

In the status column, a red square would be displayed if the ECR is delayed, a yellow triangle if the deadline is within seven days, and a green circle if the deadline is more than seven days. The number of days between the green and yellow has been considered as an example of seven but can be changed by the user according to specific needs and appropriateness to the personal context. However, this number should always take into account the regularity with which the project manager carries out this assessment. For example, if this task is performed once a week, this number should be higher or at least equal to seven days, because only then would the ECRs with deadlines between assessments be highlighted and the project manager be visually informed of the importance of accelerating the defined task of that phase. The greater the number of ECRs, the more advisable it is to carry out an assessment more regularly because there would be more status changes and also because it would be necessary to prioritise activities, and so it would be possible to have a more segmented distribution of the deadlines of the ECRs, reducing the difference between the yellow and green alerts.

In addition, this evaluation should be carried out from the oldest to the most recent deadline, showing first those that have been overdue for some time and ordering the ECRs according to the upcoming deadline.

The importance of this tracking is also demonstrated, for example, by the existence of open ECRs that have been stuck in a phase for more than a year (Figure 37), never approved or, if so, cancelled. This could have happened for a variety of reasons, but in the end, no action was taken on these requests because they were most likely forgotten and no longer open to view their status. Now, with this report, all ECRs would be considered and it would never happen that one would be forgotten and kept in the same status indefinitely.

ECR Number	ECR Title	Creation Date	ECR status	Process step	Deadline	Status	Comments
[illegible]	[illegible]	09.09.2020 10:01:19	25	Final Review and Customer Phase is	28/02/2021	■	Needs approvals -> Push for approvals
[illegible]	[illegible]	21.06.2021 09:57:23	40	Change valid (with Customer Phase	04/02/2022	■	Implementation ongoing-> check activities w/ production
[illegible]	[illegible]	09.06.2022 13:02:26	24	Customer Phase pending + Valid. Ph	01/12/2022	■	Validation ongoing -> check activities w/ production
[illegible]	[illegible]	01.08.2022 13:33:04	40	Change valid (No Customer Phase)	06/09/2022	■	Implementation ongoing-> check activities w/ production

Figure 37: Screenshot of the oldest deadlines in the Excel ECR tracking proposal

In summary, this approach suggests that the change representative should start exporting the ECRs data and that tracking should be done so that it is possible to avoid delays and have a continuous knowledge of the status and further activities required. The exported data would need to be uploaded into an Excel spreadsheet containing all the information required for the report. This would save the manager a lot of time as he wouldn't have to open each ECR separately to see the status, but would only have to download and then upload the document to have a global view of all the selected ECRs. In the case where the project manager is not the change representative, this would also allow control and ensure that the project is on schedule. Ultimately, the responsibility would remain with the Change representative, but in this way it would also allow the Project Manager to have a realistic view, taking into account possible delays in some of the ECRs.

5.2.3 Approach 2

In parallel to the first approach, this second approach addresses the tracking of the ECRs using Microsoft Power BI. This tool would allow for a more graphical and interactive analysis where the user could easily search in detail and see the intended results. In addition, this platform would make it possible for an even greater volume of data to be captured and be directly integrated with ECMFuture. While the primary objective is clear, the execution requires time to develop the necessary tools and structures capable of handling the substantial data volume while ensuring its validity. Therefore, this approach will begin by introducing a proposed implementation that aligns with the current structure. Subsequently, it will be explored additional opportunities that can be pursued if the company chooses to proceed with integrating data between the ECMFuture platform and Power BI.

At the moment, as mentioned above, there is no structure for a direct flow of data and it is not even possible to export all the details of the ECR. However, using the data currently available, through its manual extraction already explained in subsection 5.2.1, a first version of ECR tracking in Microsoft Power BI is proposed. It is important to emphasise that the aim should still be to integrate the two platforms and ensure a continuous flow of data from one to the other. This dashboard proposal will only work as a preliminary solution, as it does not include all the features that are intended to be included.

The tracking of ECRs would be divided into two dashboards, with the main objective being to separate the ongoing change requests from those already closed (completed or cancelled). In this way, it is possible to perform different analyses on the ECRs, analysing the ongoing ones in terms of time status for each of them, tracking all of them and ensuring the deadlines in the different statuses. On the other hand, the closed ECRs would have a different analysis, more focused on the report of the performance of the whole process, including the days delayed in each of the three phases (Team Review, Final Review and

Implementation) and the costs resulting from each ECR.

