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ENGINEERING CHANGE MANAGEMENT FRAMEWORK FOR PRODUCTS WITH MULTIPLE PARTS AND SUB-SYSTEM ASSEMBLY PRODUCED AS HIGH VOLUME AT A SMALL-TIME RATE

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Dissertação submetida ao Programa de Pós-Graduação em Engenharia e Ciências Mecânicas da Universidade Federal de Santa Catarina para a obtenção do título de mestre em Engenharia e Ciências Mecânicas.
Orientador: Prof. Dr. Pedro Paulo de Andrade Júnior

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Paola Pimentel Barroso Guieiro

Engineering change management framework for products with multiple parts and sub-system assembly produced as high volume at a small-time rate

O presente trabalho em nível de mestrado foi avaliado e aprovado por banca examinadora composta pelos seguintes membros:

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Certificamos que esta é a **versão original e final** do trabalho de conclusão que foi julgado adequado para obtenção do título de mestre em Engenharia e Ciências Mecânicas.

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Este trabalho é dedicado ao meu esposo Raphael França Guieiro por seu apoio incansável durante desenvolvimento do estudo e aos meus pais por ser fonte inesgotável de encorajamento e compreensão.

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RESUMO

Gestão da mudança de engenharia (ECM) é a chave para produção de produtos customizados e a solução para superar a competição no mercado. Entretanto, apesar de uma importante vantagem competitiva, existem poucos estudos a esse respeito. Por isso, essa pesquisa desenvolve um framework para ECM com suporte prático de implementação através de templates para produtos com múltiplas partes e montagem de sub-sistemas produzidos como alto volume em pouco tempo. Esse estudo executou uma análise bibliométrica e revisão sistemática selecionando 12 documentos para avaliação de estado-da-arte, conduziu uma pesquisa in loco identificando 5 maiores razões para mudança e 9 problemas possíveis durante ECM com suas consequências, simulou 3 casos de aplicação do framework em um bebedouro comercial e obteve 28 respostas na avaliação do framework que levou a versão final com 16 passos, 12 templates de suporte e CANVAS para monitoramento. Oportunidades para futuros estudos são o aumento de teste, adaptação do framework para múltiplos tipos de companhias, proposição de um software para gerenciar o framework, adoção de teste de aceitação de usuário e definição de como executar gestão de risco nos processos de tomada de decisão do framework.

Palavras-chave: ECM. Gestão de Mudança de Engenharia. Framework.

RESUMO EXPANDIDO

Introdução

Com o acirramento da competição no mercado e a necessidade de aumento do ciclo de vida dos produtos, as empresas precisaram ajustar o modelo de desenvolvimento de produtos para adotar a criação de variantes através de pequenas mudanças a fim de manter o nível de excelência e atratividade no mercado. Desenvolvimento de novas famílias de produto estão associadas a altos custos enquanto a adaptação através da alteração de componentes após entrada para produção em alto volume é a chave para garantir a rentabilidade. Sendo a mudança de engenharia conceituada por Jarratt et al (2011) com sendo a alteração de partes, desenhos e software já liberados durante o processo de desenvolvimento e tendo qualquer tamanho, número de pessoas envolvidas e duração, a gestão dessas atividades é a gestão da mudança de engenharia. Apesar de sua importância estratégica, a gestão da mudança de engenharia não possui tantos estudos estruturados quanto outras áreas tendo seis vezes menos publicação que o tema de gestão de projetos. Tendo em vista que a gestão adequada da mudança de engenharia pode levar a problemas como falha na identificação de stakeholders, identificação insuficiente de propagação de impactos de design e planejamento falho de phase-in/out que pode ocasionar perdas em inventário e interrupção de fornecimento, a gestão adequada da mudança de engenharia é uma ferramenta para aumento de rentabilidade. Devido à falta de estudos estruturados, essa pesquisa propõe um framework de gestão de mudanças de engenharia com suporte prático de implementação através de templates para produtos com múltiplas partes e montagem de sub-sistemas produzidos como alto volume em pouco tempo para empresas com nível de maturidade minimamente 1 na proposta de CANGELIR & KARADEMIR (2013) na qual a empresa possua estrutura de produto com informações mínimas acerca de qualidade, teste e gestão de configuração.

Objetivos

Como objetivo geral esse estudo visa desenvolver um framework de gestão de mudanças de engenharia com suporte prático de implementação através de templates para produtos com múltiplas partes e montagem de sub-sistemas produzidos como alto volume em pouco tempo. Como objetivos específicos irá conduzir uma análise bibliométrica e revisão sistemática para identificar os documentos relevantes para composição de um referencial teórico para estudo da gestão da mudança de engenharia, executar uma pesquisa in-loco para identificar as principais características de mudanças de engenharia em produtos com múltiplas partes e montagem de sub-sistemas produzidos como alto volume em pouco tempo, simular o uso do framework em um bebedouro comercial, avaliar os resultados do framewrok proposto através do feedback de profissionais e estudiosos da gestão da mudança de engenharia e atualizar o framework com base nos feedbacks para apresentar sua versão final.

Metodologia

Essa pesquisa tem natureza aplicada pois apresenta conhecimento sobre gestão da mudança de engenharia e resolve uma lacuna específica acerca do tema, seu objetivo é exploratório já que adota análise bibliométrica e revisão sistemática assim como análise da compreensão da aplicação em um bebedouro comercial com questionário a profissionais e estudiosos da área, a abordagem é qualitativa pois a aplicabilidade não pode ser traduzida em números mas é baseada em feedback tal que análises estatísticas não podem ser aplicadas, o método é hipotético-dedutivo a partir de perguntas de pesquisa, a coleta de dados é não-probabilística e intencional tal que amostras da população são intencionalmente selecionadas para representar um grupo adequado tanto na seleção da empresa para pesquisa in-loco quanto nos participantes do questionário para feedback da aplicação do framework, o instrumento de pesquisa é observação

e questionário no qual o pesquisador é instrumento chave para análise dos resultados da análise bibliométrica, revisão sistemática e feedback dos profissionais e estudiosos da gestão da mudança de engenharia e o procedimento técnico é estudo de caso através da aplicação simulada em um bebedouro comercial da uso do framework proposto no estudo.

Resultados e Discussão

Considerando a hipótese de que os principais documentos para compor um referencial teórico acerca da gestão da mudança de engenharia pode ser identificado através de uma análise bibliométrica e revisão sistemática, esse estudo identificou 62 documentos alinhados com o objetivo da pesquisa, 12 documentos foram selecionados como estado da arte e tiveram uma comparação de forças e fraquezas realizadas para assegurar que nenhuma das propostas atendia ao objetivo proposto pelo trabalho. Adicionalmente, considerando a hipótese de que uma pesquisa in-loco pode identificar as principais características da gestão da mudança de engenharia em produtos com múltiplas partes e montagem de sub-sistemas, foram identificadas 5 principais razões para mudanças e 9 possíveis problemas da gestão da mudança de engenharia com suas consequências. Para a hipótese de que o melhor framework para gestão da mudança de engenharia é baseado no conhecimento acadêmico somado a aplicabilidade profissional, o fluxo de processo de gestão da mudança com os templates para suportar o uso do framework foi desenvolvido. Considerando a hipótese de que o framework proposto pode ser avaliado por profissionais e pesquisadores do tema de gestão da mudança de engenharia, foi elaborado um vídeo explicativo com um questionário composto por 7 questões mandatórias e 6 questões opcionais com obtenção de 28 respostas. Para avaliar a hipótese que a simulação em um bebedouro comercial pode verificar a aplicabilidade do framework, 3 casos simulados foram desenvolvidos considerando as possibilidades do framework (fast track, full track e processo de encerramento). Finalmente, para verificar que o melhor framework possível é baseado na associação do conhecimento acadêmico com aplicabilidade profissional melhorada pelo feedback de profissionais e pesquisadores da área, 5 oportunidades de melhorias foram executas no framework e 5 oportunidades de estudos futuros foram identificadas a partir das restrições da pesquisa e do feedback do questionário.

Considerações Finais

O framework proposto após feedback de pesquisadores e especialistas da gestão da mudança de engenharia é composto por 16 processos em sua versão full-track e 15 processos em sua versão fast-track, todos suportados por 12 templates e um CANVAS para monitoramento. De modo geral, o framework proposto foi avaliado como relevante pelos respondentes do questionário. Oportunidades para futuros estudos são o aumento de teste, adaptação do framework para múltiplos tipos de companhias, proposição de um software para gerenciar o framework, adoção de teste de aceitação de usuário e definição de como executar gestão de risco nos processos de tomada de decisão do framework.

Palavras-chave: ECM. Gestão de Mudança de Engenharia. Framework.

ABSTRACT

Engineering Change Management (ECM) is the key to produce customer variants and the solution to overcome hard competition on the marketplace. However, despite effective ECM is an important competitive advantage, a lack of structured studies is notable. For this reason, this research develops a framework for ECM with practical implementation support through templates for products with multiple parts and sub-system assembly produced as high volume at a small-time rate. This study performed a bibliometric analysis with systematic review selecting 12 documents for state of the art evaluation, conducted a in loco research identifying 5 major reasons for change and 9 ECM possible problems with consequences, simulated 3 cases for framework application on a commercial drinking fountain and obtained 28 responses on framework evaluation that lead to a final version with 16 steps on its full track process, 12 support templates and a CANVAS for monitoring. Further studies opportunities are increase testing, adapt the framework for multiple types of companies, propose a software to manage the framework, adopt UAT – user acceptance testing and define how to execute risk management on decision taking process on framework.

Keywords: ECM. Engineering Change Management.Framework.

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LISTA DE ABREVIATURAS E SIGLAS

BOL	Beginning of life
BOM	Bill of Materials
CAD	Computer-Aided Design
CAI	Change Administrator I
CAII	Change Administrator II
CAIII	Change Administrator III
CAM	Computer-Aided Manufacturing
CIB	Change Implementation Board
CMII	Configuration Management Model
CRB	Change Review Board
CRM	Customer Relationship Management
DFX	Design for X
EC	Engineering Change
ECM	Engineering Change Management
ECN	Enterprise Change Notice
ECR	Enterprise Change Request
EHS	Environment, Health and Safety
EOL	End-of-life
ERP	Enterprise Resource Planning
IBBL	Indústria Brasileira de Bebedouros Ltda
ICM	Institute of Configuration Management
MCM	Manufacturing Change Management
MOL	Middle-of-life
NPD	New Product Development
PDCA	Plan-Do-Check-Act
PDM	Product Data Management
PLM	Product Lifecycle Management
PMO	Project Management Office
SCM	Supply Chain Management
TBC	Template for Business Case
TCA	Template for Change Audit
TCN	Template for Change notice
TCP	Template for Change Plan
TCPA	Template for Change Plan Approval
TCR	Template for Change Request
TH	Template for Homologation
THA	Template for Homologation Approval
TIP	Template for Impact Propagation
TPFast	Template for Prioritization on Fast Track
TPFull	Template for Prioritization on Full Track
TPR	Template for Problem Report
UAT	User Acceptance Testing

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SUMÁRIO

1INTRODUCTION

1.1RESEARCH PROBLEM CONTEXT

For years, New Product Development (NPD) process was guided by sequential thinking of launching large series of expensive products that remained on the market for a long time. However, product lifecycle has been decreasing mainly due to hard competition on the marketplace as highlighted by Pikosz & Malmqvist (1998).

In this new scenario, the companies need to adjust their development process to produce customer variants with a fast adoption of customer needs and enlarge product lifecycle through product improvement, by creating new product variants and performing minor changes to keep products level of excellence and attractiveness to market.

Tavčar & Duhovnik (2005) explains that a longer lifecycle increases product profitability because the development of a new product family is associated with considerable cost and Fiedler & Kampa (2016) emphasis the need of adapting product development to mass customization by modifying product's components after the product entered high volume of similar product produced at a small-time rate.

For this reason, Engineering Change Management (ECM) has seen increased interest within engineering research. Jarratt et al (2011) defines Engineering Change (EC) as "an alteration made to parts, drawings or software that have already been released during the product design process. The change can be of any size or type; the change can involve any number of people and take any length of time" and Shivankar, Kakandikar & Nandedkar (2015) defines ECM as "the process of organizing, controlling and managing the workflow and information flow for engineering change".

Therefore managing properly the ECM in order to adjust development process for producing customer variants is the solution to overcome hard competition on the marketplace.

However, despite effective ECM is an important competitive advantage of a company as mentioned by Li & Moon (2012), a lack of structured studies is notable. Storbjerg, Brunoe & Nielsen (2016) highlights that current ECM literature does not provide comprehensive guidance for proper engineering change management and Ullah, Tang & Yin (2016) conducted a literature review on publications until August 2015 selecting 366 documents on engineering change management. For comparison purposes, the literature review conducted by Padalkar &

Gopinath (2016) for project management resulted in 2,268 publications in the period of 2000-2015, which is more than 6 times the number of publications for ECM.

Considering not managing properly the ECM may lead to problems such as failure on identifying all impacted stakeholders, insufficient design propagation identification and poor phase-in/out planning that can cause wasted inventory or supply disruption, to proper manage ECM is an important tool to increase company profitability.

Since there are not many structured studies on this regard, this research will present a background study about ECM, current available methods and tools, clarify importance of ECM along Product Lifecycle Management (PLM) and propose a model of framework for ECM with practical instructions over implementation with templates.

The proposed framework is to be applied on products with multiple parts and sub-system assembly produced as high volume at a small-time rate on companies with product development process on at least Maturity Level 1 proposed by CANGELIR & KARADEMIR (2013) in which the company has product structure and minimum information regarding quality, testing and configuration management.

1.2RESEARCH GOALS

1.2.1General goal

Develop a framework for Engineering Change Management with practical implementation support through templates for products with multiple parts and sub-system assembly produced as high volume at a small-time rate.

1.2.2Specific goal

In order to develop a framework for ECM with practical implementation support through templates for products with multiple parts and sub-system assembly produced as high volume at a small-time rate, this research specific goals are illustrated on Board 1.

Board 1 – Specific Goals

SPECIFIC GOALS
Conduct a bibliometric analysis and systematic review to identify the main relevant documents to compose a theoretical referential on ECM control study
Perform in-loco research to identify main ECM characteristics for a products with multiple parts and sub-system assembly produced as high volume at a small-time rate.
Simulate the framework application on a commercial drinking fountain
Evaluate application results for proposed framework with ECM experienced professionals and researchers
Update framework based on feedback to present final framework version for ECM

Source: Author (2019)

Once all these specific goals are completed, the general goal of this research will be achieved.

1.3JUSTIFICATION

Engineering change management used to be considered by companies as a source of negative impact on productivity and papers from early 2000´s and before that mentioned that ECM used to focus on developing strategies and methods to eliminate and prevent changes from happening. However, hard competition and a decrease of product lifecycle on the marked forced companies to realize ECM is in fact the mechanism to reduce time to market, increase product customization and make a product more profitable during its lifetime.

Since studies on proper management of changes gained visibility only in the past few years, the number of structured papers and methodologies is not as numerous as other engineering management areas such as project management and is mentioned by authors such as Storbjerg, Brunoe & Nielsen (2016) as not having the necessary practical approach to support a process implementation in the industry.

On the past five years authors proposed methods and tools to manage engineering change. Wu et al (2014) has a good proposal of CMII-based framework with focus on impact analysis however it does not explore the financial and technical feasibility of the change. On the other hand, Yu et al (2013) presents a good methodology to manage the evaluation of need and multiple areas involvement on engineering change but only applied to small/medium

companies. Wilberg et al (2015) proposes a systematic approach using very modern concepts such as multidomain-matrix and viable system model and is evaluated as difficult to understand by professionals.

Since none of them succeed on presenting a framework that covers all ECM aspect, this research will present a framework to manage engineering change applied in a simulated scenario and evaluated by ECM experienced professionals and researchers to present a framework with practical implementation support through templates for products with multiple parts and sub-system assembly produced as high volume at a small-time rate.

An approach as described by this research that is based on current available academic knowledge associated with market best practices and professional applicability was not identified among ECM papers described in Chapter 2 and represents a gap in product development that will be filled by this study.

Considering ECM's potential to influence innovation and increase company profitability, a framework as described by this research covering the existing gap is important and relevant in advancing knowledge frontier on Engineering Change Management.

1.4STUDY STRUCTURE

This study is divided into 6 chapters where chapter 1 is an introduction to the topic with research problem context and goals, chapter 2 presents the theoretical base and the state of the art ECM methodologies and tools, chapter 3 is the method considering the bibliometric analysis, the systematic review and the in loco research results, chapter 4 is the proposed framework with evaluation and limitations, chapter 5 is the application of the proposed framework with results as well as the evaluation of the framework application and chapter 6 is the conclusion and further studies opportunities.

2THEORETICAL BASE

2.1NEW PRODUCT DEVELOPMENT

Launching new or improved products is what keeps a company profitable in the market. Considering the competitive environment on a global level, the NPD process is crucial for corporate competitiveness and has been a relevant research topic in pasts decades.

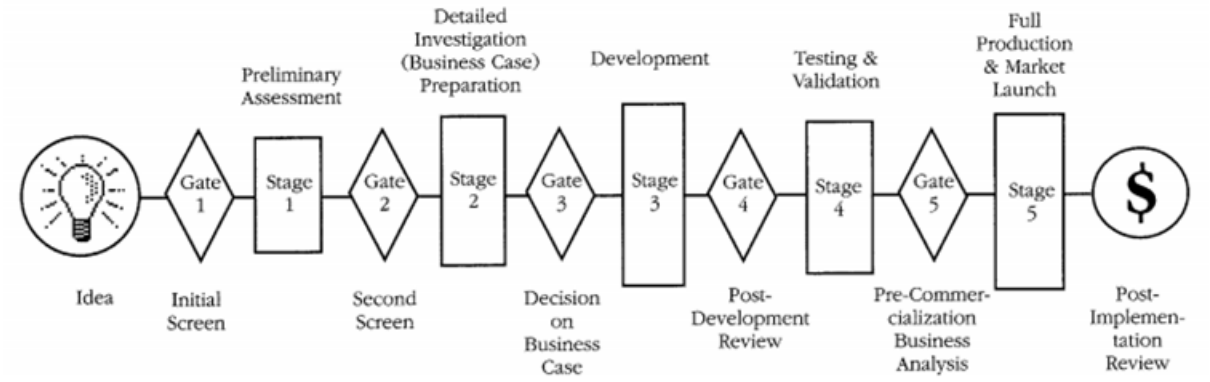
Currently a wide variety of NPD processes are available, from generic approaches as presented by Rozenfeld et al (2000) to specific proposals focused on a product type such as luxury products presented by D'Avolio et al (2017) or process mindset as Lean Product Development discussed by Marodin et al (2018).

When the product development is focused on a mindset, it's commonly defined as "Design for X" (DFX), where the X can be replaced for multiple purposes. Eastman (2012) suggests design for manufacturing, for assembly, for environment, for competition, for dimensional control, for assembly cost, for inspectability, for effective material storage and distribution, for reliability, for serviceability, for recycling, for quality and for modularity. Ulrich et al (2008) describes design for healthcare while Oya, Kato & Higashi (2008) presents parameters related to design for aesthetics.

Despite this ramification, all major NPD processes continues to follow the stage-gate system proposed by Cooper (1990). Each research optimizes the stage and the gates for specific purposes as well as increases the level of details on each one, but the core remains as illustrated in Figure 1.

In Figure 1 Cooper (1990) presents a flow with 12 steps from the idea aiming to implement a new product to reviewing the finished product after it is released for market. On this proposal, there are five gates in which a specific list of deliverables and requirements must be met to allow the product to proceed to the next stage. This process is referred as stage-gate system and adopted by multiple authors after 1990.

Figure 1 - An overview on a stage-gate system



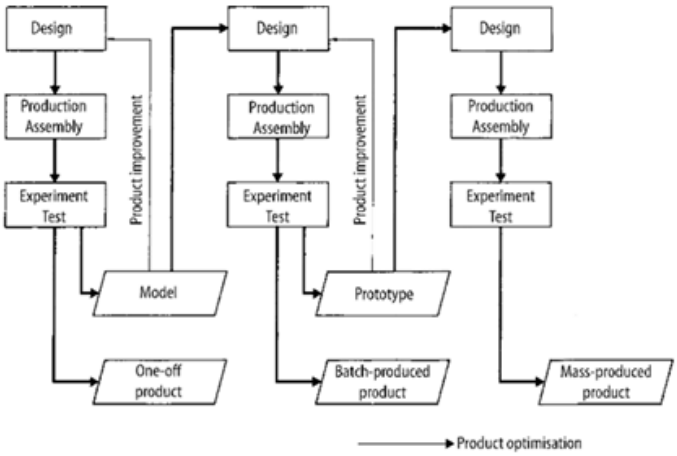
Source: Cooper (1990)

Considering the relevance increase for Concurrent Engineer and Agile methods, different process may be found on studies and researches, but for the purpose of this work, the process from Cooper (1990) illustrated in Figure 1 is more relevant and didactic.