Figure 38 shows an example of the preliminary dashboard for ongoing change requests, displaying all the data manually retrieved from ECMFuture. As can be seen, there is a section on the left where it is possible to select filters for the time period to be analysed, the project(s), the change initiator(s), the change representative(s) and the manager(s) of the initiator in order to analyse only the intended requests. This allows, instead of making an export already conditioned by an analysis you want to perform, as in the Excel approach presented above, it would be possible to make a global export and then perform the different analyses intended.

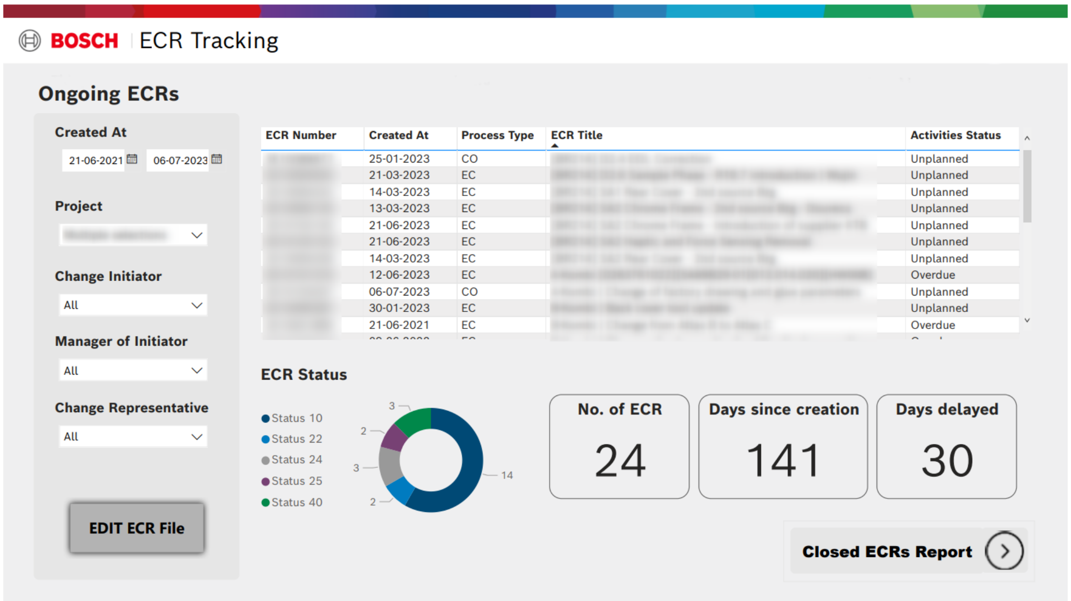


Figure 38: Power BI dashboard for ongoing ECRs

The report would then display, for all ECRs matching the filters, a table with the information for each ECR number, the creation date, the process type of change (EC, CO or SF), the title and the status of the activities (Unplanned, Overdue or On Time). The user can then also see the number of requests, a status overview with the number of requests in each status, and an average of the values for days since creation and days delayed. However, it is advisable to see in the table the status of the activities for each ECR and then, for the specific request, the status in which it is currently located, as well as the days since its creation and the days delayed based on the planned date for the next deadline.

The report would also include a button to directly access the ECR page on ECMFuture and possibly add or change any information. This would allow the user to see the status of the ECRs in the report and quickly access the file if any action is required. A button was also included to allow the user to quickly navigate to the closed requests report. Finally, as mentioned above, the aim is to include even more data in this dashboard, with the tasks for each participant being a really important topic to be added because this would allow the user to immediately see the exact tasks that are missing.

The closed ECRs report is shown in Figure 39. As in the ongoing requests report, there is a section with the filters and then one with the data visualisation. There is also placed a button to navigate to the ongoing report.

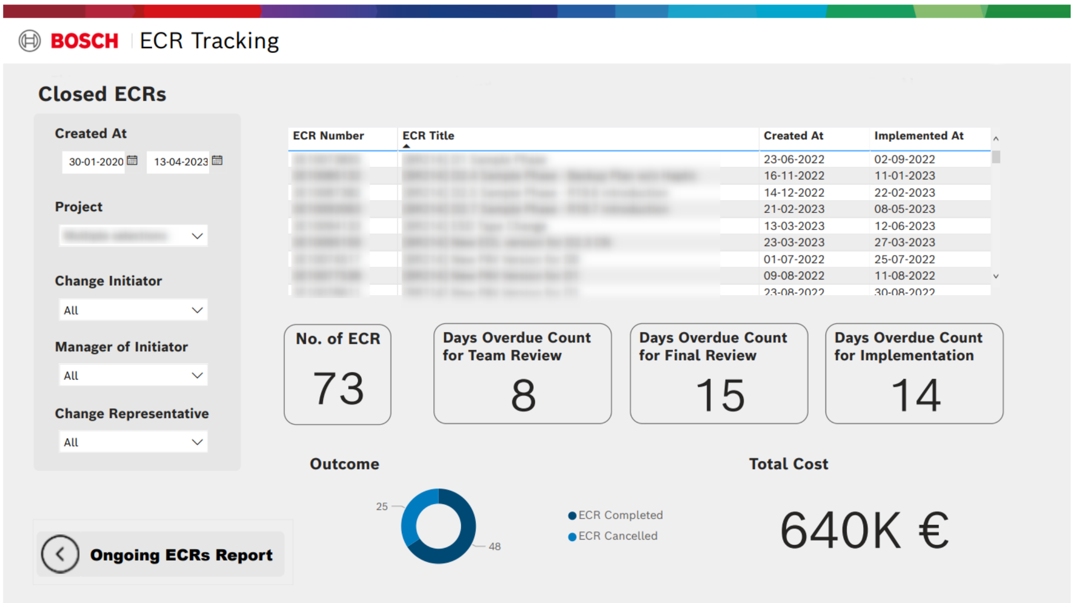


Figure 39: Power BI dashboard for closed ECRs

Regarding the data displayed, for each ECR number, the title, the creation date and the implementation date are displayed. Then there are three indicators showing the average number of days of delay in three different stages, taking into account the planned date in relation to the current date. The lower part of the report shows the distribution of completed and cancelled changes, as well as the total cost of the changes.

This dashboard for closed ECRs also plays a really important role once the implementation dates are provided and it can be seen the delays and the costs of specific ECR, so that it can be used and taken into account this knowledge in the future related requests to be created.

Even though it is presented as the preliminary proposal that can already be implemented (through the manual export) and help in the ECR tracking, the main objective of these dashboards proposal is to create a direct flow of information between the two platforms. This would allow an evaluation based on real-time data and also have a highly interactive component allowing the project managers to navigate through the different topics and easily have an overview of the different statuses. In this way, the constant updating of the data with the creation of new ECRs, the completion, cancellation or simply the updating of the data entered will be constantly reflected in the dashboard, ensuring a correct evaluation and reducing the risk of using outdated data to perform the evaluation.

This requires additional effort and resources to collect and transform the data so that all the information is presented in the intended way. Implementing direct data flow can be very challenging for organisations, such as the one in the study, that have a large volume of data. In these cases, the challenge is to ensure that the data is processed in the right way, that it is collected and transformed without overloading the system and causing performance problems, and that it is always valid and free from errors and inconsistencies that would affect the accuracy of the analysis. Finally, it is also necessary to ensure security by implementing some measures such as encryption and access control. Overall, this integration between the ECM tool and the PowerBI requires careful planning, effective data management processes and a significant allocation of resources to address these issues. However, with this approach the organisation can use its data to gain greater knowledge of the process and be better informed about ECR issues, leading to higher and better performance in this area.

For the reasons explained above, this proposal could not be fully analysed in practice, as the company would have to find and allocate the necessary resources and then develop all the measures required for integration. In addition, the ECM tool needs to be updated to allow the export of some other data relevant to the analysis. The researcher contacted the experts of the tool and agreed on the possibility of the planned changes. These changes were considered relevant and noted for future implementation.

Since it would be possible to evaluate the status of the ECRs in real-time, an extremely relevant topic to have in the report is the status of the approvers, identifying if the approver has already checked and approved the content and showing those who still need to approve or to perform a given task. To do this, it is necessary to first create this tracking within the ECM tool, as there is no such definition at this stage, and then allow the export of the same data (topic already discussed with the tool's experts and agreed for future implementation).

In this sense, in order to keep track of activities, a step for creating tasks for each of the participants, including setting deadlines, should be implemented in the normal ECR creation process.

In order to do this, the change representative should create tasks in ECMFuture, specifying the person who should respond, a description of the task and the planned deadline. As shown in Figure 40, there is a line in the Process Overview section relating to team collaboration. As can be seen in the figure, there are no tasks for the ECR example presented, because this is not part of the current process/procedure.