Pahl & Beitz (2013) presents a more detailed version for stages 3, 4 and 5 in Cooper (1990) system because it considers that previous stages are more related to business than to product development.

In Figure 2, Pahl & Beitz (2013) details the stages “Development”, “Testing & Validation” and “Full Production & Market Launch” from Cooper (1990) into 3 interactions consisted in “Design”, “Production Assembly”, “Experiment test” and “Product” that promote product improvement at each interaction until the final mass produced product.

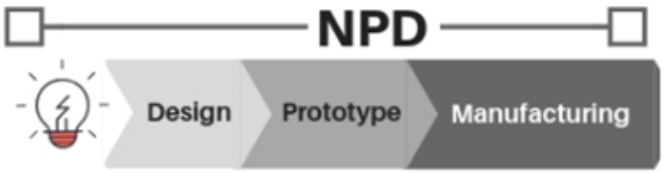
Figure 2 - Stepwise development of a mass-produced product



Source: Pahl & Beitz (2013)

Summarizing Cooper (1990) system and considering Pahl & Beitz (2013) understanding about stages that are related to business and to product development, for this research, the following flow will represent NPD.

Figure 3 - NPD process



Source: Author (2019)

In this flow from Figure 3, the idea as well as stages 1 and 2 from Cooper (1990) are changed to before design, and the gates are omitted in the stage change to create a simpler description. However, since the product life doesn't finish when product enters high volume of similar product produced at a small-time rate, the product lifecycle management is also important to comprehend and will be described in item 2.2

2.2PRODUCT LIFECYCLE MANAGEMENT

According to Kiritsis, Bufardi & Xirouchakis (2003) and reinforced by Terzi et al (2010) and Matsokis & Kiritsis (2010), the product lifecycle refers to the physical phases a product goes through from its conception to discontinuity, mainly divided into 3 major steps:

- Beginning of life (BOL), that comprehends the design and manufacturing;
- Middle-of-life (MOL) related to distribution, use and support;
- End-of-life (EOL) when product is retired and recollected for recycling or disposal.

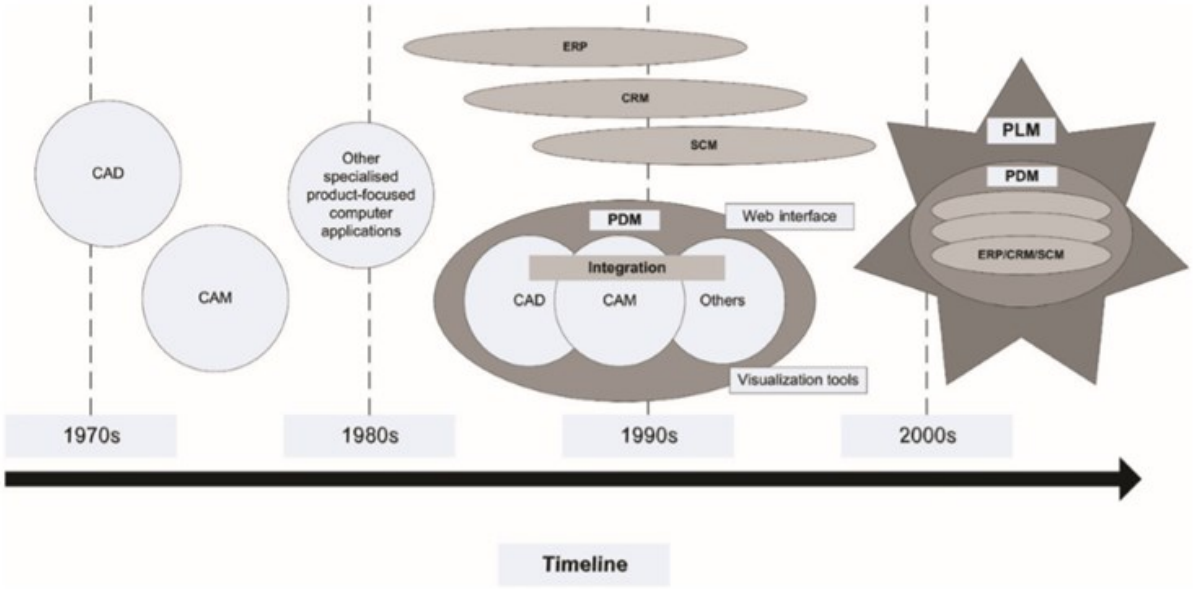
Product lifecycle management aims to manage the business processes and associated data through all product lifecycle phases. As simply explained by Ameri & Dutta (2005), PLM is a business strategy for creating a product-centric environment. Sudarsan et al (2005) highlights PLM’s possibility to streamline product development and boost innovation in manufacturing by seamlessly integrating all information produced throughout all products

phases and making it available for everyone in the organization, including suppliers and customers.

Traceability, control, and sharing are keywords for understanding the concept of PLM. For this reason, PLM is both a concept and a toolkit of methodologies to support business in driving decisions based on product knowledge and smart information.

Cao & Folan (2012) presents a historical evolution for computer supporting tools over the decades and emphasizes PLM as an integrated platform for the creation, organization, and dissemination of product related information. Figure 4 presents the timeline for the evolution of computing applications to support product development from Cao & Folan (2012).

Figure 4 - Timeline for the evolution of computing applications



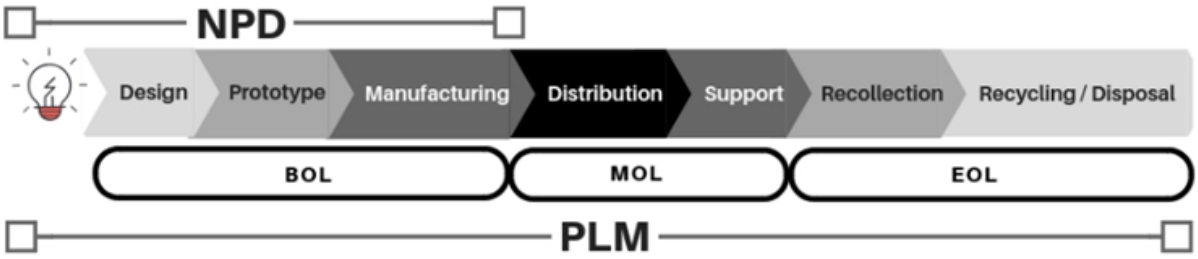
Source: Cao & Folan (2012)

The timeline in Figure 4 describes the time from early engineering design applications such as Computer-Aided Design (CAD) or Computer-Aided Manufacturing (CAM), through the integration of Enterprise Resource Planning (ERP), Customer Relationship Management (CRM) and Supply Chain Management (SCM) solutions. Besides it´s possible to see that the development of isolated computer applications was merged to form basic product data management (PDM), and then advanced by supplementing them with additional web and

visibility tools. PLM occurred in the new millennium with the incorporation of separate systems such as ERP, CRM and SCM, into PDM.

Currently, PLM is the integration of these widely varying systems into coherent, inter-organizational solutions. To better understand how PLM encompasses NPD, the flow from Figure 5 consolidates the view.

Figure 5 - PLM and NDP relation

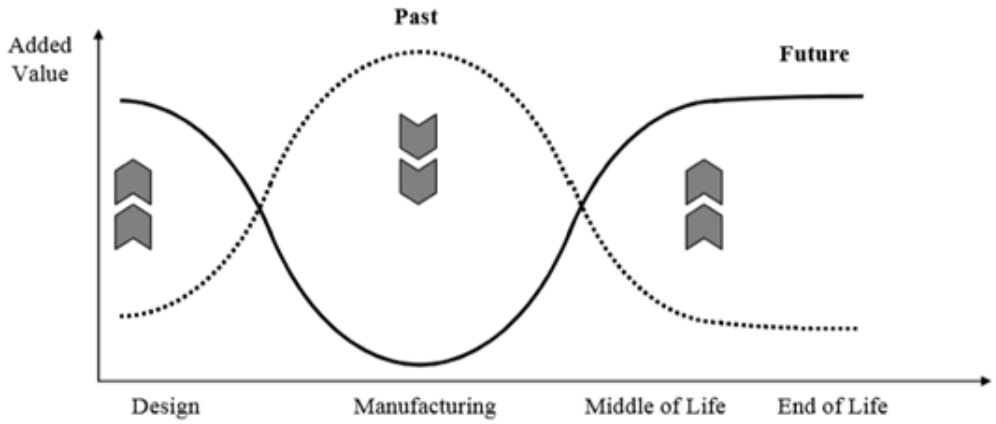


Source: Author (2019)

Figure 5 represents how the NPD comprehends the beginning-of-life in PLM but a product life-cycle goes far over it.

During high volume of similar product produced at a small-time rate, distribution, and support the product has the chance to adapt and change to become more profitable and to increase the time on middle-of-life. Terzi et al (2010) highlights how the importance of the product's lifecycle stages in the company value creation has changed on Figure 6.

Figure 6 - Change of importance of the product's lifecycle stages in the company value creation



Source: Terzi et al (2010)

The phenomenon shown on Figure 6, which in the past the manufacturing part of PLM was the most important while the future is expected Design, MOL and EOL to become more valuable, is directly related to Engineering Change Management and its potential to extend MOL increasing products profitability.

2.3CONCEPTS FOR ENGINEERING CHANGE AND ENGINEERING CHANGE MANAGEMENT

Jarratt et al (2011) defines Engineering Change (EC) as “an alteration made to parts, drawings or software that have already been released during the product design process. The change can be of any size or type; the change can involve any number of people and take any length of time”. This definition is also adopted by Serapelo, Erasmus, & Pretorius (2017), Sommer, Dukovska-Popovska & Steger-Jensen (2013), Storbjerg, Brunoe & Nielsen (2016) and Wilberg et al (2015). This means that changes may occur at any point during the product lifecycle, from design to production stage.

Ahmed & Kanike (2007) split the changes into 3 major phases of the product lifecycle: development & prototype, manufacturing & testing and service (high volume of similar product produced at a small-time rate). The cost for changing increases as the product lifecycle progresses because more stakeholders are impacted and it is more difficult is to evaluate the impact propagation of the change.

During earlier stages, the concern relates to product performance and quality and mainly design impacts are evaluated. When a change occurs during the manufacturing & testing phase, besides the design impact, project cost and project schedule are also affected as highlighted by Serapelo, Erasmus, & Pretorius (2017). After product releases for high volume of similar product produced at a small-time rate, the design impact continues being a risk to be considered when performing a change but manufacturing impact such as production lead time and scrap rate; supply chain impact like disruption and mixture during line supply and wasted inventory; supplier impact due to tools change; customer impact due to product change and technical support impact due to retraining necessity also need to be evaluated.

For this reason, a process to organize and control engineering changes is necessary and is called Engineering Change Management. Shivankar, Kakandikar & Nandedkar (2015)

defines ECM as “the process of organizing, controlling and managing the workflow and information flow for engineering change”.

The proper management for a change is highly impacted by the type of the change. Jarratt et al (2011) proposes two classes for changes:

- Emergent: changes arise from the properties of the product itself
- Initiated: changes are requested from a stakeholder to promote improvements, enhancements or adaptations of a product.

Besides that, strategies to cope with changes are also important and a five strategy guide is proposed by Fricke et al (2000) and adopted by Kattner & Lindemann (2017) briefly explained below.

- Prevention: reduce number of changes by performing in-depth analysis and taking decisions at the correct timing;
- Front-loading: earlier detect changes and monitor potential risks;
- Effectiveness: identify necessary and more beneficial changes;
- Efficiency: optimize use of resources for inevitable changes;
- Learning: knowledge management to ensure experience transfer after performing change.

Knowing the origins of Engineering Changes and the best strategies to cope with them is what makes the different to turn ancient approaches like proposed by Huhtala, Lohtander & Varis (2014) considering changes mean more money and more time spent on the product to new mindset presented by Hamraz et al (2013b) to positively utilize EC potential.

Properly managing change type and adequate strategy is the key to enlarging product lifetime and fast adapt to customization. However, a well defined process is what allows the company to capture these benefits.

2.3.1Engineering Change Management process

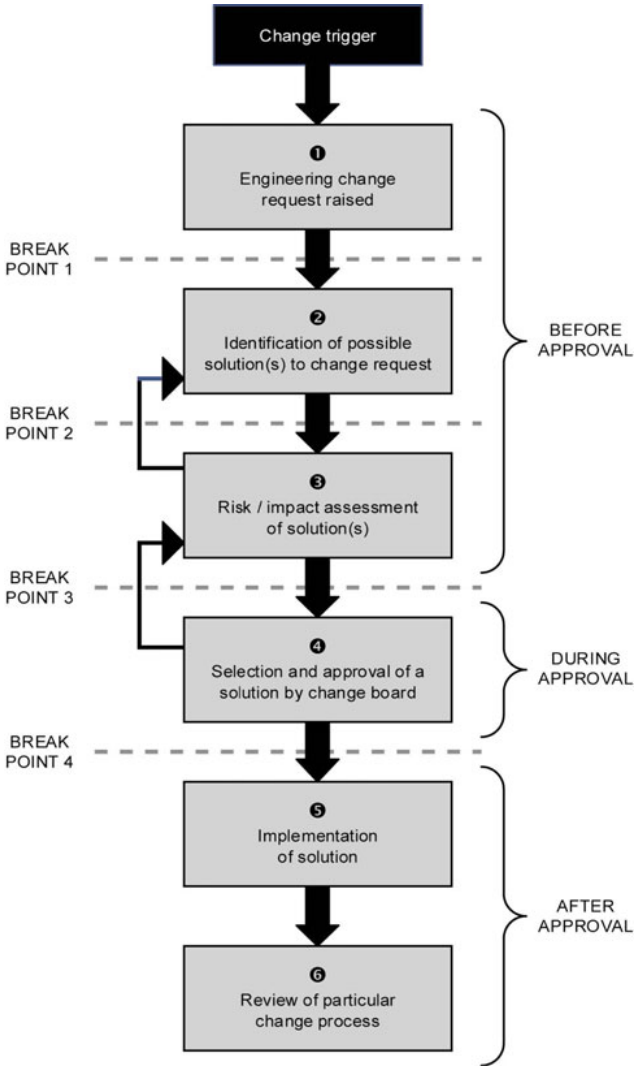
Each EC management process is designed according to the company need or the research purpose and the studies do not consider a standard definition for ECM process flow.

In a generic approach, considering the core idea adopted on researches, ECM process can be summarized into four stages to identify, evaluate, implement and audit the changes.

The generic ECM process described by Jarratt et al (2011) with six-steps that is illustrated on Figure 7 and is usually used as reference being adopted by Elezi, Maier & Lindemann (2013) and Ullah, Tang & Yin (2016) .

Huhtala, Lohtander & Varis (2014) presents a simpler version while Shivankar, Kakandikar & Nandedkar (2015) and Storbjerg, Brunoe & Nielsen (2016) propose each one a more detailed flow. Manufacturing activities are included on the flows adopted by Wu et al (2014), Stekolschik (2016) and Sommer, Dukovska-Popovska & Steger-Jensen (2013).

Figure 7 - Generic ECM process from Jarratt et al (2011)



Source: Jarratt et al (2011)

On Figure 7 Jarratt et al (2011) describes the six-steps in which a request for an engineering change is made, potential solutions to the request for change are then identified, the impact or risk of implementing each solution is assessed, a particular solution selected is approved, and the implementation of the change can occurs immediately or get phased in. Finally, after a period of time, the change should be reviewed to see if it achieved what was initially intended and what lessons can be learned for future change processes.

Despite the variety of process definitions available, managing engineering change is not an easy assignment. Mutingi, Mbohwa & Mapfaira (2015) identified five major contributors and obstacles to implement an engineering change successfully as shown in Board 2.

Board 2 - Five major contributors and obstacles to implement EC successfully

Major contributors to Project Success	**Major contributors to Project Failure**
Top management support	Worker or employee resistance
Worker involvement	Middle-management resistance
Skilled change management team	Poor executive sponsorship
Effective and targeted communication	Limited resources
Well planned approach	Corporate inertia

Source - Author's adaptation from Mutingi, Mbohwa & Mapfaira (2015)

From Mutingi, Mbohwa & Mapfaira (2015) findings presented on Board 2, it's possible to note the influence of people and communication skills on the overall ECM process . This happens because the person responsible for executing the management is the main source for possible problems associated with engineering change implementation.

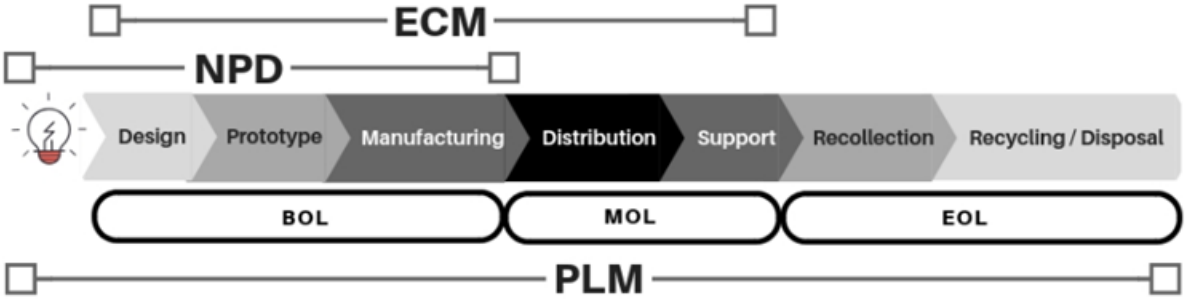
It´s important to highlight that Mutingi, Mbohwa & Mapfaira (2015) were not the only ones to study influences over EC implementation. Elezi, Maier & Lindemann (2013) list a series of studies conducted to identify negative impacts of changes in product development but reinforce that a well-structured process helps to decrease these effects.

For this reason, studies focusing on self-assessment on companies ECM maturity level are developed by Wilberg et al (2015) and Storbjerg, Brunoe & Nielsen (2016) and are good references for evaluating current ECM process on companies.

Considering engineering change management is an important aspect of product lifecycle management, once without proper documentation of changes performed on the

product it's not possible to rely upon available information to maintain a sustainable product-centered strategy for company competitiveness, the flow from Figure 8 demonstrates the correlation between PLM, NPD and ECM.

Figure 8 - Correlation between PLM, ECM and NPD



Source: Author (2019)

Figure 8 illustrates how ECM can occur during NPD and how it impacts the MOL of PLM. This impact of ECM on MOL presents a great advantage for exploring change to enlarge the liefetime and make the company more profitable. However, it’s also important to highlight that ECM also happens during NPD, especially on products with multiple parts and sub-system assembly that are released separately. The ECM process works on both situations, while NPD is running and after product entered high volume of similar product produced at a small-time rate.

2.4CONFIGURATION MANAGEMENT MODEL

Considering PLM and its interaction with NPD and ECM, the Institute of Configuration Management (ICM), a private company, launched the Configuration Management Model (CMII) as a breakthrough process to accommodate change and provide the needed business process infrastructure to keep product information clear, concise and valid. Training and certificates on this methodology are offered by ICM and referred as best practices for ECM.

Because of the lack of structured research about ECM discussed in Chapter 1 , the industry adopted CMII as a standard reference and its terminology is currently used for change

management processes in major PLM software commercially available such as Aras® Product Engineering and PTC® Windchill.

The CMII model proposes the change process to be managed as in Figure 9.

On Figure 9, it´s possible to identify that (1) Problem Report is used to report problems with a released part or document and to propose a product enhancement. Any part involved in product development, including customer and supplier, is allowed to raise a problem report. The problem report is analyzed (2) by a Change Administrator I (CAI) defined by the company as responsible for approving rejecting the problem report for execution. A problem report approved for execution turns into an (3) Enterprise Change Request (ECR).