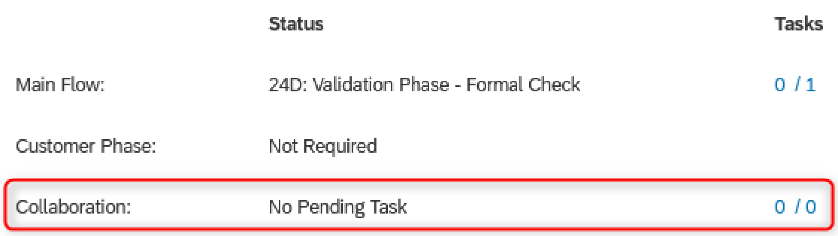


Figure 40: Screenshot of the collaboration option in ECMFuture

However, clicking on the tasks number of the highlighted collaboration line will open the collaboration tab (Figure 41) where it is possible to create tasks for the team and also to track the tasks already created. In this case, there is "No data available" because no task has been created yet. However, it is possible to create one by clicking on the plus sign.

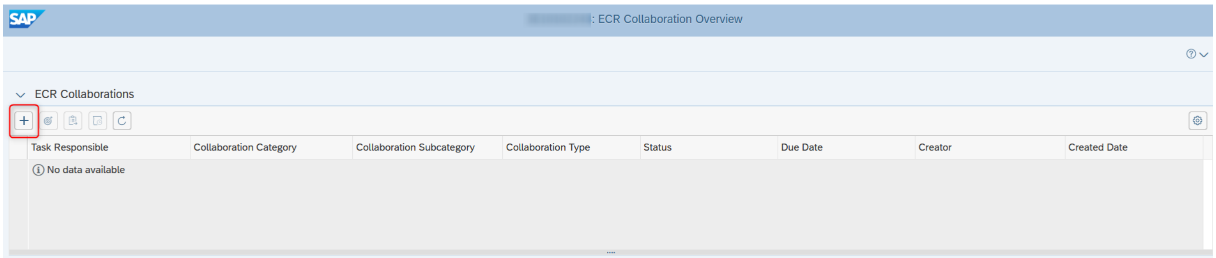


Figure 41: ECR collaboration overview tab

To create the task, as shown in Figure 42, the change representative must enter the user responsible for it, the subject, a short description (for example, a list of required inputs), and finally a deadline. Once this task has been created in the ECR, an email is sent to the person responsible, indicating the need for action in this ECR. In addition, from that moment on, the change representative will have the task listed in the collaboration tab.

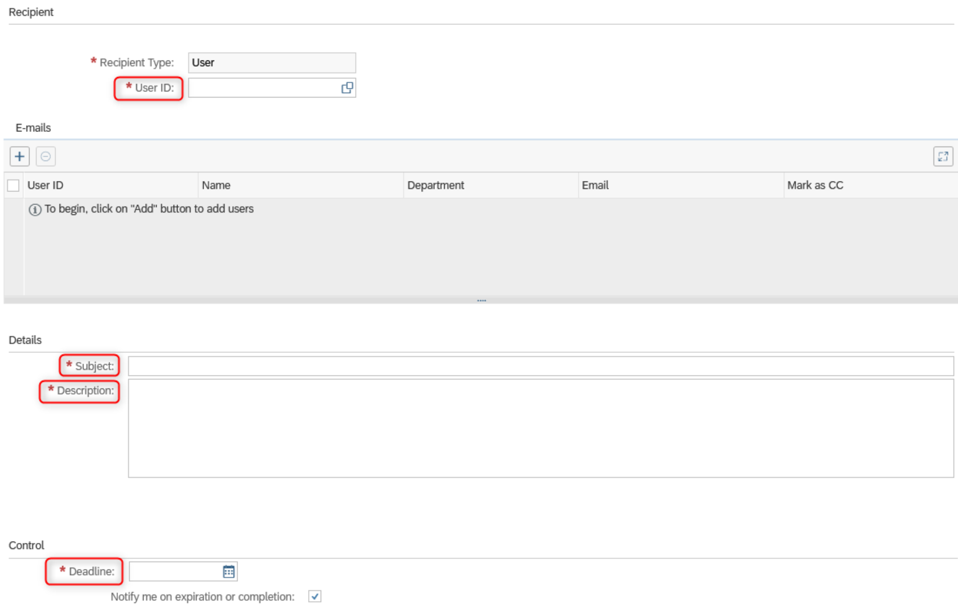


Figure 42: Screenshot of collaboration task creation

With all the tasks created, it would be possible to have greater control and global knowledge of the tasks that have been performed on each ECR, and would also make the people to be notified of the need for input from their side. This approach would mean an increase in the creation effort for the change representative, and an increase in the effort for the participants, who would have to mark the task as done when completed. However, it would provide a clear set of activities, ensuring that none are forgotten and that the deadlines for each of them are better tracked, minimising possible delays.

The aim would then be to extract this data and also include it in the ongoing ECRs dashboard so that it would be possible to see on the dashboard, not only the status in which the ECR would be, but also the blocker(s) for moving on to the next status. This would make it possible to quickly identify people and, if there is a delay, to know who should be triggered to complete the task as soon as possible.

Ultimately, the dashboards would work as an integrated framework where not just the change representative or project manager, but all the people involved could have an overview of the situation and identify activities for which they are responsible and on which their feedback is required. This would improve the visibility of the activities to be realised, increase the self-awareness of all team members and therefore improve compliance with the defined timeline and even improve the duration of the implementation of the ECRs.

5.2.4 Comparative Analysis of Approaches 1 and 2

The proposal in Excel is an important proposal because, from the experience of the pilot project, it would allow an easy implementation and adoption once the different people are more familiar with this tool. In addition to this, the necessary inputs are already accessible to be exported and used for the evaluation. It would only be necessary to add the manual export of the data and its analysis in Excel to the normal activities of the change representative. Moreover, this proposal can also be improved in the future if the company decides to follow with the gathering of more information. If that were the case, the Excel proposal should be improved so that it can integrate a higher detail and information.

Overall, the proposal of using Power BI has several advantages for all those involved in the ECRs process, allowing a large volume of data analysis, improving the visibility and therefore the opportunity to respond quickly to delays. The proposal as it is would already be a great help in reducing the time spent on the task by those responsible for ensuring compliance with the deadlines and the integration and participation of all team members in the defined timeline. Nevertheless, if not only the preliminary dashboards presented are implemented, but also the already discussed possibilities of integration and consideration of tasks, the proposal should be used as a framework where people could quickly evaluate the global status of the group of ECRs for which they are responsible and, if necessary, take the respective necessary actions. The fact that all the data would be integrated would also make it possible for the creation and the evaluation by the management of the team performance through KPIs.

Finally, the proposals were discussed with the pilot project PM. The understanding was that the Excel file could be implemented in an easier way as it has all the necessary conditions to implement the proposal as it is. However, the Power BI approach is perceived as the one with higher benefits if the company actually decides to move forward and invest in implementing the full proposal of integrating all the data. The Power BI would then act as a framework that unifies all the EC topics and improves the visibility of the real state of the different ECRs, allowing a more efficient collaboration between all the members involved.

Chapter 6

Conclusions and Future Work

This chapter presents the main conclusions of this thesis project and some suggestions for future work.

6.1 Conclusions

The main objective of this thesis was to study the possibility of improvements in the ECM processes in order to increase the efficiency of the activities, to ensure compliance with the defined deadlines and to increase the overall visibility of the process.

The first stage of the project was to spend some time on integration within the department and the pilot project team. This was followed by a diagnostic phase aimed at understanding the way project teams work within the company, attending meetings and understanding the company's project management activities and the ECM processes. At the same time, a diagnosis was made directly with the project members and the project manager through unstructured interviews, and the main literature available on the subject was searched to increase the researcher's knowledge.

Having a good understanding of the current activities, a number of problems and opportunities for improvement were identified. Once this list was defined, it was possible to carry out a study in parallel with the project already underway and to define proposals to respond to the issues raised.

The proposals can be divided into two main groups. The first refers to a standard of activities for each phase of the ECR process, defining in each one which activities should be started, delivered or further developed. In this sense, it defines, on the basis of the lead time of the activities, the moment when they should be initiated, instead of defining only the moment when they should be delivered. On the other hand, the second proposal is related to the tracking of the ECR activities, where two different possible approaches are presented. The first approach is to create an Excel file and the second approach is to integrate the data into Power BI dashboards. These approaches were explored given the current state of the ECM tool and the data available to be exported, but it is also pointed out the path that the company should follow to maximise the performance and benefits of the proposal. Both approaches would be an improvement and a way to ensure better compliance with the defined deadlines and, in the limit, a reduction in the necessary ECR implementation time. Nevertheless, the second approach, if fully implemented with all the suggestions, can work as a framework for all the projects and all participants to have a clear view of the status of the ECRs in real-time and even for the management to have an overview of the performance of the projects.