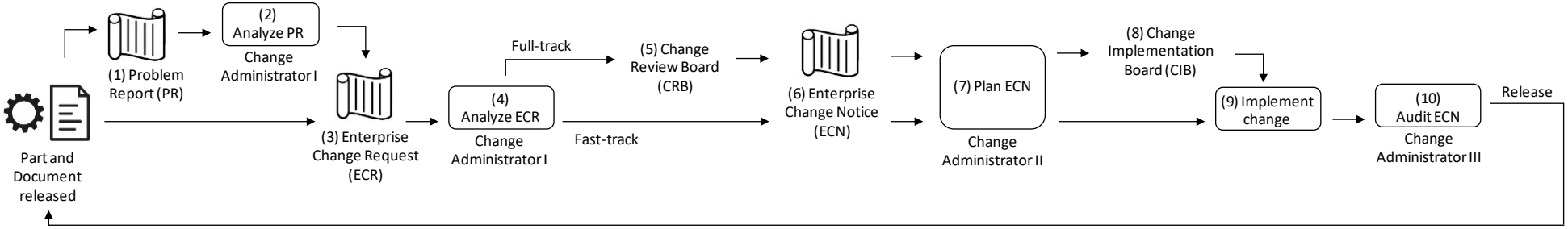
An Enterprise Change Request, also commonly called Engineering Change Request, is used to request a change on a released part or document and to request a product enhancement. It differs from the problem report by the detail of information requested and by restrictions to people allowed to open. Usually companies restrict the ECR privileges to open for groups with enough product knowledge to provide sufficient information to support a business decision to be made. The ECR is also analyzed (4) by a Change Administrator I for approval or rejection.

Approved ECRs may be designated by the CAI for Full-track or Fast-track. Changes requiring detailed analysis and approvals because of their great impact are treated as Full-Track while simple changes that don't require complex analysis are treated as Fast-track to reduce the bureaucracy burden.

In cases of ECRs defined as Full-track, a review from a (5) Change Review Board (CRB) with cross-functional members with representation from different company departments is required and a business decision as to whether to proceed with implementation planning is taken. Fast-track ECRs do not require a review from CRB.

After ECRs is approved for Fast-track or approved by the CRB for Full-track, it turns into an (6) Enterprise Change Notice (ECN), also commonly called Engineering Change Notice, to be planned (7) for implementation by a Change Administrator II (CAII). The CAII is defined by the company as the person responsible for planning changes to be executed.

Figure 9 - CMII proposed model for Change Management



Source: adapted by author from commercially available information regarding CMII (2019)

In Full-track cases, the plan created by CAII is submitted for approval by a (8) Change Implementation Board (CIB) with cross-functional members with representation from different company departments to evaluate whether the plan is complete and ready to be executed. If necessary, the CAII is requested to re-plan and submit for new approval. Fast-track ECNs do not require a review from CIB.

After that, the planned changes are implemented (9) and audited (10) by a Change Administrator III (CAIII) defined by the company as the person responsible for change audit and if approved, all changes in part and documents, as well as the PR, ECR and ECN, are considered released. A new change may be requested for the parts documents released after change's approval, and for this reason this methodology is considered a closed-loop process as illustrated on Figure 9.

On this proposal from CMII model, three distinct Change Administrator roles (CAI, CAII and CAIII) are required, each with a different set of responsibilities that govern the process, but this doesn't mean that they need to be performed by three different people.

Each PLM software commercially available customizes the details on this process keeping the naming convention as reference. Since management softwares exist to support company process and not to guide them, the CMII model major contribution is providing standardization for ECM professionals.

In this process, without templates and clear requirements, the CMII model doesn´t support company in managing Engineering Change. For this reason, Wu et al (2014) proposes an advanced CMII-based ECM framework and highlights that despite previous studies on ECM issues presented valuable results, few studies proposed a framework under the CMII standards for implementation in industrial contexts.

This evidence that without a framework, the CMII model neither solves the issues related to ECM nor enhances process excellence with appropriate guidelines for implementation on companies.

2.5MANAGING ENGINEERING CHANGE ON PRODUCTS

As mentioned by Mutingi, Mbohwa & Mapfaira (2015) and illustrated in Board 2, there are many challenges with managing engineering change.

The confusion of concepts regarding when ECM is applicable can be noticed by comparing Han, Lee & Nyamsuren (2015) that focus on how to manage engineering change

during projects for new product development with Koch, Michels & Reinhart (2016) that discuss changes in manufacturing for products in production stage.

This difference leads to disregard of correlation between NPD, PLM and ECM in ECM studies and results on many propositions and methodologies developed focusing on only one aspect of the engineering change.

Schuh et al (2017) proposes an engineering change management agile model to be applied during NPD completely disregarding that engineering changes may also occur during manufacturing phase of PLM.

On the other hand, Koch, Gritsch & Reinhart (2016) describes the problems that manufacturing process faces when an engineering change is required for a product in high volume similar produced at a small-time rate and suggest a methodology for Manufacturing Change Management (MCM) that would be a specific ECM framework for when the change will impact manufacturing process. This proposal also focuses on only one aspect of ECM instead of considering the complete concept of engineering change.

For this reason, this research considers all aspect of ECM and its interaction with NPD and PLM to propose a framework with practical implementation support through templates for especially on products with multiple parts and sub-system assembly that are released and separately produced as high volume at a small-time rate valid for the entire cycle that engineering change is applicable.

Besides, aiming to have a friendly interface for ECM professionals in companies, the terminology used is CMII-based is currently the standard for PLM softwares commercially available.

Considering NPD, PLM and ECM interactions combined with CMII-based terminology, the proposal of this study contributes to cover the gap existing in engineering change management research described on Chapter 1 and presents a feasible framework to be applied on industrial process.

2.6ECM STATE OF THE ART METHODS & TOOLS

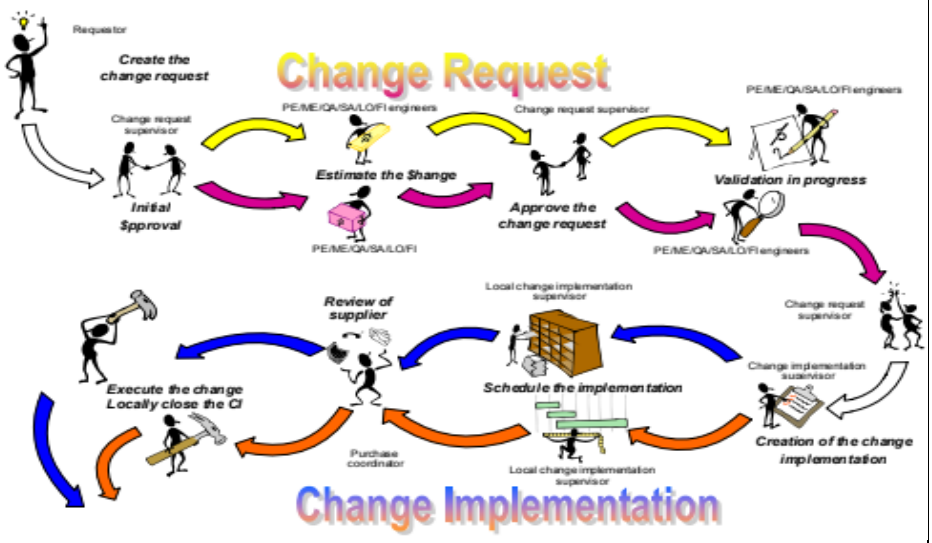
Considering the systematic review conducted on item 3.4, 12 publications were selected as the main relevant documents to compose a theoretical referential on ECM control study. The summary of these ECM methods and tools is presented ahead.

2.6.1Shivankar, Kakandikar & Nandedkar (2015)

Shivankar, Kakandikar & Nandedkar (2015) proposes a nine-step change management process composed of two main sub-processes (change request and change implementation) and uses the PDCA (plan-do-check-act) approach to present a one page methodology to guide engineering change implementation. In this case the goal is to maintain discipline through a systematic approach aiming to reduce risk of cost impact, to promote efficient communication and to prevent unauthorized change implementation. The proposal was applied to an automotive company in India.

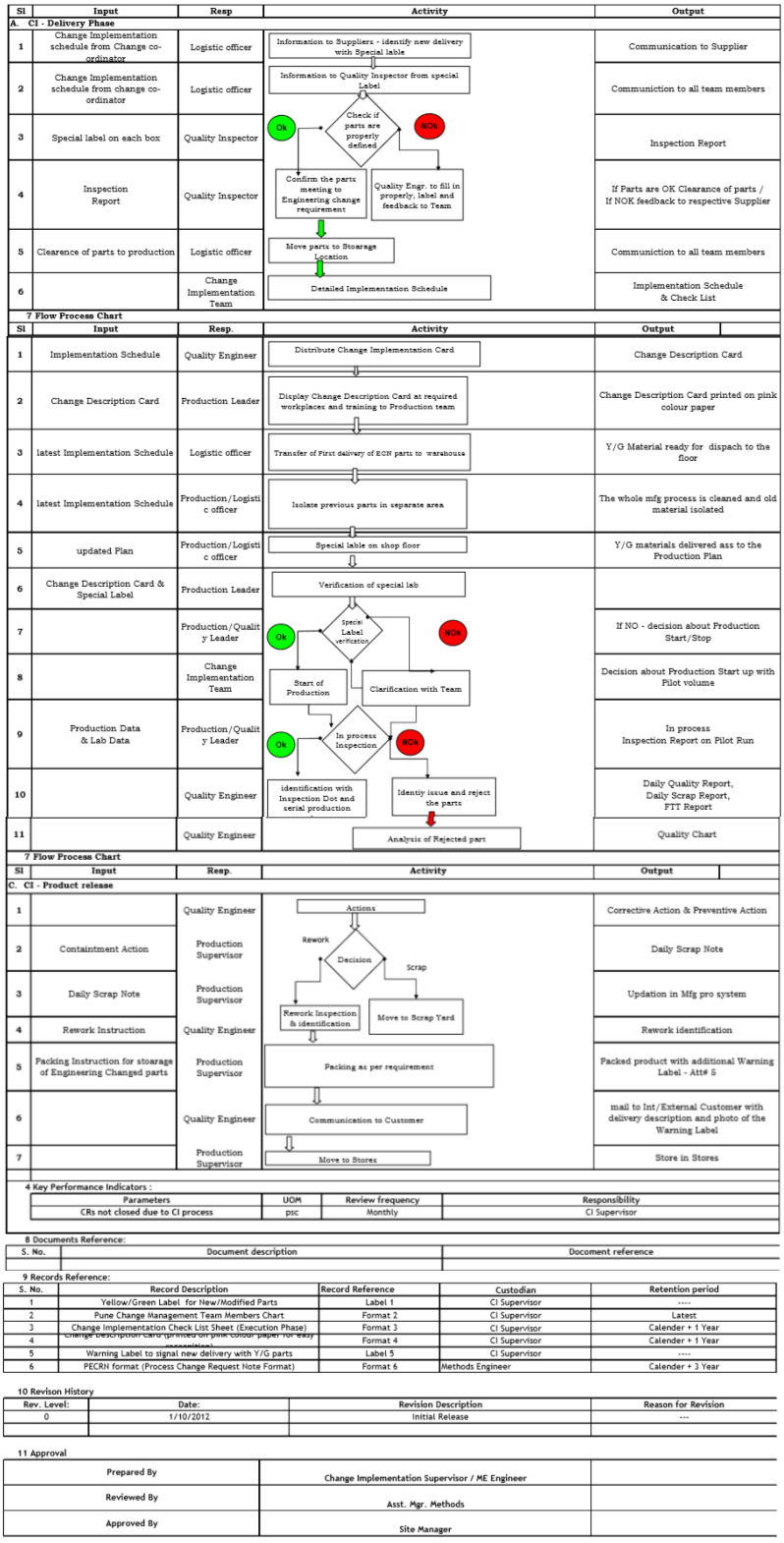
Board 3 presents the main characteristics of the study from Shivankar, Kakandikar & Nandedkar (2015)

Board 3 - Shivankar, Kakandikar & Nandedkar (2015) study characteristics

Change Management Process	

Board 3 - Shivankar, Kakandikar & Nandedkar (2015) study characteristics (cont.)

Flow chart of EC implementation



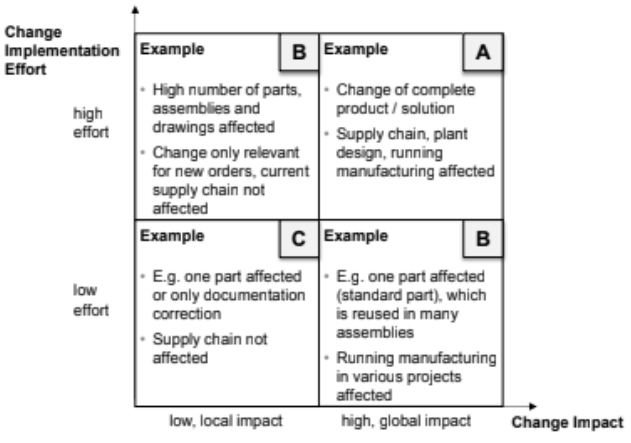
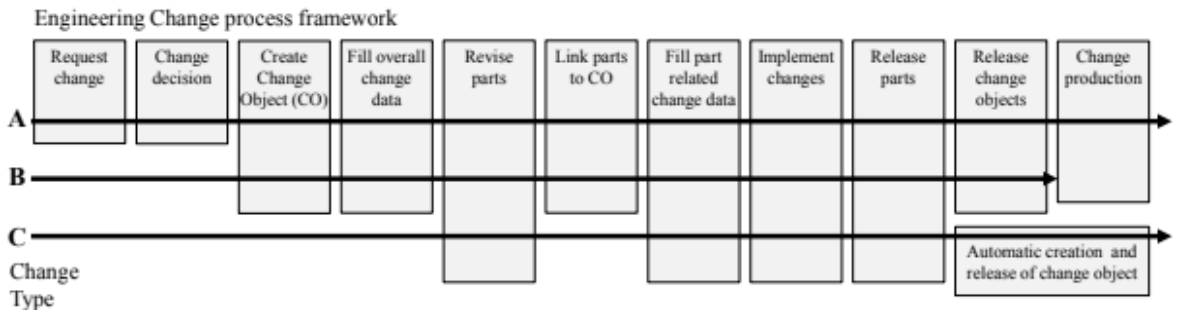
Source: Shivankar, Kakandikar & Nandedkar (2015)

This proposal from Board 3 presents a clear overall approach on ECM process management but focus the step-by-step on the shopfloor management which makes it a good complementary material to support the change process but can not be considered as a complete framework for ECM.

2.6.2Stekolschik (2016)

Stekolschik (2016) proposes an ECM approach based on change complexity with generic business process from change initiation until change implementation at production. Board 4 presents the main characteristics of Stekolschik (2016) research.

Board 4 - Stekolschik (2016) study characteristics

<table>
<tr><th>ECM process considered for the method</th><th>Change classification</th></tr>
<tr><td>The ECM process can be broken down into a number of key stages as follows:
● Identification of engineering change requirement, evaluation of benefits, implications, and affected products
● Preliminary authorization of change request
● Engineering of detailed solution
● Final authorization of the proposal
● Implementation of the solution and final review</td><td> 
</td></tr>
<tr><th colspan="2">Engineering change process framework</th></tr>
<tr><td colspan="2"> 
</td></tr>
</table>

Source: Stekolschik (2016)

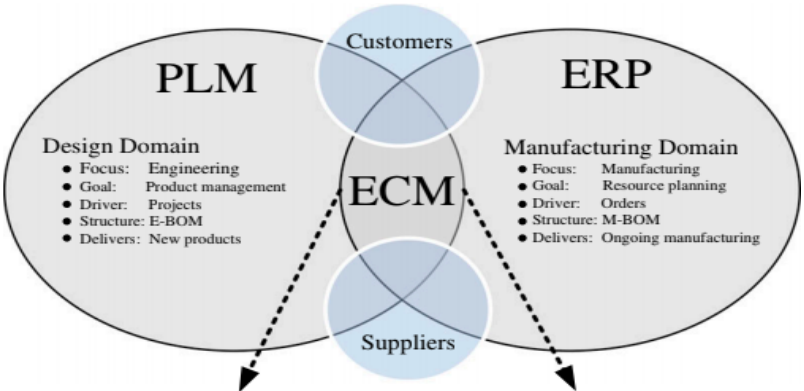
The complexity approach illustrated on Board 4 is a relevant characteristic of the research. Despite that, Stekolschik (2016) proposal does not monitor impacts after and relies upon IT systems and tools that may not be available for all companies.

2.6.3Wu et al (2014)

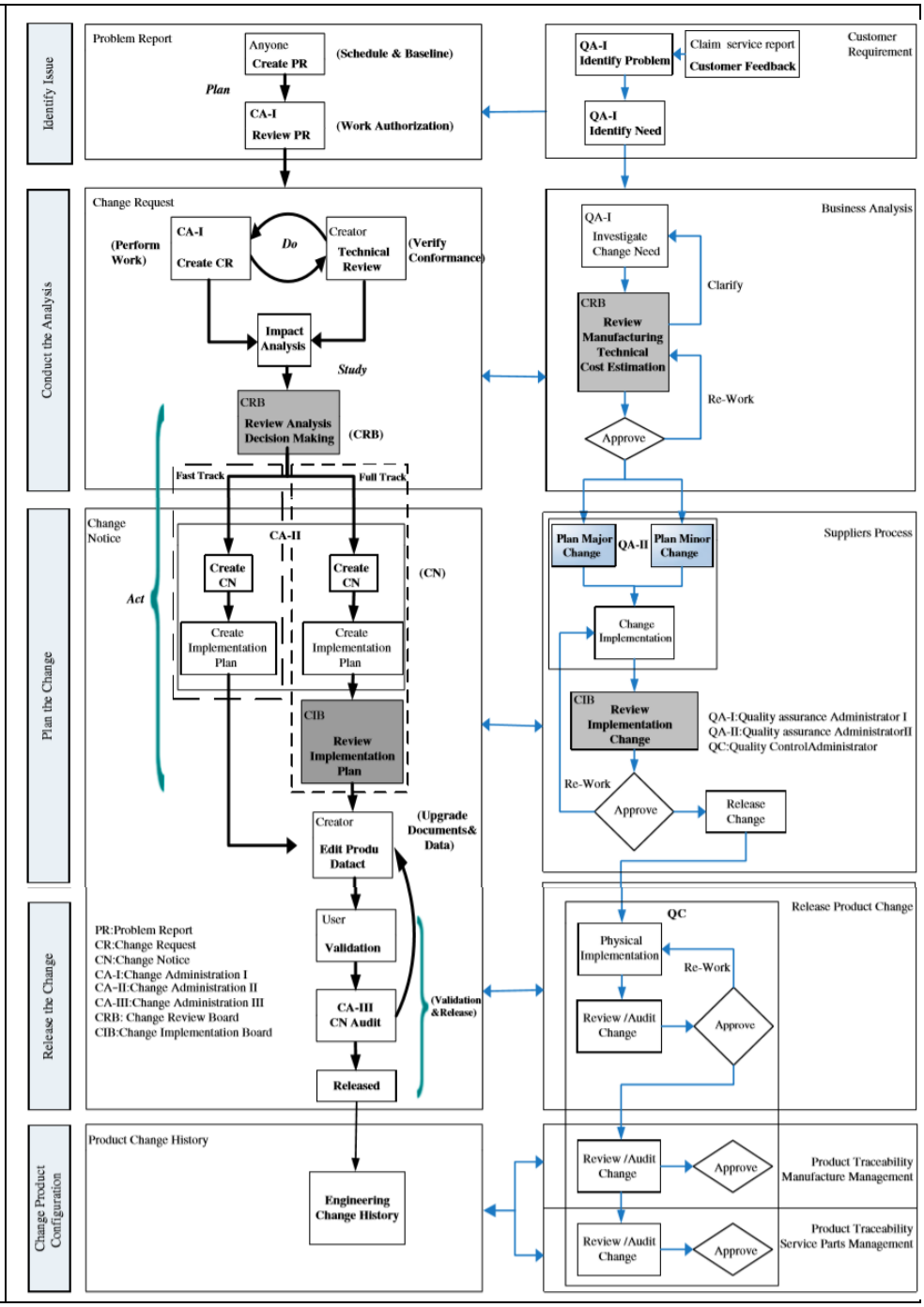
Wu et al (2014) proposes a CMII-based ECM Framework integrating PLM and ERP perspective to consider both design and manufacturing domains. Board 5 presents the main characteristics of Wu et al (2014) research.

Excellent proposal from Wu et al (2014), the framework detailed on Board 5 is a good guide for ECM process, however does not explore the financial and technical feasibility of the change, focusing on the impact analysis only. For mature environment on managing ECM, this step may be disregarded by the assumption that all changes need to be executed, however for the most part of companies the amount of change request is superior than resource available and a feasibility analysis to identify champions requests is essential for ensuring profitability.

Board 5 - Wu et al (2014) study characteristics

Advanced CMII-based ECM framework	 Engineering Change Management (ECM) Phases / Design Activities / Manufacturing Activities Identify the Issue — Problem Report — Customer Requirement Conduct the Analysis — Engineering Change Request — Business Analysis Planning the Change — Engineering Change Notice — Supplier Process Release the Change — Validation/Audit/Release — Release Product Change Change Product Configuration — Engineering Change History — Product Traceability

Board 5 - Wu et al (2014) study characteristics (cont.)

Detailed view - Advanced CMII-based ECM framework	

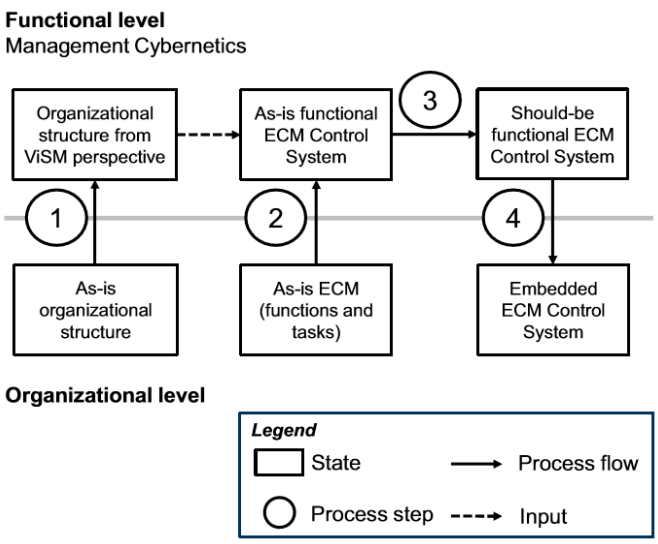
Source: Wu et al (2014)

2.6.4Wilberg et al (2015)

Wilberg et al (2015) presents a systematic approach based on a viable system model to overcome challenges on ECM. The proposal is to use four steps to derive a functional ECM

control system by mapping the “as-is” situation and using a multi-domain-matrix to deploy the “should-be” process for ECM control through functional abstraction. Board 6 presents the main characteristics of Wilberg et al (2015).

Board 6 - Wilberg et al (2015) study characteristics

Approach for organizational implementation of ECM	

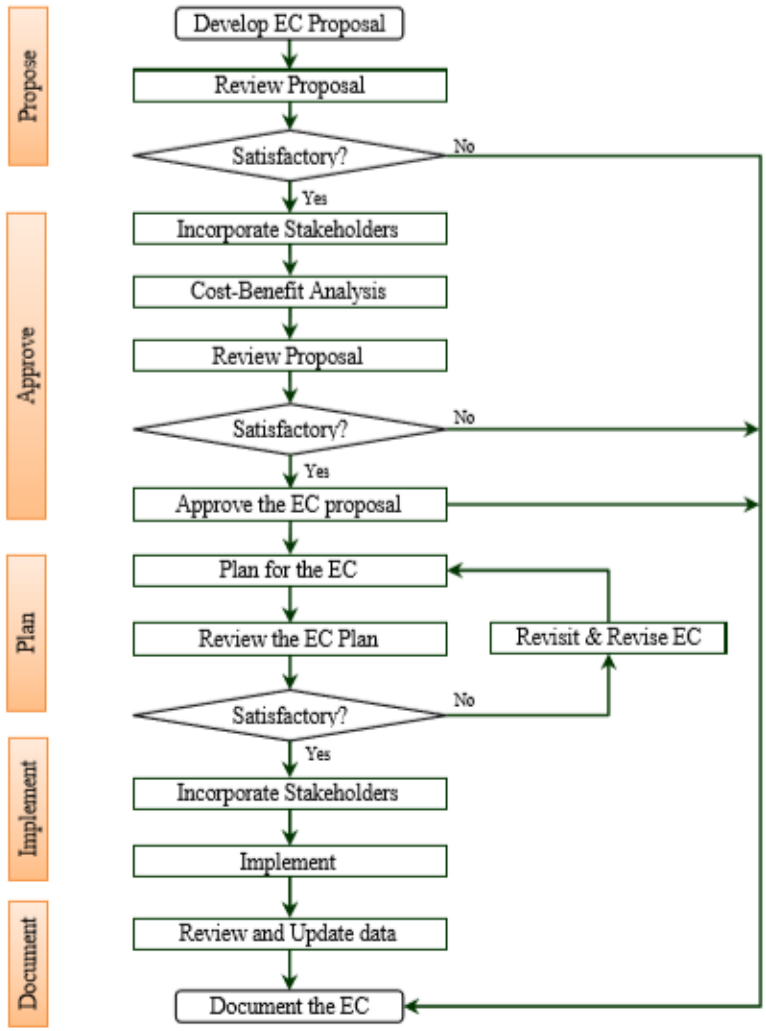
Source: Wilberg et al (2015)

On Board 6, it’s possible to note the use of very modern concepts such as multi-domain-matrix and viable system model, however when applied on a study case the proposal from Wilberg et al (2015) was evaluated as difficult to understand.

2.6.5Mutingi, Mbohwa & Mapfaira (2015)

Mutingi, Mbohwa & Mapfaira (2015) proposes an ECM framework based on critical success factors identified by the research as major contributors to project success. The study incorporates those factors to a generic ECM framework to be useful for organizations intending to implement engineering change projects. Board 7 presents the framework proposed by Mutingi, Mbohwa & Mapfaira (2015).

Board 7 - Mutingi, Mbohwa & Mapfaira (2015) proposed framework

Proposed ECM Framework	

Source: Mutingi, Mbohwa & Mapfaira (2015)

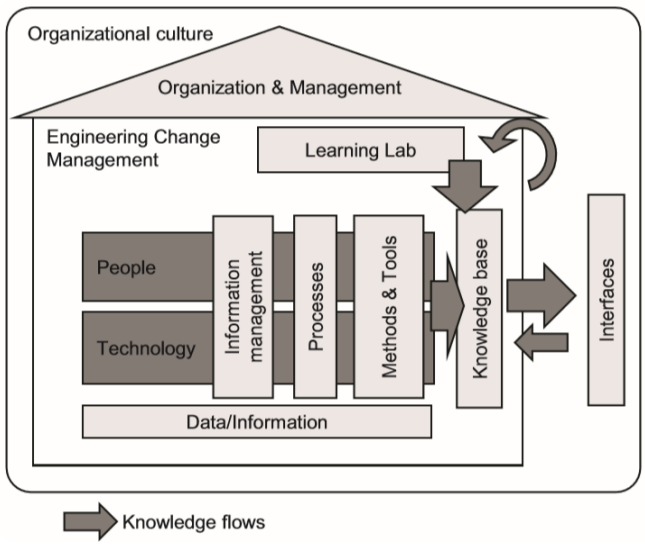
On Board 7, the proposed framework includes success factor but despite that, Mutingi, Mbohwa & Mapfaira (2015) proposal is a generalized framework. The impact propagation analysis and not relevant impact evaluation are not clearly mentioned on the study.

2.6.6Hollauer, Wickel & Lindemann (2014)

Hollauer, Wickel & Lindemann (2014) presents a learning-oriented ECM framework consisting on building blocks derived from concepts presented on ECM literature. The framework contains two conceptual layers and interlocking components to address individual

aspects. The goal is to use the framework as guideline for identifying potentials for impromevement. Board 8 presents the Hollauer, Wickel & Lindemann (2014) framework overview.

Board 8 - Hollauer, Wickel & Lindemann (2014) framework overview

Framework overview	

Source: Hollauer, Wickel & Lindemann (2014)

On Board 8, Hollauer, Wickel & Lindemann (2014) framework is focused on managerial aspect of ECM bringing valuable concepts from the ECM literature, but lack of practical use since the study next steps would be to submit the proposal for practical evaluation.

2.6.7Huhtala, Lohtander & Varis (2014)

Huhtala, Lohtander & Varis (2014) proposes an approach to avoid engineering changes through product data management and design for manufacturing and assembly. From Huhtala, Lohtander & Varis (2014) study perspective if the company is using a fully implemented product data management system, no changes would occur during manufacturing stage and if even though a change is necessary, with design for manufacturing and assembly this change wouldn´t compromise the rest of the product.

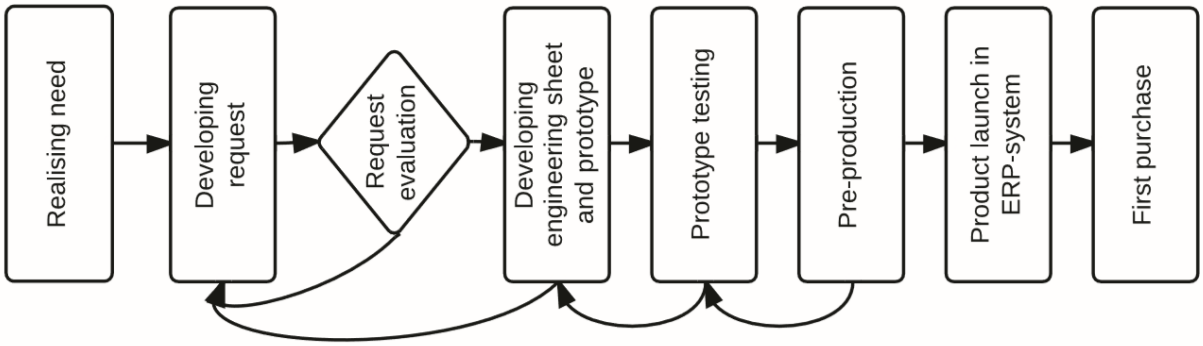
The main focus of the research is not to present a framework or methodology but to reinforce why proper data management can support product development and avoid further engineering changes.

2.6.8Sommer, Dukovska-Popovska & Steger-Jensen (2013)

Sommer, Dukovska-Popovska & Steger-Jensen (2013) proposes an integrated process model for customer-driven product development by unifying ECM and collaborative product development. The result is a centralized process to manage from small changes to development of entirely new products and the case study was conducted on technology-intensive mass-production company. Board 9 presents the Sommer, Dukovska-Popovska & Steger-Jensen (2013) proposed integrated process model.

Board 9 - Sommer, Dukovska-Popovska & Steger-Jensen (2013) proposed integrated process model

Proposed integrated process model for customer-driven product development



Source: Sommer, Dukovska-Popovska & Steger-Jensen (2013)

From Board 9 it´s possible to note that the main contribution from the proposal is the perspective that new product requests may be solved through changes on existing products while a change request may be so complex that is not a change anymore and characterizes the development of a new product. For companies that divide the NPD team and ECM team into two different areas, the transition between them may be significantly easier with an integrated process model for customer-driven product development.

2.6.9Yu et al (2013)

Yu et al (2013) proposes to strengthen the assessment of the different types of design changes and an evaluation whether the engineering change should happen or not in order to promote a better control of ECM at small and medium enterprises.

The study suggest to maintain standard ECM process for small and medium enterprises but to focus on proper evaluate change need and impact on multiple areas of the company by adopting different approval levels for different types of change, using a table of contents to assess the change attractiveness from different areas and creating a rating to define if the change should be executed or not. Board 10 presents the main contribution from Yu et al (2013).

Board 10 – Main contribution from Yu et al (2013)

Table I – Comparison of approval authority of different types of change

Compare content	Minor change	General change	Major change
Change Request	Change sector workers	Change sector competent	Project Manager
Change approval	Change sector competent	General manager	General manager and sector competent
Change assessment	Change sector competent	Project manager	General manager and sector competent
Change release	Change sector competent	Project manager	General manager

Table II – The contents of design change review

The indicators and contents of design change review	
The review indicators of meeting customer needs and making customer satisfied	1、Compare the technical specifications of materials, products and processes with customer needs expressed in the product specifications
	2、Validate the design through experimental prototype (sample)
	3、The ability to work in the intended use and environmental conditions
	4、Unintended use and misuse
	5、Safety and environmental compatibility
	6、Compared with competitive design
	7、Meet regulatory requirements, national and international standards and organizational practices
	8、Compared with similar design ,analyzing the problems that occur both within and outside organization in the past, in order to prevent the problem from happening again
The review indicators about product specifications	1、Reliability and durability requirements
	2、Tolerance and comparison of process capability
	3、The criteria of product acceptance
	4、Installation, Easy assembly, Storage requirements, Shelf life, Disposability
	5、Benign failures and failure safety features
	6、Aesthetic norms and acceptance criteria
	7、The ability of diagnose and correcting problem
	8、Failure mode and effects analysis
	9、Label, precautions, identification, traceability requirements and instructions for use
	10、The extent of standardization, serialization, universalization
The review indicators about process specifications	1、The products meet the ability of design, including special process requirements, mechanization and automation, parts assembly and installation
	2、Inspection and laboratory capabilities of design, including special testing and experimental requirements
	3、Specification of materials, parts and components, including approved supplies and supplier availability
	4、The requirements of packaging, handling, storage and shelf life, especially safety factors relating goods out and in

Board 10 – Main contribution from Yu et al (2013) (cont.)

Table III – The nine proportional scale table

x_i to x_j	Extremely important	Highly important	Obviously important	Slightly important	Equally important
Quantized value	9	7	5	3	1

Table IV – The rating Criteria Table

Rating interval	1-3	4-6	7-9
Judgment standard	Discard change	Improve change	Implement change

Source: Yu et al (2013)

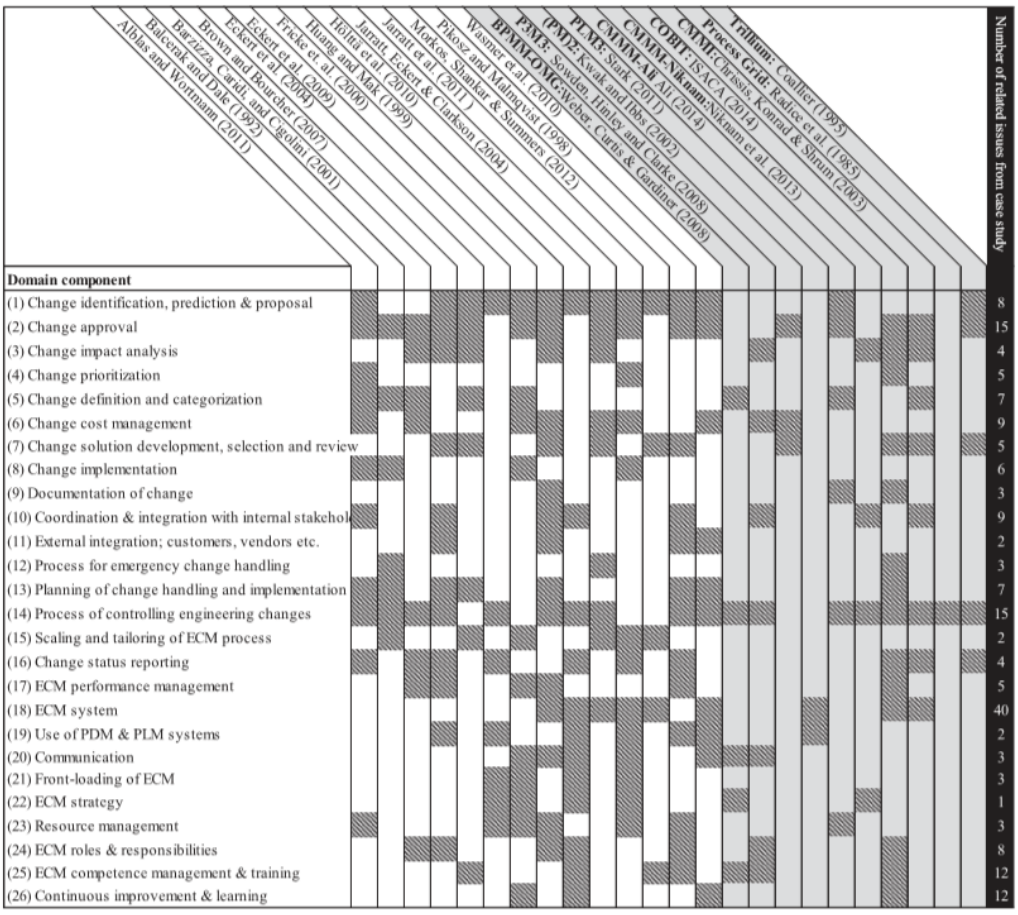
Despite focusing on small and medium enterprises, Yu et al (2013) proposal illustrated on Board 10 presents good methodology to manage the evaluation of need and multiple areas involvement on engineering change. It can not be considered a full ECM framework because it focus only on two aspects because they are the most relevant to small and medium enterprises.

2.6.10Storbjerg et al (2013)

Storbjerg et al (2013) focused on challenges with the handling of changes and solutions to a more efficient handling in order to clarify the areas that an organization needs to develop its capabilities within in order to ensure an efficient change handling. The result is the definition of 27 capability areas within 8 overall areas all relating to the handling of changes. Board 11 presents the framework with the capability areas and overall areas from Storbjerg et al (2013).

Storbjerg et al (2013) despite a good review of existing literature for challenges on handling changes as illustrated on Board 11, doesn´t propose a guidance on how to improve the ECM performance or how to use the areas defined as essential to contribute on ECM process.

Board 11 – Framework: capability areas and overall areas from Storbjerg et al (2013)

Overview of literature analyzed & ECM Capability framework	

Source: Storbjerg et al (2013)

2.6.11Obidallah et al (2013)

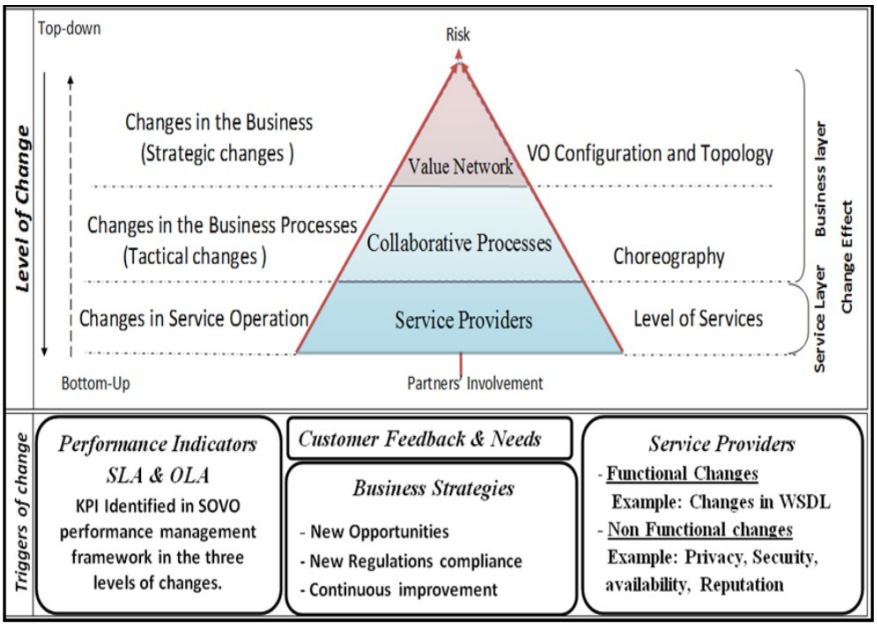
Obidallah et al (2013) proposes a framework that provides a supporting methodology to guide Virtual Organization's participants in the process of change management to increase the flexibility, agility, competitive advantage and the value added to their services. Board 12 presents the structural framework and the procedural framework adopted by Obidallah et al (2013).