In summary, the main objective of this thesis was achieved with both proposals contributing to a significant improvement in the process flow so that the ECM procedures can be performed efficiently and effectively. It is expected that the application of the proposals will potentially reduce the time spent by the project manager on the activities, the overdue dates and ultimately the cost that the ECR process represents to the organisation. The study contributed to the business process improvement literature and provided a new approach to addressing issues related to engineering change management tracking. The findings of this research can also be applied to other organisations facing similar change management and tracking challenges and may inspire future research in this area.

6.2 Future Work

As mentioned before, this research was carried out in the context of the pilot project, which means that certain issues may be slightly different when the proposals are applied to different projects. It is therefore important to extend the proposals to other projects and assess their feasibility and appropriateness. It is important to take into account the specificity of each project and to study whether it would be useful to include another topic or another action in the standardisation activities.

In addition, it is recommended that the organisation continues to communicate with the ECM tool experts about exporting more data than is currently available. It is important that data such as the collaboration and the participants involved in each ECR are available to be extracted from the tool.

A final suggestion is for the organisation to effectively implement direct data flow between the ECM tool and the dashboard, as this would mean a reduction in loading errors and time spent manipulating the data. A team or person should also be appointed to check the data and ensure the quality and validity of the framework.

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Appendix A

ECR typical team participants and their tasks

Team	Typical participants	Detailed tasks
ECR Team: prepare and plan ECR	• Change initiator (optional) • Depending on ECR content, participants for system / HW / mechanical / electrical / SW / Plant / Purchasing / Sales • Change representative • Change coordinator	• prepare ECR
Review Team: review ECR in status 22+24 Established as SAP distribution lists for every customer.	• Change representative, Change coordinator	• Review the validation result
	• Quality representative: e.g. Dev-PQM, Plant-PQM, PQC	• Review, if mandatory info is available and easy to understand: schedule (complete), QA plan (22: complete, 24: passed), customer info or involvement • Generally: check consistency
	• PM/SCPdM	• Review affected products/plants, budget, resources, schedule (conflicts), AA topics, rework/scrap.
	• “content experts” for system / HW / mechanic / electric / SW / Plant (e.g. GrpM / DH)	• Review the technical content and QA plan.
	• other stakeholders: e.g. AA, CP, LOG, MFC	• Review for own area, if change can be implemented as planned.
	• Customer contact: Sales, or delegated to Plant PQM/PQC	• Review customer involvement and customer information.
Approver: approve ECR in status 22 and 24	• Budget responsible (e.g. CI1: PD/PM, CI2: PD)	• Check, if review was done • Ensure that ECR was updated, if necessary
	• Quality representative (e.g. BU/QMM1 GrpM)	