In Obidallah et al (2013), the structural framework from Board 12 identifies the levels of changes and the triggers of changes in Service Oriented Virtual Organization while the

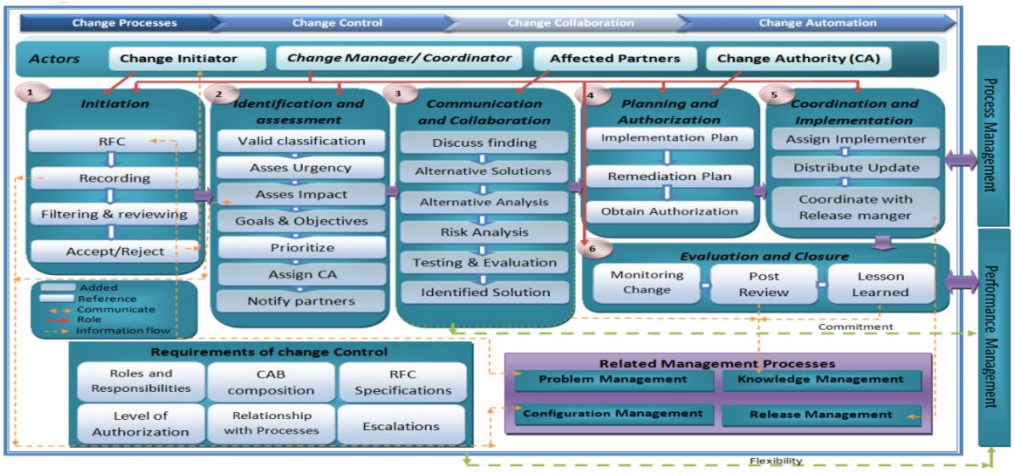
procedural framework identifies the change processes, controls, methods and partners change collaboration. All the study is focused on Service Oriented Virtual Organization.

Board 12 - Structural framework and procedural framework from Obidallah et al (2013)

Structural Framework



Procedural Framework



Source: from Obidallah et al (2013)

2.6.12Elezi, Maier & Lindemann (2013)

Elezi, Maier & Lindemann (2013) proposes cybernetic support to ECM by adopting a holistic approach that would enable communication, coordination, control and deal with unpredictability through flexibility to react on influences. The main goal is to explain a

theoretical background to present Viable System Model as alternative to manage engineering change. Board 13 presents the Elezi, Maier & Lindemann (2013) main topics discussed on the study.

Board 13 - Elezi, Maier & Lindemann (2013) main discussion topics

Study structure	I. Introduction II. Theoretical Background A. The Engineering Change Management process B. Challenges within Engineering Change Management C. Short introduction of Management Cybernetics D. Cybernetic support to Engineering Change Management III. Discussion

Source: Author adapted from Sommer Elezi, Maier & Lindemann (2013)

Elezi, Maier & Lindemann (2013) idea detailed on Board 13 was later adopted and explored by Wilberg et al (2015) with a more practical approach.

2.7ECM STATE OF THE ART METHODS AND TOOLS COMPARISON

Considering the methods and tools proposed as state of the art, a comparison between them is necessary to evaluate whether one of them can be considered a complete ECM framework. This comparison is described on Board 14.

Board 14 – ECM state of the art comparison

Author	Proposal	Strength	Weakness
Shivankar, Kakandikar & Nandedkar (2015)	Nine-step change management process composed of two main sub-processes (change request and change implementation) and uses the PDCA (plan-do-check-act)	Clear overall approach on ECM process management with valuable guide of items that should be included in the change implementation plan	Focus the step-by-step on the shopfloor management which makes it good only as complementary material to support the change process

Board 14 – ECM state of the art comparison (cont.)

Author	Proposal	Strength	Weakness
Stekolschik (2016)	ECM approach based on change complexity with generic business process from change initiation until change implementation at production	Complexity approach is a relevant characteristic of the research	Proposal does not monitor impacts after implementation and relies upon IT systems and tools that may not be available for all companies
Wu et al (2014)	CMII-based ECM Framework integrating PLM and ERP perspective to consider both design and manufacturing	Good proposal CMII-based with focus on impact analysis	Framework does not explore the financial and technical feasibility of the change
Wilberg et al (2015)	Systematic approach based on a viable system model using four steps to derive a functional ECM control system with a multi-domain-matrix	Use of very modern concepts such as multidomain-matrix and viable system model	Difficult to understand
Mutingi, Mbohwa & Mapfaira (2015)	ECM framework based on critical success factors identified by the research as major contributors to project success	Success factor approach	Generalized framework that don´t clearly mention impact propagation and homologation
Hollauer, Wickel & Lindemann (2014)	Learning-oriented ECM framework consisting on building blocks derived from concepts presented on ECM literature	Focus on managerial aspect of ECM bringing valuable concepts from the ECM literature	Proposal not submitted to practical evaluation
Huhtala, Lohtander & Varis (2014)	Approach to avoid engineering changes through product data management and design for manufacturing and assembly	Conclusion that strong data management is essential on any ECM process and may avoid unnecessary changes related to incorrect documentation	Opposite to studies that focus on improving ECM, this research focus on avoiding changes

Board 14 – ECM state of the art comparison (cont.)

Author	Proposal	Strength	Weakness
Sommer, Dukovska-Popovska & Steger-Jensen (2013)	Integrated process model for customer-driven product development by unifying ECM and collaborative product development	Synergy between NPD and ECM	Study does not present a detailed guide for managing engineering change
Yu et al (2013)	Better control of ECM at small and medium enterprises by strengthen the assessment of the different types of design changes and an evaluation whether the EC should happen or not	Good methodology to manage the evaluation of need and multiple areas involvement on engineering change	Only applied to small/medium companies
Storbjerg et al (2013)	Challenges with the handling of changes and solutions to a more efficient handling	Good review of existing literature for challenges on handling changes	Proposal is not a guidance on how to improve the ECM performance
Obidallah et al (2013)	Framework that provides a supporting methodology to guide Virtual Organization's participants in the process of change management	Good results for Virtual organization segment	All the study is focused on Service Oriented Virtual Organization
Elezi, Maier & Lindemann (2013)	Cybernetic support to ECM by adopting a holistic approach to enable communication, coordination, control and deal with unpredictability through flexibility to react	Theoretical background on challenges within ECM	Very complex concept related to cybernetics to support ECM and is very theoretical without any practical guidance

Source: Author (2019)

Considering strengths and weaknesses of the 12 proposals selected as state of the art for ECM, despite good references, none of them have a complete ECM process framework to guide change management properly as the one proposed by this research.

3METHOD

3.1METHODOLOGICAL PROCEDURES

3.1.1RESEARCH CHARACTERIZATION AND QUESTIONS

This study aims to develop a framework for Engineering Change Management with practical implementation support through templates for products with multiple parts and sub-system assembly produced as high volume at a small-time rate and it´s characteristics are detailed on Board 15.

Board 15 - Research characteristics

Item	**Characteristic**	**Research**
Nature	Applied	Generate knowledge about Engineering Change Management and to solve the specific gap on product development due to lack of a framework with practical implementation support through templates for products with multiple parts and sub-system assembly produced as high volume at a small-time rate.
Goal	Exploratory	Bibliometric analysis and systematic review on ECM current researches and methodologies as well as the analysis of example to stimulate comprehension through the application of proposed framework on commercial drinking fountain and interview with people that has practical experiences such as ECM experienced professionals and researchers to evaluate the application of proposed framework.
Approach	Qualitative	The dynamics between the framework for ECM and its understandability and applicability cannot be translated into numbers, this characteristic will be evaluated through the analysis and feedback from ECM experienced professionals and researchers. Besides that the dynamics do not require statistics analysis since it feedback will be evaluated individually as contribution for improvement
Method	Hypothetic-deductive	Research questions identified for each specific goal as described in detail on Board 16.

Board 15 - Research characteristics (cont.)

Item	Characteristic	Research
Data collection	Non-probabilistic and intentional	Samples chosen among the population to represent a good judgment for the research topic on all 3 major moments of data collection: bibliometric analysis with systematic review, research in loco for ECM cases and feedback from ECM experienced professionals and researchers
Research instruments	Observation and questionnaire	During bibliometric analysis with systematic review and research in loco for ECM cases the observation with researcher as key-instrument to analysis is considered. For feedback from ECM experienced professionals and researcher's questionnaire is the instrument.
Technical procedure	Case study	Exhaustive and deep analysis about Engineering Change Management in order to allow its wide and detailed knowledge to present a framework with practical implementation support through templates for products with multiple parts and sub-system assembly produced as high volume at a small-time rate simulated on a commercial drinking fountain case.

Source: Author (2019)

Considering the research characteristic of hypothetic-deductive, the research problems and hypothesis are presented on Board 16.

Board 16 - Research questions

ID	Problem	Hypothesis
I	Are there main relevant documents to compose a theoretical referential on ECM control study?	Main relevant documents to compose a theoretical referential on ECM control study can be identified through a bibliometric analysis and a systematic review
II	Which are the main ECM characteristics for products with multiple parts and sub-system assembly?	In loco research can identify main ECM characteristics for products with multiple parts and sub-system assembly.
III	Which is the base for the best framework for ECM?	The best framework for ECM is based on current available academical knowledge associated to market best practices and professional applicability

Board 16 - Research questions (cont.)

ID	Problem	Hypothesis
IV	How to verify the ECM framework applicability?	Simulating the framework application on a commercial drinking fountain will verify the framework applicability
V	How to evaluate ECM framework?	Application results for proposed framework can be evaluated with ECM experienced professionals and researchers
VI	How to improve the ECM framework to get the best possible framework?	The best possible framework is the one based on academic knowledge associated with market best practices and professional applicability and improved by feedback from ECM experienced professionals and researchers

Source: Author (2019)

The hypothesis will be deployed into more details in further chapters and will be supported by the data collection.

3.1.2DATA COLLECTION INSTRUMENTS

As mentioned in item 3.1, the data collection may be divided into 3 major moments and for all of them the samples are non-probabilistic and intentional.

For the bibliometric analysis and systematic review, the Scopus base will be used to select documents related to Engineering Change Management and relevant to compose a theoretical referential for developing a framework for ECM with practical implementation support through templates for products with multiple parts and sub-system assembly produced as high volume at a small-time rate. In this case, the instrument is observation and analysis performed according described in Chapter 3.

For the research in loco for ECM cases, a company manufacturing product with multiple parts and sub-system assembly was selected and the changes performed within a five-

year period were evaluated to identify main ECM characteristics. In this case, the instrument is also observation and analysis performed according described in item 3.1.2.

For the feedback from ECM experienced professionals and researchers, the data collection instrument used is a questionnaire with a series of orderly questions to be answered considering the objective of receiving feedback regarding the proposed framework to promote improvements. Detailed steps about the questionnaire are discussed in item 5.4 and APPENDIX C.

3.1.3METHODOLOGY COMPOSITION AND VALIDATION

In order to compose the research and evaluate the hypothesis, the list of variables is presented on Board 17.

Board 17 - Research Methods and Variables

ID	Hypothesis	Method	Variables
I	Main relevant documents to compose a theoretical referential on ECM control study can be identified through a bibliometric analysis and a systematic review	Bibliometric analysis and a systematic review	List of main relevant documents to compose a theoretical referential on ECM control study
II	In loco research can identify main ECM characteristics for a product with multiple parts and sub-system assembly.	In loco research	ECM Characteristics -Change Origins -Possible problems -Strategy to cope
III	The best framework for ECM is based on current available academic knowledge associated with market best practices and professional applicability	Observation and proposal	ECM framework
IV	Simulating the framework application on a commercial drinking fountain will verify the framework applicability	Simulation	ECM framework applied to a commercial drinking fountain
V	Application results for proposed framework can be evaluated with ECM experienced professionals and researchers	Questionnaire	Feedback from ECM experienced professionals and researchers

Board 17 - Research Methods and Variables (cont.)

VI	The best possible framework is the one based on academic knowledge associated with market best practices and professional applicability and improved by feedback from ECM experienced professionals and researchers	Observation and proposal	ECM framework improved version

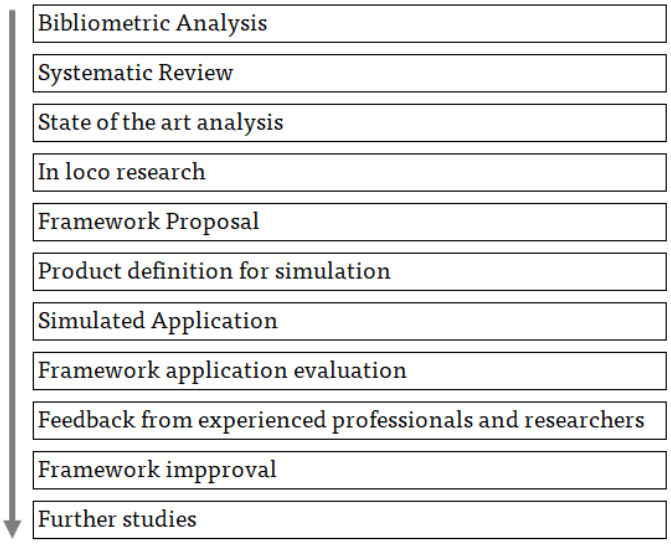
Source: Author (2019)

These variables will lead to the final version of the framework and the conclusion of the research.

3.2RESEARCH SUMMARY PROCESS

To answer the research hypothesis and present the variables, the flow described on Figure 10 presents the summary process of the study.

Figure 10 – Research summary process



Source: Author (2019)

This process represents the study and lead to the conclusion of the research.

3.3BIBLIOMETRIC ANALYSIS

3.3.1Methodology

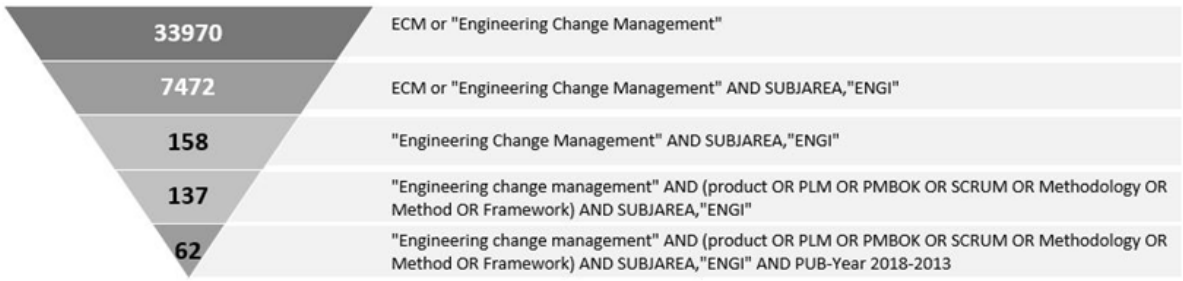
In order to identify the list of main relevant documents to compose a theoretical referential on ECM control study, a bibliometric analysis was conducted using a method comparable to Jonkers & Derrick (2012).

In the first moment, Scopus was defined as research base considering publications until March 31st, 2018. Later the title, abstract and keywords were considered to locate bibliometric publications. The topic search started from a large scope and was narrowed according to research objectives. With a five-step structure described on APPENDIX A it was possible to identify appropriate search string and resulted on 62 documents to be evaluated.

3.3.2 Results and discussion

Using the five-step structure described on APPENDIX A, the initial 33970 documents were narrowed to 62 aligned with research purpose as detailed on Figure 11.

Figure 11 - Summary of methodology use for Bibliometric Analysis



Source: author based on Scopus data from March 31, 2018 (2019)

Figure 11 describes the strings used to narrow the generic results for ECM from Scopus on March 31st, 2018 to get to the final string with 62 documents to support this study.

These 62 documents were evaluated according their characteristics for document type, year distribution, main publisher and country, main authors, main sources, keywords and keywords combination described on APPENDIX A.

These analyses indicate that despite increase interest on ECM within engineering research , there is still a gap in structured studies, most part of knowledge is centralized on few

institutions and need a worldwide spread. Besides that, there is a strong correlation between "Engineering Change Management (ECM) and Product Lifecycle Management (PLM)" that can be explored on future studies.

3.4SYSTEMATIC REVIEW

3.4.1Methodology

After the bibliometric analysis, a systematic review was conducted to evaluate the content of publication in order to identify the group highly relevant for developing a method for better control of Engineering Change Management. In this phase, the 62 documents resulted from bibliometric analysis were read in full.

The documents were classified based on three focus and sixteen core themes as illustrated in Board 18.

Board 18 - Focus and Core theme used to classify bibliometric analysis documents

Focus	**Description**	**Core theme**
System	Documents related to change propagation simulation through computer system, system development to support change feasibility calculation and computer alternatives to improve Engineering Change Management record and control	Change feasibility Change Propagation ECM Control
Method	Documents that review Engineering Change Management research, evaluate expanding application of Engineering Change Management literature to other change control or propose methods and frameworks to control or analyze changes cause and feasibility	Change during project development Change feasibility Change management ECM analysis ECM control MCM, Review
Out of scope	Documents not directly related to Engineering Change Management or duplicated	IoT, ERP PLM , 3D-CAD Conference review Duplicated

Source: Author (2019)

The core themes from Board 18 were defined based on documents content according to author's classification to make easier the evaluation process. The results will be presented in next session.

3.4.2Results and discussion

Considering the methodology described in item 3.4.1 the main contributions for 62 documents identified on the bibliometric analysis are listed on Board 19, Board 20 and Board 21.

Board 19 - Main contribution split within the themes – System

SYSTEM		
Core theme	**Author**	**Main Contribution**
Change feasibility	Hesselmann et al (2017)	Micro-meso-macro coordination architecture to represent and reconcile opposing interest and conflicting requirements on changes
Change Propagation	Eltaief, Louhichi & Remy (2018)	CAD management model for change propagation impact analysis
Change Propagation	Hein, Voris & Morkos (2018)	Identification of requirements most relevant for change propagation impact analysis
Change Propagation	Masmoudi et al (2017b)	Novel classification of ECM methods according dependency model
Change Propagation	Yin et al (2017)	Method to acquire product changes automatically and evaluate design change propagation
Change Propagation	Lee & Hong (2017)	Use of Bayesian Network to model and analyze change propagation
Change Propagation	Masmoudi et al (2017a)	Two steps method to predict approach for changes in two dimensional geometrical product model
Change Propagation	Kattner et al (2017)	Model that combine a matrix-based approach of modeling interrelations with knowledge of expert to identify change propagation
Change Propagation	Lee & Hong (2015)	Use of Bayesian Network to model and analyze change propagation
Change Propagation	Masmoudi et al (2015)	Approach to map dependency links among components of products

Board 19 - Main contribution split within the themes – System (cont.)

Core theme	Author	Main Contribution
Change Propagation	Mahmoud et al (2017)	Regression analysis to identify type of dependencies between two dimensions
Change Propagation	Hamraz et al (2015)	FBS Linkage Method for modeling and analyzing engineering changes
Change Propagation	Reddi & Moon (2013)	Interaction between new product development and ECM
Change Propagation	Hamraz et al (2013a)	Enhanced change prediction method incorporating interface information
ECM control	Yan (2016)	System to solve asynchronism between product data management and quality systems in case of changes
ECM control	Hamraz & Clarkson (2015)	FBS Linkage Method for modeling and analyzing engineering changes
ECM control	Sonzini, Vegetti & Leone (2015)	Ontology to capture product changes
ECM control	Do (2015)	Product data management database to support engineering change analysis
ECM control	Ganesan (2015)	Database to prioritize, select and manage scope and resources for cost reduction and value improving ideas
ECM control	Sriram, Alfnes & Kristoffersen (2014)	IT based collaborative decision support framework
ECM control	Hamraz et al (2013b)	Enhanced ECM method based on change prediction management

Source: author based on Scopus data from March 31, 2018 (2019)

Board 20 - Main contribution split within the themes – Method

METHOD		
Core theme	**Author**	**Main Contribution**
Change during project development	Schuh et al (2017)	Framework for adaptive ECM to enable agile product development
Change during project development	Kattner, Wang & Lindemann (2016)	Performance metrics in ECM
Change during project development	Han, Lee & Nyamsuren (2015)	Model to capture design changes and share with stakeholders during product development

Board 20 - Main contribution split within the themes – Method (cont.)

Core theme	Author	Main Contribution
Change during project development	Alblas & Jayaram (2015)	Categorization of design resilience in relation to organizational resilience
Change during project development	Wickel, Behncke & Udo (2013)	Approach to support determination of optimal checkpoints to detect deviation during product development
Change feasibility	Rebentisch et al (2017)	Multilayer network model to identify most cost-effective solution in cases of change request
Change feasibility	Gebhardt (2017)	Model for predicting indirect process cost in ECM based on a task characteristic perspective
Change feasibility	Gebhardt, Schmied & Mörtl (2016)	Model for predicting indirect process cost in ECM
Change feasibility	Kurdve et al (2016)	Evaluation of manufacturing impact in cases of changes
Change feasibility	Bueno & Borsato (2014a)	Decision-making support method for identifying opportunities for product improvement
Change management	Stekolschik (2016)	Framework for controlling engineering changes at mechanical engineering companies
Change management	Wilberg et al (2015)	Approach based on Viable System Model to improve the as-is ECM
Change management	Mutingi, Mbohwa & Mapfaira (2015)	ECM framework based on critical success factors
Change management	Wu et al (2014)	Advanced CMII-based ECM framework
Change management	Sommer, Dukovska-Popovska & Steger-Jensen (2013)	Process model for customer-driven product development
Change management	YU et al (2013)	Model for ECM at small and medium-sized companies
Change management	Storbjerg et al (2013)	ECM capability framework
Change management	Obidallah et al (2013)	Framework and methodology to manage changes in virtual organizations
ECM analysis	Kattner & Lindemann (2017)	Procedure to support project management in investigating ECM
ECM analysis	Jokinen, Vainio & Pulkkinen (2017)	Reasons for engineering change requests to vary processing times
ECM analysis	Grieco, Pacella & Blaco (2017)	Self Organizing Map to clustering text of engineering requests

Board 20 - Main contribution split within the themes – Method (cont.)

Core theme	**Author**	**Main Contribution**
ECM analysis	Storbjerg, Brunoe & Nielsen (2016)	Maturity framework to guide improvement on ECM and critical success factors for efficient ECM
ECM analysis	Kukulies, Falk & Schmitt (2016)	Approach for improving inspection planning and controls based on engineering changes lessons learned
ECM analysis	Subrahmanian et al (2015)	Support system to reduce cognitive load of design engineer in case of changes
ECM analysis	Wickel & Lindemann (2014)	Indicators to sign best engineering change strategy based on past data
ECM control	Shivankar, Kakandikar & Nandedkar (2015)	ECM process to communicate through all supply chain
ECM control	Hollauer, Wickel & Lindemann (2014)	Framework to manage and cultivate knowledge from ECM
ECM control	Huhtala, Lohtander & Varis (2014)	Technique to handle engineering change using product data management system
ECM control	Elezi, Maier & Lindemann (2013)	Systematic approach to coordinate communication in ECM
MCM	Koch, Gritsch & Reinhart (2016)	Design of Manufacturing Change Management based on ECM concepts
MCM	Koch, Michels & Reinhart (2016)	Context model for a process-oriented Manufacturing Change Management
Review	Serapelo, Erasmus & Pretorius (2017)	ECM Systematic review listing frameworks available
Review	Karthik & Reddy (2013)	Overview about ECM and its implication in product design
Review	Ullah, Tang & Yin (2016)	Systematic review highlighting methods and tools proposed by previous researches

Source: author based on Scopus data from March 31, 2018 (2019)

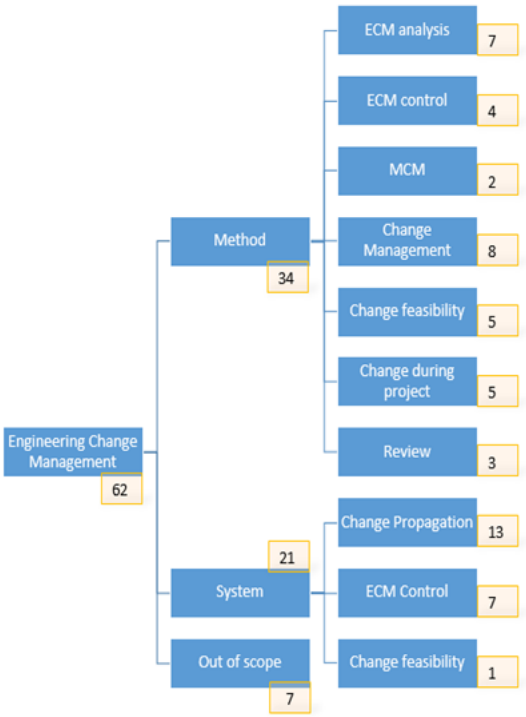
Board 21 - Main contribution split within the themes - Out of scope

OUT OF SCOPE		
Core theme	**Author**	**Main Contribution**
IoT	Zdravković et al (2017)	List of scientific disciplines to support resolution for IoT implementation problems
ERP	Comuzzi & Parhizkar (2017)	Methodology to identify impact on enterprise systems in cases of changes on enterprise resource planning systems
PLM	Bricogne et al (2014)	Collaborative PLM platform
3D-CAD	Brière-Côté, Rivest & Maranzana (2013)	Evaluation trials upon commercially available 3D-CAD model comparison tools
Conference review	CMSM (2017)	Conference review
Conference review	IOP (2016)	Conference review
Duplicated	Bueno & Borsato (2014b)	Repeated with Bueno & Borsato (2014a) but presented at different conference

Source: author based on Scopus data from March 31, 2018 (2019)

The main contribution from Board 19, Board 20 and Board 21 was defined based on documents content according to authors understanding. The results are consolidated on Figure 12.

Figure 12 - Documents distribution according to main focus and core themes



Source: author based on Scopus data from March 31, 2018 (2019)

In Figure 12, the quantities for each focus and core theme can be identified highlighting that “Method” is the focus with more document while “Change Propagation’ is the core theme more numerous.

Considering this research goal detailed on Chapter 1 to develop a framework for ECM, the documents with “Method” focus are more adherent to compose a theoretical referential. However, only this would reduce the study to 34 documents that is still very numerous.

Therefore the core theme from “Method” needs to be evaluated and considering the ECM framework needs to cover both the NPD and MOL phases from PLM as described as gap in Chapter 2, the core theme “MCM”, “Change feasibility” and “Change during project” were excluded as base for theoretical referential because they consider only part of the scope. The “Review” was also excluded because despite informative, they don´t contain substantial proposal to serve as reference and “ECM Analysis” documents focus on improving how a company relates to ECM instead of describing a process to manage engineering change and was also considered not relevant for the main goal of this research.

For this reason, better adherence to the theme may be identified within the 12 documents from Method focus with core theme change management and ECM control. List of these articles is presented on Board 22.

Board 22 - List of main relevant documents to compose a theoretical referential on ECM control study

Title	**Year**	**Focus**	**Core Theme**
Engineering Change Management Method Framework in Mechanical Engineering	2016	Method	Change management
Supporting the Implementation of Engineering Change Management with the Viable System Model	2015	Method	Change management
An alternative framework for managing engineering change	2015	Method	Change management
Implementing engineering change management through product life cycle management in automotive field	2015	Method	ECM control
An advanced CMII-based engineering change management framework: The integration of PLM and ERP perspectives	2014	Method	Change management
Learning from past changes-Towards a learning-oriented engineering change management	2014	Method	ECM control

Board 22 - List of main relevant documents to compose a theoretical referential on ECM control study (cont.)

Title	Year	Focus	Core Theme
Product data management systems as a tool in engineering change management	2014	Method	ECM control
Activity-based process model for customer-driven product development	2013	Method	Change management
Study on design change review for small and medium-sized enterprises	2013	Method	Change management
Development of an engineering change management capability framework for enterprise transformation	2013	Method	Change management
Service oriented virtual organizations: A service change management perspective	2013	Method	Change management
Engineering change management challenges and management cybernetics	2013	Method	ECM control

Source: author based on Scopus data from March 31, 2018 (2019)

With these articles from Board 22 resulted from a bibliometric analysis followed by a systematic review described in item 3.1.2 it's possible to compose a theoretical referential on ECM control study using highly relevant documents for the theme. Those 12 documents are described in Chapter 2 after the in loco research results from item 3.5.

3.5IN LOCO RESEARCH

3.5.1Methodology

For in loco research, a large manufacturing company from the refrigeration sector was evaluated. It was considered changes performed from 2013 to 2016 on Brazil manufacturing site for a product segment with more than 80 building components, 7 product families and about 15 Million units produced by year.

The change origins were classified considering the motive described on the request for the change and the possible problems were extracted from a lessons learned section in the change implementation report. The lessons learned section is where project managers describe reasons for change project delays and difficulties faced during execution.

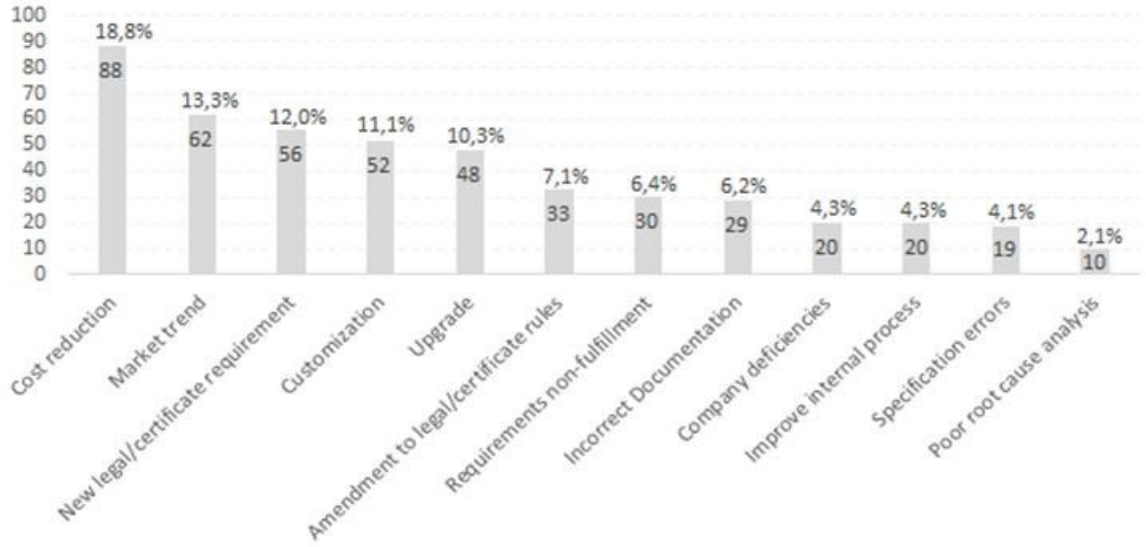
After that, the origins were consolidated into 5 major reasons and confronted with strategies to cope with changes proposed by Fricke et al (2000) and adopted by Kattner & Lindemann (2017) as described on item 2.3.

Besides that, the possible problems were classified according the ECM phases with results presented on item 3.5.2.

3.5.2Results and discussion

During the period from 2013-2016 on a manufacturing site were 476 performed changes on the selected product segment from refrigeration sector and the changes origins are illustrated on Graphic 1.

Graphic 1 - Changes origins distribution: Product segment from refrigeration sector



Source: author based on company 2013-2016 database for changes executed (2019)

In Graphic 1 it is identified that major change origins are distributed among 12 sources for the product segment selected for in loco research. These origins can be consolidated into 5 major reasons as illustrated on Board 23 and confronting them with strategies to cope described in item 2.3 it's possible to define the best strategy for each major reason detailed on Board 24.

Board 23 - Engineering Change Origins: Five Major reasons

Major reason	**Origin description (with examples)**
Mistakes	• Incorrect documentation (CAD data, report, technical document); • Specification errors (material, tolerance chain, software code); • Requirements non-fulfillment (performance, safety, quality, manufacturability, maintainability).
Legislation/ Certification	• New legal/certificate requirement in force (environmental, security, performance level); • Amendment on existing legal/certificate requirement (change on approval criteria, inclusion of requirements);
Customer driven	• Customization (shape, color, accessories, features); • Market trend (new location, new public, window of opportunity on events and celebrating dates);
Internal process	• Upgrade (improve technology, performance, quality, safety); • Improve Manufacturability, Maintainability and Transport; • Cost reduction (new supplier, new part design, change material).
Not product related	• Company deficiencies on business process (logistics failures, machinery break, bad process capability); • Poor root cause analysis - failure without cause identification

Source: Author (2019)

Board 24 - Strategy to cope with engineering change based on its origins

Origin	**Strategy**	**Justification**
Mistakes	Front-loading	Mistakes are part of human nature, but to earlier detect and monitor potential risks of mistake reduces the impact of the change
Legislation/ Certification	Efficiency	Legislation/Certification changes are inevitable and the faster and leaner execution the better.
Customer driven	Effectiveness	Customization and market trend changes are financially beneficial for the company, therefore properly identify the best business cases and implement them makes a company more profitable
Internal process	Effectiveness	Encourage internal driven changes and identify cost reduction or loss avoidance opportunities also makes a company more profitable
Not product related	Prevention	Change design because of a not product related cause is not beneficial for the company and need to be reduced.

Source: Author (2019)

Considering the total amount of 467 changes evaluated in this in loco research, 18 didn't have a change implementation report and on 55 cases the lessons learned section was blank and no information was provided. For this reason, the possible problem evaluation considers 394 results distributed as Table 1.

Table 1 - Possible problem during ECM execution

Problem	**Qty**	**Percentage**
Incomplete change documentation	61	15,5%
Failure on resource availability constraints evaluation	58	14,7%
Poor phase in/out planning	48	12,2%
Unnecessary change request	47	11,9%
Insufficient design propagation identification	40	10,2%
Incorrect identification of need	39	9,9%
Failure on identifying all impacted stakeholders	38	9,6%
Failure on change conflict identification	34	8,6%
Not proper evaluate impacts after implementation	29	7,4%
TOTAL	394	100,0%

Source: author based on company 2013-2016 database for changes executed (2019)

After the identification of possible problems in Table 1, the classification of those possible problems according to phase for the ECM process together with the inclusion of possible consequences of the problem result on Board 25.

Board 25 - Possible problems during ECM process

ECM Process	**Possible problem**	**Consequence**
Identify engineering change need	Incorrect identification of need	Implemented change will not solve root cause
	Unnecessary change request	Unnecessary costs (development, prototype, tests, documentation changes etc)

Board 25 - Possible problems during ECM process (cont.)

ECM Process	Possible problem	Consequence
Evaluate technical and financial feasibility for the change	Failure on resource availability constraints evaluation	Delays on other projects from portfolio
	Failure on change conflict identification	Change overlapping without impact propagation analysis
Evaluate impact propagation for the change	Insufficient design propagation identification	Product quality problems (performance decrease, scrap increase etc)
	Failure on identifying all impacted stakeholders	Supply chain issues, customer complaints, legal problems etc
Implement the change	Poor phase-in/out planning	Wasted inventory and supply disruption
	Incomplete change documentation	Future change required to proper document
Audit the change to ensure Not relevant impacts	Not proper evaluate impacts after implementation	Product quality problems not identified (performance decrease, scrap increase etc)

Source - Author (2019)

The results from Board 25 allows the identification of main ECM characteristics for a product with multiple parts and sub-system assembly produced as high volume at a small-time rate and at which stage of ECM process flow they are concentrated. Besides that, the strategy to cope with each problem origin and its possible consequences are good input for developing this research framework.

3.6METHOD CONCLUSION

The data evaluated on bibliometric analysis and systematic review evidence that despite its great importance as competitive advantage for companies because it is the alternative to become more flexible and satisfy customer needs, ECM is not very representative in terms of number of researches.

The publications focusing ECM only increased during the past 18 years and the studies are still concentrated on few publishers and countries.

The systematic review performed in the 62 documents from the bibliometric analysis and illustrated on Figure 12, indicate that:

- 34% of evaluated documents relate to change propagation simulation through computer system, system development to support change feasibility calculation and computer alternatives to improve Engineering Change Management record and control. This group was considered as System focus.
- 55% of evaluated documents concentrate on reviewing Engineering Change Management research, evaluate expanding application of Engineering Change Management literature to other change control or propose methods and frameworks to control or analyze changes cause and feasibility. This group was considered as Method focus.
- 11% of evaluated documents were not directly related to Engineering Change Management or were duplicated. This group was considered Out of Scope.

Narrowing the 34 documents that represents the 55% with Method focus, considering core theme “change management” and “ECM control” it was possible to identify 12 publications as the main relevant documents to compose a theoretical referential on ECM control study. Those documents are detailed on Chapter 2.

Besides that, a strong relation between ECM and PLM was shown by the keywords analysis and considering the increasing interest in PLM on the company's side, there is a good perspective for developing further studies on ECM.

To finalize, considering in loco research, despite majority of changes origins requests that benefits the company such as Customer Driven (24%) and Internal process improvement (33%), a considerable amount of resource is invested on matching to Legislation/Certification (19%) or wasted on Mistakes (17%) and Not product related changes (6%).

Besides that, most part of problems happens during change implementation stage (27,7%), evaluation of technical and financial feasibility (23,3%) and identification of engineering change need (21,8%). Even though the evaluation of impact propagation (19,8%) and audit to ensure Not relevant impacts (7,4%) can’t be disregard.

These results reinforce the need of a proper engineering change management method to drive company toward better use of resources.

4PROPOSED FRAMEWORK

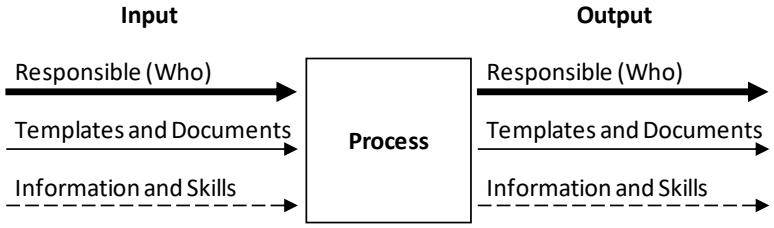
4.1INITIAL CONSIDERATIONS

Considering the theoretical knowledge from the documents regarding ECM control study identified with bibliometric analysis and systematic review combined with main ECM characteristics and problems resulted from the in loco research on a product with multiple parts and sub-system assembly produced as high volume at a small-time rate, this research framework was developed.

CMII naming convention was considered as described on item 2.4 in order to keep the proposed framework aligned with market best practices and standard reference.

For process modeling, a standard input/output process description was adopted considering the definitions shown on Figure 13.

Figure 13 - Process Modeling definitions

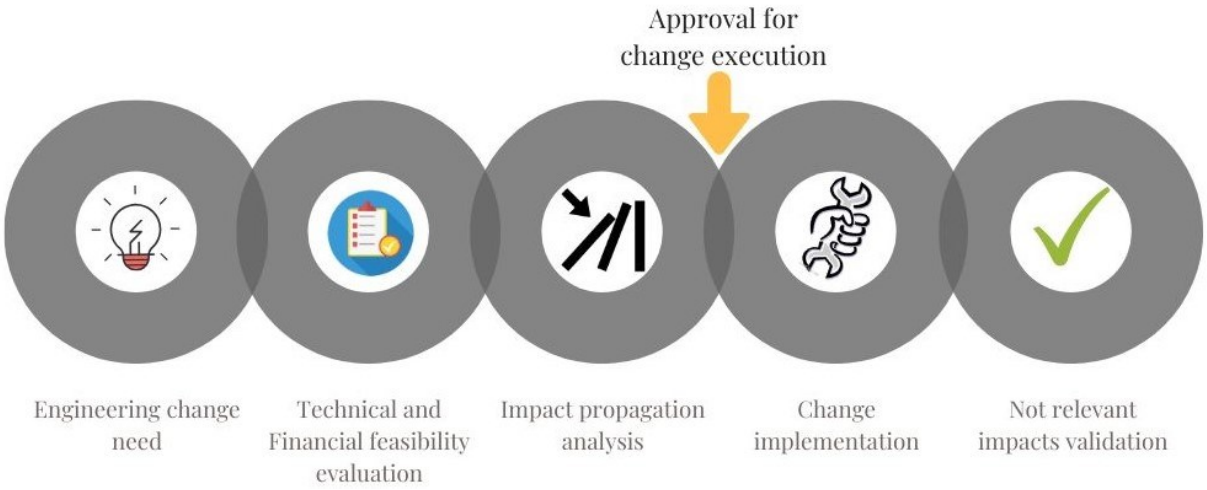


Source - Author (2019)

Besides that, considering the ECM process illustrated on Figure 7 and the results from in loco research from item 3.5 it´s possible to present Figure 14 with the framework ECM process.

On the process illustrated in Figure 14, the engineering change need is the first stage and the request can come from a variety of origins but all of them will require a technical and feasibility analysis. If its implementation demonstrates to be attractive and beneficial, the propagation impact analysis considering all stakeholders (design, manufacturing, supply chain, supplier, customer, technical support etc) is performed and approved to be implemented. Each company may define specifics standards for approval and implementation but the execution will proceed and in the end, validate that no unexpected impacts occurred is essential to consider the change process finished.

Figure 14 – Framework ECM process flow



Source: Author (2019)

The framework will be presented based on ECM process flow steps illustrated in Figure 14 and requires company to have defined previous process that will support the ECM framework.

The company needs to have product development process on at least Maturity Level 1 proposed by CANGELIR & KARADEMIR (2013) with product structure and minimum information regarding quality, testing and configuration management.

The product must have a Bill of Materials (BOM) divided into subsystems, a correlation matrix for each part impacting on subsystems need to be available, a supplier list for each part and a customer list for each product is mandatory. Besides that, the map where the product is manufactured, list of certified institutes for each product and definition for High/Medium/Low impact adopted by the company is also required.