Table 3: ECR team: participants and their tasks

Appendix B

Customer involvement matrix

1) Does the change require an ECR process according to the MP-308.01 XC Realize Product and Process Changes in Series and Aftermarket Production?	2) Does it affect special characteristics agreed with the customer?	3) Does it affect a technical interface to the customer?	4) Change type?	5) Does it affect contract documents (e.g., specification sheet, customer drawing, offer drawing, TCD, data records,	6) Does it affect fit, form, function, performance, reliability?			Classification	
Yes	Yes	All	All	All	All		Changes in the special characteristics of parts, electr. Components, processes, products or Printed Circuit Board	A	1
Yes	No	Yes	All	All	All		E.g. Changes to electrical or hydraulic components, bracket to the vehicle, electrical components or printed	A	2
Yes	No	No	Electrical components: refer to MP-308.01-004 Electronic Components-Matrix						
Yes	No	No	Printed Circuit Board: refer to MP-308.01-005 Printed Circuit Board-Matrix						
Yes	No	No	design change	Yes	Yes		E.g. changes in design, circuit, tooling	A	3
Yes	No	No		Yes	Yes		E.g. changes in the software (SW) at the product (parameter, architecture)	A	4
Yes	No	No		Yes	No		E.g. Changes in a sealing material, change in an EMC capacitor	A	5
Yes	No	No		No	Yes		E.g. Changes in dimensions that are not included in the customer drawing	A	6
Yes	No	No		No	Yes		Material changes	A	7
Yes	No	No		No	No		Changes to Bosch specification or changes in tolerance, outside of customer specification	A	8
Yes	No	No		No	No		Changes to Bosch specification or changes in tolerance, within the customer specification [3)ECR]	-	9
Yes	No	No		No	No		Changes to the name or description of parts and materials [3)ECR]	-	10
Yes	No	No		No	No		Changes in rough machining stages (e.g. pre-turning dimension of a shaft, wafer mounting) [2)ECR, 3)ECR]	-	11
Yes	No	No	change in the process	Yes	No		E.g. Change in the process chain including sub-supplier	A	12
Yes	No	No		Yes	No		E.g. Change in testing, test procedure or for other reasons	A	13
Yes	No	No		No	Yes		E.g. Change in the hardness parameters, injection temperature	A	14
Yes	No	No		No	Yes		E.g. Change in the process chain including sub-suppliers	A	15
Yes	No	No		No	No	Production-assembly	Changes in the number of cavities in the tool [4)ECR]	I	16
Yes	No	No		No	No		Duplication or replacement of tooling with the same amount of cavities [1)ECR]	-	16a
Yes	No	No		No	No		Duplication of production and test equipment [2)ECR]	I	17
Yes	No	No		No	No		Procurement and use of new machine type [4)ECR]	I	18
Yes	No	No		No	No		Change in the existing tool new device , new Poka Yoke [1)ECR]	-	19
Yes	No	No		No	No		Change in the process including roughing stages (for example, no. 11) [3)ECR]	-	20
Yes	No	No		No	No		Change in the setting parameters (e.g. injection temperature), manufacturing resources (e.g.	-	21
Yes	No	No		No	No	Testing	Change in the test, risk higher	not permitted	
Yes	No	No		No	No		Change in the test method without change in the process sequence. Risk unchanged or reduced	I	23
Yes	No	No		No	No		Expansion of the test without changing the method (e.g. increase in random sample) [1)ECR]	-	24
Yes	No	No		No	No		Reduction/ cancellation of a not customer relevant testing (e.g. random sample) [1)ECR]	-	24a
Yes	No	No		No	No	Relocation of production	Relocation of Tools within similar lines [1)ECR]	-	25
Yes	No	No		No	No		Relocation of non-mobile equipment in a location without changing the process chain [2)ECR]	I	26
Yes	No	No		No	No		Relocation of mobile equipment in a location without changing the process chain [2)ECR, 3)ECR]	-	26a
Yes	No	No		No	No		Change in the location: Relocation of the equipment, parallel production [4)ECR]	A	27
Yes	No	No		No	No		Change in the location: Relocation of the equipment, parallel production for roughing stages [3)ECR]	-	27a
Yes	No	No	change in the logistics	Yes	All		New supplier, supplier changes sub-supplier	A	28
Yes	No	No		No	Yes		New supplier, supplier changes sub-supplier	A	29
Yes	No	No		No	No		New supplier [4)ECR]	I	30
Yes	No	No		No	No		New forwarding agent (carrier), external service provider, internal service provider [1)ECR]	-	30a
Yes	No	No		No	All		Packaging to the customer, shipping, billing [1)ECR]	A	31
Yes	No	No		No	All		Internal packaging (e.g. plant-plant, within plant,...) and delivered packaging [1)ECR]	-	31a
Yes	No	No	change in the docu-ments	Yes	All		Document adaptation to the condition of the released product	A	32
Yes	No	No		No	No		Document adaptation to the condition of the released product or correction of formal error (ECR-correction)	-	33
Yes	No	No		No	No		Change in non-product-related documents (e.g. from work instructions, accurate manufacturing instruction)	-	34
No	Re-use of tools after 12 or more months standstill [1)ECR]							-	35
No	Servicing/maintenance of existing tools or fast wearing tools [1)ECR]							-	36
No	Change in compiler version, Changing SW-tool without effect on customer-SW (Change in the debugger is not relevant here) [1)ECR]							-	37
No	Exchange with identical machine or with machine with identical process core, interchanging identical testing device [1)ECR]							-	38

Figure 43: Customer involvement matrix

Appendix C

Excel sheet for ECR support

Filter | Clear All | Report | Create Template

Index of assignment change	ECMF Role	[illegible]	Name of Responsible	Status Phase	Affected Project	Phase									Change type							Change cost			Location	
						23	23	24	24D	25	25	39	40	48												
						Team Review	Team Review Simplified Flow	Customer Phase Cockpit	Formal ECR Check	Final Review	Final Review Simplified Flow	Change Product Data Issue EC	Confirm Local Change Coordinator	Confirm Global Change Coordinator	Mechanical	HW	SW	Display	PAV	Packaging	Process	Less 2500€	Between 2500€ and 10000€	More than 10000€	Braga	Wujin
[illegible]	Change Coordinator	[illegible]	[illegible]	Before QGC5	[illegible] Braga								A		X	X	X	X	X	X		X	X	X	X	
[illegible]	Cost Center Responsible	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A				A					X	X	X	X	X	X			X	X	X	
[illegible]	Cost Center Responsible	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A				A					X	X	X	X	X	X				X	X	
[illegible]	Documentation Office	[illegible]	[illegible]	Before QGC5	[illegible] Braga				A			A			X	X	X	X	X			X	X	X	X	
[illegible]	Documentation Office	[illegible]	[illegible]	Before QGC5	[illegible] Braga				A			A			X	X	X	X	X			X	X	X	X	
[illegible]	Documentation Office	[illegible]	[illegible]	Before QGC5	[illegible] Braga				A			A			X	X	X	X	X			X	X	X	X	
[illegible]	Documentation Office	[illegible]	[illegible]	Before QGC5	[illegible] Braga				A			A			X	X	X	X	X			X	X	X	X	
[illegible]	Documentation Office	[illegible]	[illegible]	Before QGC5	[illegible] Braga				A			A			X	X	X	X	X			X	X	X	X	
[illegible]	Documentation Office	[illegible]	[illegible]	Before QGC5	[illegible] Braga				A			A								X		X	X	X	X	
[illegible]	Engineering	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A				A					X							X	X	X	X	
[illegible]	Engineering	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A				A						X						X	X	X	X	
[illegible]	Engineering	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A				A							X					X	X	X	X	
[illegible]	Engineering	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A				A								X				X	X	X	X	
[illegible]	Engineering	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A				A									X			X	X	X	X	
[illegible]	Engineering	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A				A										X		X	X	X	X	
[illegible]	Logistics	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A									X	X	X	X	X	X		X	X	X	X	
[illegible]	Manager of Initiator	[illegible]	[illegible]	Before QGC5	[illegible] Braga		A				A				X	X	X	X	X	X		X	X	X	X	
[illegible]	Manufacturing_SW	[illegible]	[illegible]	Before QGC5	[illegible] Braga					A							X					X	X	X	X	
[illegible]	Manufacturing	[illegible]	[illegible]	Before QGC5	[illegible] Braga					A					X	X	X	X	X	X		X	X	X	X	
[illegible]	Product Responsible Engineer	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A				A					X	X	X	X	X	X		X	X	X	X	
[illegible]	Product Responsible Manufacturing	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A				A					X	X	X	X	X	X		X	X	X	X	
[illegible]	Product Responsible Quality	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A	A			A					X	X	X	X	X	X		X	X	X	X	
[illegible]	Purchasing	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A				A					X	X	X	X	X	X		X	X	X	X	
[illegible]	Quality	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A	A			A					X	X	X	X	X	X		X	X	X	X	
[illegible]	Quality	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A	A			A					X	X	X	X	X	X		X	X	X	X	
[illegible]	Quality	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A	A			A					X	X	X	X	X	X		X	X	X	X	
[illegible]	Sales	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A									X	X	X	X	X	X		X	X	X	X	
[illegible]	Sales_cpc	[illegible]	[illegible]	Before QGC5	[illegible] Braga			A							X	X	X	X	X	X		X	X	X	X	
[illegible]	AA Sales Coordinator	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A									X	X	X	X	X	X		X	X	X	X	
[illegible]	OE Sales Coordinator	[illegible]	[illegible]	Before QGC5	[illegible] Braga	A	A								X	X	X	X	X	X		X	X	X	X	
[illegible]	Type Approval Authority	[illegible]	[illegible]	Before QGC5	[illegible] Braga					A					X	X	X	X	X	X		X	X	X	X	
[illegible]	Type Approval Authority	[illegible]	[illegible]	Before QGC5	[illegible] Braga					A					X	X	X	X	X	X		X	X	X	X	
[illegible]	Type Approval Authority	[illegible]	[illegible]	Before QGC5	[illegible] Braga					A					X	X	X	X	X	X		X	X	X	X	

Figure 44: Excel sheet screenshot for the ECR team of Braga