The company needs to have established criteria for prototype, test, production and homologation certification requirement for product, process, supplier and customer. Also is mandatory to define the technical difficulty definition levels.

The company also must have a clear list of major quality issues on product, process, supplier and customer. It's necessary to have the product functional modeling and primary / secondary function matrix for each part as well as acceptable parameters for variation on tolerance, weight and raw material quantity.

Is required from the company to define acceptable scores for Business Case and Technical Score, clear rules of what to consider Fast Track or Full track and the score ranges for priorities high, medium and low.

With all those requirement met, the company will be able to use the templates from the framework ant to apply the steps detailed on item 3.4.

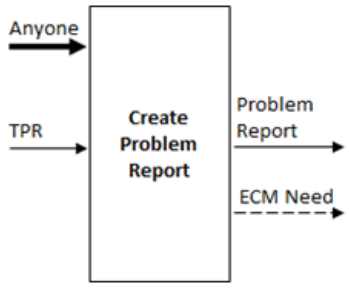
4.2PROPOSED FRAMEWORK CHARACTERIZATION

4.2.1Engineering Change Need

The incorrect identification of need and to perform unnecessary changes were the main problems associated with identify change need phase according to the in loco research results illustrated on Board 25. For this reason, a template to facilitate the identification and reasons to perform the change is essential on an ECM framework and is proposed in this study as Problem Report.

For this reason, the first step to manage engineering change is creating a Problem Report as illustrated on Figure 15.

Figure 15 - Engineering Change Need steps



Source: Author (2019)

On Figure 15 it´s possible to identify that anyone in the company can create the problem report using the TPR (Template for Problem Report) described in APPENDIX B and the result of the information will be the ECM need properly identified and the Problem Report as a document to start the engineering change.

This step concludes the “Engineering Change Need” phase and the next stage on the ECM flow as illustrated on Figure 14 is the “Technical and Financial feasibility evaluation”.

4.2.2Technical and Financial feasibility evaluation

In order to ensure proper resource availability constraints evaluation, which is one of the problems associated to evaluate technical and financial feasibility according to the in loco research illustrated on Board 25, the company needs to execute changes with financial benefit for the business and be aware about the proper technical challenge to execute it.

Focusing on executing the changes with good cost benefit will decrease the resource availability constraints. Gebhardt, Schmied & Mörtl (2016) highlights the importance of proper identifying change costs and how this is being neglected for most ECM process. Therefore, the first step in this stage is to evaluate the problem report for feasibility analysis.

In this step, the problem report with proper ECM need identification is necessary but also the Change Admin I (CAI) for Feasibility with specified skill to evaluate if the problem report contains all necessary information to allow the identification of technical challenges to execute the change. The CAI for Feasibility evaluates if the proposed change is technically feasible and move to the next step to create the business case.

The TBC (Template for Business Case) described on APPENDIX B contains all information related to cost and financial benefits from the change and once the TBC is completed, the financial feasibility analysis is done and the CAI for Feasibility can fill the TCR (Template for Change Request) also described in APPENDIX B to consolidate the business case and the level of technical difficult and risk associated with the change in order to create the Change Request. At any point of this process, in case the evaluation is not positive, the change request is not created, the problem report is closed, and the problem report requester must be informed.

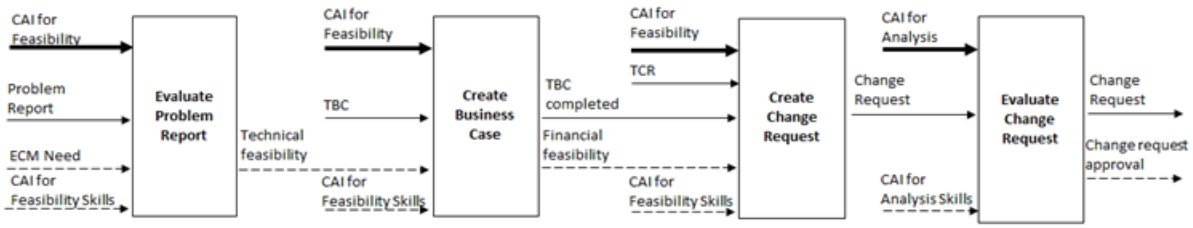
To be capable of performing the technical and financial feasibility analysis, the CAI for Feasibility need to have product and costs knowledge as well as analysis skills. Besides that, the CAI for Feasibility needs to have access to all projects and changes in progress in order to be able to identify if the proposed change have any conflict or overlap with activity being executed on the company.

With the change request created, the CAI for Analysis evaluates the change request to identify if it contains all necessary data to allow the proper impact propagation analysis. If positive, the change request is approved and if negative, the change request is sent for CAI for

Feasibility review. If review doesn't add information to the change request, then it is closed and the problem report requester is informed. The CAI for Analysis needs to have a deep product knowledge and impact propagation analysis skills.

The overall flow for Technical and Financial feasibility evaluation is illustrated on Figure 16.

Figure 16 - Technical and Financial feasibility evaluation steps



Source: Author (2019)

In Figure 16, all the steps are illustrated with the templates and responsibilities from CAI for Feasibility and CAI for Analysis. The flow completes the steps when the change request is approved. The next stage on the ECM flow illustrated on Figure 14 is the "Impact propagation analysis".

4.2.3Impact propagation analysis

The two major problems identified by the in loco research illustrated on Board 25 on regarding impact propagation analysis is insufficient design propagation identification and failure in identifying all impacted stakeholders.

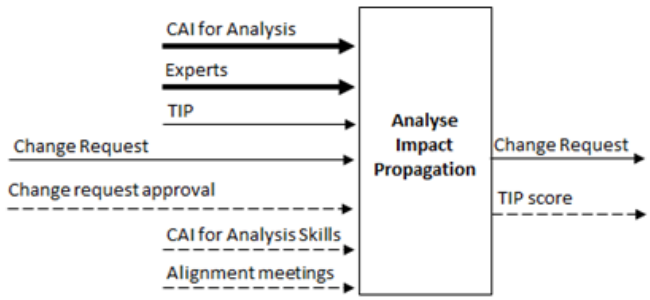
Aiming to prevent those issues, besides the change request, to analyze the impact propagation is necessary that the CAI for Analysis fills the TIP (Template for Impact Propagation) detailed on APPENDIX B and perform alignment meetings with stakeholders and impact propagation specialists.

Impact propagation analysis is one of ECM topics with larger amount of studies. Lee & Hong (2017) presents a bayesian network approach, Eltaief, Louhichi & Remy (2018) presents a CAD management model, Masmoudi et al (2017a) presents a two steps method to predict approach for changes in two dimensional geometrical product model and many others could be mentioned.

Since this framework focus on the engineering change management as a process the details on how to execute the impact propagation analysis will not be considered but to execute it is an important step to ensure change will neither negatively impact the product nor have significant effect over company quality and image.

For the purpose of this research it´s defined that the impact propagation analysis is completed and after that the CAI for Analysis includes on the change request the TIP score to allow approval steps to forward. The Figure 17 presents the summary of the flow for impact propagation analysis.

Figure 17 - Impact propagation analysis steps



Source: Author (2019)

After analyzing the impact propagation, the “Impact propagation analysis” phase is concluded and the next stage in the ECM flow illustrated in Figure 14 is the “Change Implementation”.

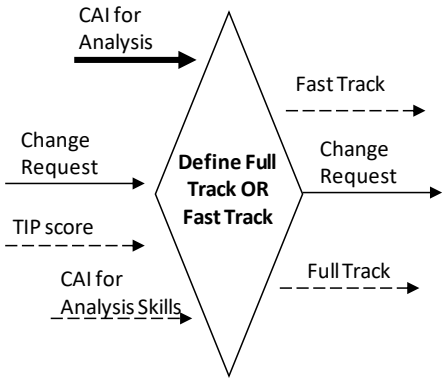
4.2.4Change Implementation

Considering the impact propagation analysis is completed and the TIP score is defined, the CAI for Analysis must define the flow for the Change Notice between Fast Track (for less complex changes that don’t require board approvals for implementation plan and execution) or Full Track (complex changes with high impact that requires board’s approval for implementation plan and execution). The company can maintain a pre-established rule based on TIP score to facilitate this definition.

The decision for Fast Track or Full Track is illustrated on Figure 18 and the main inputs are the change request, the TIP score and the CAI for Analysis with proper skills.

For Fast track implementation, the Project Management Office (PMO) need to fill the TPFast (Template for Prioritization on Fast Track) described on APPENDIX B in order to prioritize the implementation of the change request. The TPFast score allows the proper identification of the best cases to be executed by the company.

Figure 18 - Change Implementation: Approval for change execution steps



Source: Author (2019)

When the change request is the next to be executed, the PMO fills the TCN (Template for Change notice) described in APPENDIX B, creates the change notice and assigns it to a Change Admin II (CAII) for execution. The PMO skills required for this process are portfolio management, prioritization knowledge and alignment with company directives.

The CAII needs to define an implementation plan for the Change Notice using the TCP (Template for Change Plan) described in APPENDIX B and once it is completed, follows the company process for implementing the changes required.

After all changes are executed, the CAII have to fill the TCA (Template for Change Audit) described on APPENDIX B indicating all the changes performed, the result of the phase-in/out phase, and the list of documents updated during the change process. This document is very important to prevent incomplete change documentation and poor phase-in/out.

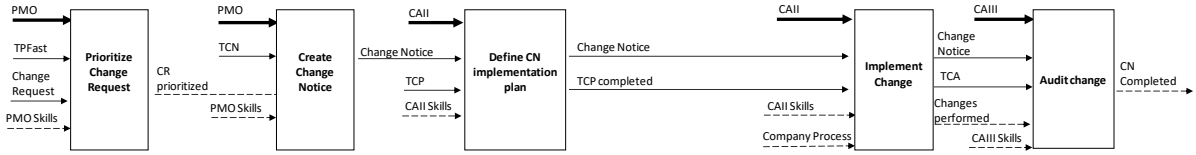
The CAII skills required are project management skills and knowledge about company's project management process and documentation standards.

With the TCA included on the change notice, the Change Admin III (CAIII) is assigned and is responsible for auditing the TCA and the change notice to ensure all changes were executed according company's standards and complete the change notice. When the change notice is completed, all changes executed are released into company document management system.

The CAIII skills required are audit and management skills and knowledge about company's project management process and documentation standards to validate changes executed by CAII.

The flow for Fast Track is illustrated on Figure 19 with the inputs and outputs from each process.

Figure 19 - Change Implementation: Fast Track steps



Source: Author (2019)

For Full track implementation, the process is similar to the Fast Track with the difference that due to change complexity, there are steps that require board approvals.

To prioritize the change, a Change Review Board (CRB) composed by a multidisciplinary team with product and company's supply chain knowledge evaluates the TPFull (Template for Prioritization on Full Track) detailed on APPENDIX B and the TPFull score allows the proper identification of the best cases to be executed by the company.

When the change request is the next to be executed, similar to the Fast Track Process, the PMO fills the TCN, creates the change notice and assigns it to a Change Admin II (CAII) for execution. The PMO skills required for this process are the same as for Fast Track, and included portfolio management, prioritization knowledge and alignment with company directives.

The CAII needs to define an implementation plan for the Change Notice using the TCP and once it is completed, consolidate the TCP with other project information available on the change notice to create the TCPA (Template for Change Plan Approval) described on APPENDIX B and submit for approval.

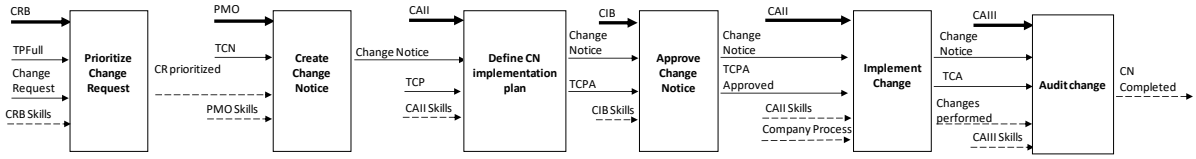
The Change Implementation Board (CIB) composed by a multidisciplinary team with product and company's supply chain knowledge evaluates the TCPA and if approved, the CAII follows the company process for implementing the changes required.

The change notice audit is the same process as for Fast Track. The CAII have to fill the TCA indicating all the changes performed, the result of the phase-in/out phase and the list of documents updated during the change process.

With the TCA included on the change notice, the Change Admin III (CAIII) is assigned and is responsible for auditing the TCA and the change notice to ensure all changes were executed according company's standards and complete the change notice. When the change notice is completed, all changes executed are released into company document management system.

Figure 20 describes the Full Track process and comparing to Figure 19 for Fast Track, the main differences are that for Full Track the CRB is responsible to prioritize the change and the extra step for approving the change notice with TCPA is included.

Figure 20 - Change Implementation: Full Track steps



Source: Author (2019)

The audit and release process concludes the "Change Implementation" phase and the next stage in the ECM flow illustrated on Figure 14 is the "Not relevant impacts validation".

4.2.5Not relevant impacts validation

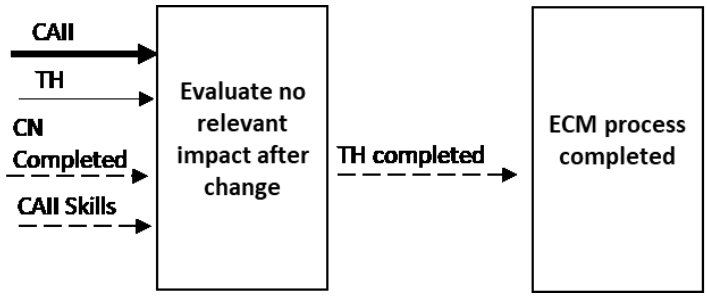
Not proper evaluate impacts after implementation is one of the problems identified during in loco research illustrated on Board 25. Besides that, Bueno & Borsato (2014a) clarifies the linkage between warranty database and ECM and highlights how ECM may have an impact on reliability and quality of the product in the field and being used by customer. To avoid any issue on this regard the not relevant impact validation is a very important phase on ECM framework proposed by this research.

After the CAII releases the Change Notice and all changes performed, the CAII need to fill the TH (Template for Homologation) described in APPENDIX B in order to plan which product characteristics will be followed-up and for how long to ensure not relevant impacts occured.

After the defined time, the product characteristics need to be evaluated to validate the not relevant impact after the change and with these results the TH is completed. If any impact is evidenced, a new problem report must be raised to correct these impacts.

On Figure 21 the process steps with inputs and outputs are illustrated and with TH completed, the ECM process finishes.

Figure 21 - Not relevant impacts validation steps



Source: Author (2019)

If no impact is evidenced, the ECM process is completed and the framework fulfilled its role of ensuring a good change management process.

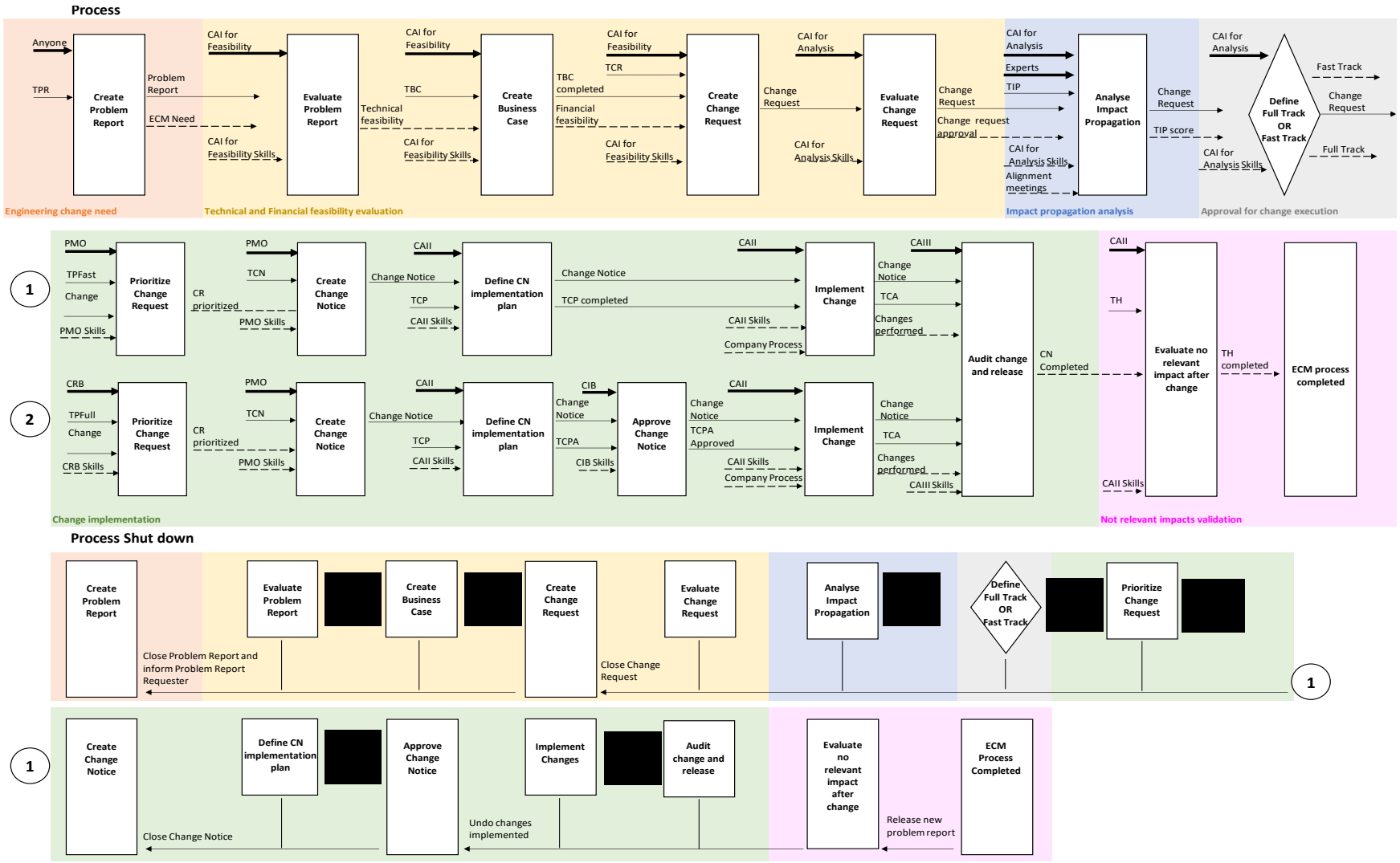
It is important to highlight that absence of impacts is never possible and even if the impact was not evidenced, it might have occurred. For this reason, the effort on previous steps is so important and risk management is a mitigating alternative.

4.3PROPOSED FRAMEWORK

Consolidating all processes from ECM flow illustrated on Figure 14 and detailed on session 6.2 into a continuous sequence of activities, the proposed framework is illustrated in Figure 22.

On Figure 22 all process with input and output are illustrated considering both alternatives of Fast Track and Full Track. It´s important to highlight that in case the flow requires the process to be interrupted because is not attractive to the company to implement the change, the process shut down steps should be followed to ensure documents created until that moment in the process are correctly closed.

Figure 22 - Proposed Framework



Source: Author (2019)

The templates to support the framework are described in APPENDIX B and applied on simulated case in Chapter 5. With these templates the framework may be applied in full on all process steps.

4.4PROPOSED FRAMEWORK ANALYSIS

Considering the proposed framework illustrated by Figure 22 and complemented by the templates in APPENDIX B, a full solution to the ECM process flow in Figure 14 is illustrated and in order to evaluate its maturity level according Storbjerg, Brunoe & Nielsen (2016) a detailed analysis is described on item 4.4.1.

4.4.1Maturity Level evaluation

Maturity grids, as described by Maier et al (2012), are used to assess and develop organizational capabilities. Considering ECM Maturity Grid from Storbjerg, Brunoe & Nielsen (2016) from Figure 23, the framework proposed in this study covers all areas that are important for effective and efficient ECM process. The indication of how the research considers each aspect of the maturity grid is illustrated on Board 26.

Figure 23 - ECM Maturity Grid

		Maturity Levels					
		Level 1 - Initial	Level 2 - Repeatable	Level 3 - Defined	Level 4 - Managed	Level 5 - Optimized
Capability area	**Sub-capability area**						
(A) ECM process	(1) Change identification, prediction & proposal						
	(2) Change approval						
	(3) Change impact analysis						
	(4) Change prioritization						
	(5) Change definition and categorization						
	(6) Change cost management						
	(7) Change solution development, selection and review						
	(8) Change implementation						
	(9) Documentation of change						
	(10) Coordination & integration with internal stakeholders						
	(11) External integration; customers, vendors etc.						
	(12) Process for emergency change handling						
	(13) Planning of change handling and implementation						
	(14) Process of controlling engineering changes						
	(15) Scaling and tailoring of ECM process						
(B) Change monitoring	(16) Change status reporting						
	(17) ECM performance management						
(C) IT tools	(18) ECM system						
	(19) Use of PDM & PLM systems						
(D) Management & communication	(20) Communication						
	(21) Front-loading of ECM						
	(22) ECM strategy						
	(23) Resource management						
(E) People, skills & competencies	(24) ECM roles & responsibilities						
	(25) ECM competence management & training						
	(26) Continuous improvement & learning						

Source: Storbjerg, Brunoe & Nielsen (2016)

Board 26 - Description of how the Maturity Grid item is covered by proposed framework

ECM Maturity Grid		Description of item on proposed ECM framework
Capability Area	Sub-Capability Area	
(A) ECM Process	(1) Change identification, prediction & proposal	Process: Create Problem Report Template: TPR
	(2) Change approval	Approval board: CRB, CIB
	(3) Change impact analysis	Process: Analyze impact propagation Template: TIP
	(4) Change Prioritization	Process: Prioritize Change Request Template: TPFast, TPFull
	(5) Change definition and categorization	Process: Define Full track or Fast Track
	(6) Change cost management	Process: Create Business Case Template: TBC
	(7) Change solution development, selection and review	Process: Define CN implementation plan, Template: TCP, TCPA
	(8) Change implementation	Process: Implement change
	(9) Documentation of change	Process: Audit change and release Template: TCA
	(10) Coordination & integration with internal stakeholders	Template: TCN
	(11) External integration; customers, vendors etc.	Template: TCN
	(12) Process for emergency change handling	Process: Define Full Track or Fast Track
	(13) Planning of change handling and implementation	Process: Define CN implementation plan Template: TCP, TCPA
	(14) Process of controlling engineering change	Process: Audit Change Notice Template: TCA
	(15) Scaling and tailoring of ECM process	Template: TIP

Board 26 - Description of how the Maturity Grid item is covered by proposed framework (cont.)

(B) Change monitoring	(16) Change status reporting	Process: Create Problem Report, Create Change Request, Create Change Notice
	(17) ECM performance management	Process: Create Problem Report, Create Change Request, Create Change Notice
(C) IT tools	(18) ECM system	Not applicable - each company may define proper ECM system
	(19) Use of PDM & PLM systems	Not applicable - each company may define use of PDM & PLM softwares
(D) Management & communication	(20) Communication	Process: Create Problem Report, Create Change Request, Create Change Notice
	(21) Front-loading of ECM	Process: Create Problem Report, Create Change Request, Create Change Notice
	(22) ECM strategy	Process: Define CN implementation plan Template: TCP, TCPA
	(23) Resource management	Process: Prioritize change request Template: TPFast, TPFull
(E) People, skills & competencies	(24) ECM roles & responsibilities	Roles: CAI, CAII, CAIII, PMO
	(25) ECM competence management & training	Roles: CAI, CAII, CAIII, PMO
	(26) Continuous improvement & learning	Process: Evaluate not relevant impact after change Template: TH

Source: Author (2019)

As illustrated on Board 26, the framework covers all the items (apart from IT Tools that are not scope of this study) considered essential to a maturity evaluation and this is a very important aspect of the framework that would make possible for a company adopting it to assess its maturity level and continuously improve the management grid.

4.5CRITICAL SUCCESS FACTORS

To successfully obtain results with the study application, the company needs to be prepared for a cultural change in order to implement the proposed framework with maximum engagement from all involved people. Disturbance in the process flow may lead to undesirable results.

Besides that, the minimum requirement described for using the templates on item 4.1 is mandatory to fully use the framework process. They need to be previously developed by the company to use the framework.

To implement the framework proposed in this study, a strong sponsorship is required to ensure the procedures to be followed involving all impacted areas and stakeholders.

It's also important to highlight that this study was developed for a specific company type and may have limitations as described on the item 4.6.

4.6STUDY BOUNDARIES AND LIMITATIONS

The framework was developed to support companies with products with multiple parts and sub-system assembly produced high volume of similar product produced at a small-time rate products and therefore to extrapolate the results for multiple types of companies is not possible. The framework would require adjustments to be applied to different segments such as software development, made to order manufacturing and small sized production that are not part of the scope of this study.

The proposed framework application requires a list of previous documents from the company that are only feasible for companies with product development process on at least Maturity Level 1 proposed by CANGELIR & KARADEMIR (2013) in which the company has product structure and minimum information regarding quality, testing and configuration management. If the company don´t have these aspects will not be able to apply the process and the templates.

The in loco research to identify main ECM characteristics was conducted on a single manufacturing company and may not reproduce all possible characteristics for change origins on different products with multiple parts and sub-system assembly produced as high volume at a small-time rate. However, Bradford & Cullen (2013) highlights that document analysis is a very useful way of conducting research because offers access to data without requiring

investment of time on data collection and as long as they are treated critically they reflect broader debates about how to construct knowledge. Therefore, the in loco research can be considered a valuable information source for the study.

The validation from experienced ECM professionals and researches is also a limitation for the study because the feedback may reflect a specific point of view and distortions may occur due to incorrect response from both unconscious and intentional purpose. A careful selection of participants on the survey aims to mitigate this effect on the research.

4.7STUDY COMPARINSON TO STATE OF THE ART METHODS AND TOOLS

This research used multiple concepts proposed by previous authors such as the complexity approach from Stekolschik (2016) that lead to the Fast Track and Full Track alternatives, the CMII naming convention also adopted by Wu et al (2014) and the guide of items to be included on change implementation plan from Shivankar, Kakandikar & Nandedkar (2015) considered on TCP.

However it presents a complete framework that covers the weakness on state of the art proposals, such as impact propagation and not relevant impact validation that is not presented by Mutingi, Mbohwa & Mapfaira (2015) as well as the support templates to guide ECM that is missing on Sommer, Dukovska-Popovska & Steger-Jensen (2013) study.

For this reason, this research advances the knowledge on ECM and contributes with engineering field of studies.

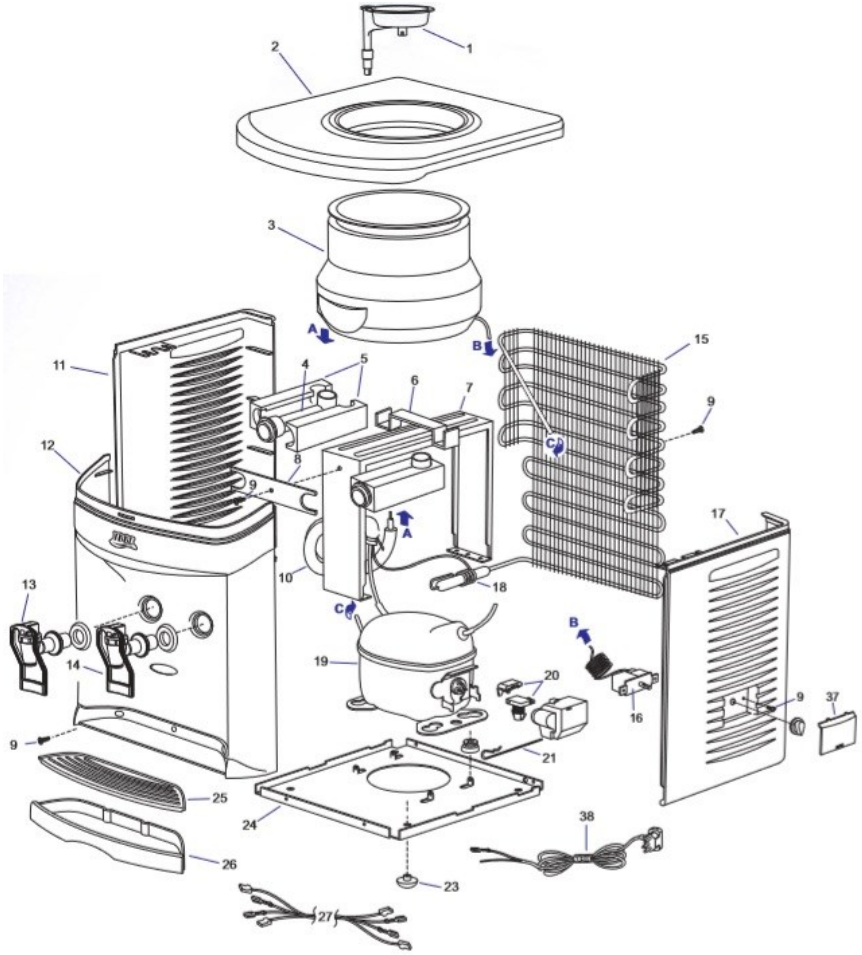
5FRAMEWORK APPLICATION

5.1SIMULATED APPLICATION PRESENTATION

5.1.1Product Description

The product defined to be used in simulating the framework application is a commercial drinking fountain from IBBL (Indústria Brasileira de Bebedouros Ltda) model Compact FN/PFN. All product characteristics were obtained in a product catalog available on company website IBBL – Loja online. The characteristics are illustrated on Figure 24 and Board 27.

Figure 24 - Drinking fountain exploded view



Source: Compact FN/PFN model catalog from IBBL (2019)

Board 27 - Drinking fountain components identification

1	Water funnel	11	Left side structure	21	Starting device cover and clamp
2	Cover	12	Front panel	23	Rubber foot
3	Plastic evaporator	13	Natural water tap	24	Compressor base
4	Long pipe	14	Cold water tap	25	Drip tray cover
5	Pipe insulation set	15	Static condenser	26	Drip tray
6	Pipe set support	16	Adjustable thermostat	27	Connecting cables
7	Evaporator support	17	Right side structure	37	Thermostat cover
8	Pipe positioner	18	Drying filter	38	Power cord
9	Zinc plated screw	19	Compressor		
10	Sponge hose	20	Compressor starting device		

Source: adapted by author from Compact FN/PFN model catalog from IBBL (2019)

Despite the product being a commercial product, all definitions regarding change management and the information for ECM framework application are simulations to support this study and were not directly provided by the company. Therefore, there are no industrial secrets or implications on distributing the information.

5.1.2Definitions to support ECM framework application

As described in Chapter 4, in order to apply the ECM templates there are some requirements that must be previously obtained by the company regarding its product and business.

The company needs to have product development process on at least Maturity Level 1 proposed by CANGELIR & KARADEMIR (2013) with product structure and minimum information regarding quality, testing and configuration management.

Since this is a simulation and data was not directly provided by the drinking fountain company, in order to be capable of applying the templates, the data illustrated in Table 2 to Table 10 and Figure 25 was created based on commercial available information for Compact FN/PFN model from IBBL and general standards for appliances manufacturing to support the framework use.

Table 2 illustrates the BOM created based on product catalog and considered for the simulated cases, on Table 3 is the correlation matrix for components from the BOM considering

appliances knowledge and on Table 4 the manufacturing map distribution example created based on general appliances manufacturing and considered for the Compact FN/PFN model from IBBL used as reference.

Table 2 – Compact FN/PFN model Bill of Material (BOM)

Material:	Drinking Fountain Compact FN/PFN model	**Basic qty:**	1 UN

Level	ID	Description	Qty	Unit
.1	**SET1**	**Structure**	**1**	**UN**
..2	2	Cover	1	UN
..2	17	Right side structure	1	UN
..2	37	Thermostat cover	1	UN
..2	11	Left side structure	1	UN
..2	12	Front panel	1	UN
..2	9	Zinc plated screw	2	UN
..2	25	Drip tray cover	1	UN
..2	26	Drip tray	1	UN
..2	24	Compressor base	1	UN
..2	23	Rubber foot	4	UN
.1	**SET2**	**Water transport**	**1**	**UN**
..2	1	Water funnel	1	UN
..2	3	Plastic evaporator	1	UN
..2	4	Long pipe	2	UN
..2	5	Pipe insulation set	2	UN
..2	6	Pipe set support	1	UN
..2	7	Evaporator support	1	UN
..2	8	Pipe positioner	1	UN
..2	9	Zinc plated screw	7	UN
..2	13	Natural water tap	1	UN
..2	14	Cold water tap	1	UN
.1	**SET3**	**Water cooler**	**1**	**UN**
..2	19	Compressor	1	UN
..2	20	Compressor starting device	1	UN
..2	21	Starting device cover and clamp	1	UN
..2	10	Sponge hose	1	UN
..2	18	Drying filter	1	UN
..2	15	Static condenser	1	UN
..2	16	Adjustable thermostat	1	UN
..2	9	Zinc plated screw	2	UN
.1	**SET4**	**Electrical connections**	**1**	**UN**
..2	27	Connecting cables	1	UN
..2	38	Power cord	1	UN
.1	**SET5**	**Transport**	**1**	**UN**
..2	-	Paper box	1	UN

Source: Author (2019)

Table 3– Compact FN/PFN model Correlation Matrix

ID	Component	Sub-systems				
		Structure	Water transport	Water cooler	Electrical connections	Transport
1	Water funnel	x	●	-	-	-
2	Cover	●	x	-	-	x
3	Plastic evaporator	x	●	x	x	-
4	Long pipe	x	●	x	-	-
5	Pipe insulation set	-	●	-	-	-
6	Pipe set support	-	●	-	-	-
7	Evaporator support	x	●	x	-	-
8	Pipe positioner	-	●	-	-	-
9	Zinc plated screw	●	●	●	-	-
10	Sponge hose	-	x	●	-	-
11	Left side structure	●	-	-	-	x
12	Front panel	●	x	-	-	x
13	Natural water tap	x	●	-	-	x
14	Cold water tap	x	●	-	-	x
15	Static condenser	x	x	●	x	x
16	Adjustable thermostat	x	x	●	x	-
17	Right side structure	●	-	x	x	x
18	Drying filter	-	-	●	-	-
19	Compressor	x	-	●	x	-
20	Compressor starting device	-	-	●	x	-
21	Starting device cover and clamp	-	-	●	x	-
23	Rubber foot	●	-	-	-	x
24	Compressor base	●	-	x	x	x
25	Drip tray cover	●	-	-	-	-
26	Drip tray	●	-	-	-	-
27	Connecting cables	-	x	x	●	-
37	Thermostat cover	●	-	-	-	-
38	Power cord	x	-	x	●	-
-	Paper box	-	-	-	-	●

Legend	
●	Member
x	Impact
-	No impact

Source: Author (2019)

Table 4 – Compact FN/PFN model Manufacturing Map

Material		Manufacturing map										
		Site1		Site2			Site3			Site4		Site5
		Assembly Line 1	Assembly Line 2	Assembly Line 3	Assembly Line 4	Assembly Line 5	Assembly Line 6	Assembly Line 7	Assembly Line 8	Assembly Line 9	Assembly Line 10	Assembly Line 11
Drinking Fountain	Compact FN/PFN model	x	x	-	-	x	-	-	-	x	-	x

Source: Author (2019)

In Table 5 a certification map for drinking fountain was created based on general certification information for drinking fountain to serve as an example for the simulated cases, in Table 6 a supplier matrix was defined based on material characteristic of the BOM items and in Table 7 a fictional customer list with annual purchase was estimated considering appliances market in Brazil to allow business case analysis on simulated cases.

Table 5 – Drinking fountain Certification map

			Drinking Fountain			
Certifying Institute	Certificate	Certification type	Compact FN/PFN model	Product2	Produc3	Product4
Institute1	Certificate1	Electrical Safety	x	x	-	x
Institute1	Certificate2	Mechanical Safety	x	x	x	x
Institute1	Certificate3	Impact Safety	x	x	x	x
Institute1	Certificate4	Heat Safety	-	-	x	x
Institute1	Certificate5	Overturning Safety	N/A	x	N/A	x
Institute2	Certificate6	Sanitary regulation	x	x	x	x
Institute2	Certificate7	Water filtering	x	x	N/A	x

Source: Author (2019)

Table 6 – Compact FN/PFN model Supplier Matrix

		Supplier list			
ID	Component	Supplier 1	Supplier 2	Supplier 3	Supplier 4
1	Water funnel	Plastic1	Plastic2	Plastic3	-
2	Cover	Plastic1	Plastic2	Plastic3	-
3	Plastic evaporator	Plastic1	Plastic2	Plastic3	-
4	Long pipe	Tube1	Tube2	Tube3	-
5	Pipe insulation set	Plastic1	Plastic2	Plastic3	-
6	Pipe set support	Metal1	Metal2	Metal3	Metal4
7	Evaporator support	Metal1	Metal2	Metal3	Metal4
8	Pipe positioner	Metal1	Metal2	Metal3	Metal4
9	Zinc plated screw	Screw1	Screw2	Screw3	Screw4
10	Sponge hose	Refrigeration1	Refrigeration2	-	-
11	Left side structure	Plastic1	Plastic2	Plastic3	-
12	Front panel	Plastic1	Plastic2	Plastic3	-
13	Natural water tap	Plastic1	Plastic2	Plastic3	-
14	Cold water tap	Plastic1	Plastic2	Plastic3	-
15	Static condenser	Refrigeration1	Refrigeration2	-	-
16	Adjustable thermostat	Refrigeration1	Refrigeration2	-	-
17	Right side structure	Plastic1	Plastic2	Plastic3	-
18	Drying filter	Refrigeration1	Refrigeration2	-	-
19	Compressor	Compressor1	-	-	-
20	Compressor starting device	Compressor1	-	-	-
21	Starting device cover and clamp	Compressor1	-	-	-
23	Rubber foot	Rubber1	Rubber2	Rubber3	-
24	Compressor base	Metal1	Metal2	Metal3	Metal4
25	Drip tray cover	Plastic1	Plastic2	Plastic3	-
26	Drip tray	Plastic1	Plastic2	Plastic3	-
27	Connecting cables	Cables1	Cables2	-	-
37	Thermostat cover	Plastic1	Plastic2	Plastic3	-
38	Power cord	Cables1	Cables2	Cables3	-
-	Paper box	Paper1	Paper2	-	-

Source: Author (2019)

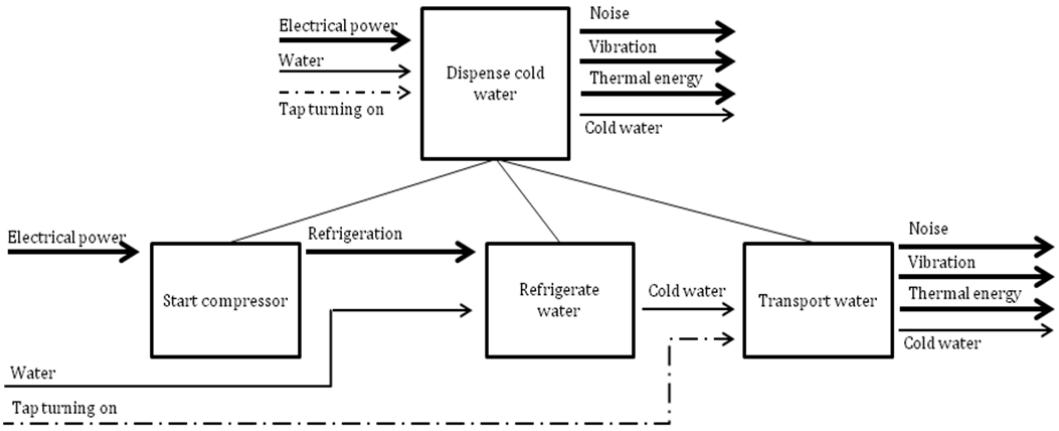
Table 7 – Compact FN/PFN model Customer list

Material:	Drinking Fountain Compact FN/PFN model	Basic qty:	100 UN

Customer ID	Type	Customer name	Annual purchase	Unit
17320	Auto Service	Customer1	10600	UN
20160	Auto Service	Customer2	10500	UN
85975	Auto Service	Customer3	9500	UN
54522	Auto Service	Customer4	9500	UN
60084	Warehouse	Customer5	8500	UN
69542	Warehouse	Customer6	8000	UN
94593	Warehouse	Customer7	7200	UN
67536	Warehouse	Customer8	6400	UN
66904	Warehouse	Customer9	5700	UN
83477	Warehouse	Customer10	5600	UN
93847	Warehouse	Customer11	5400	UN
58083	Independent Store	Customer12	4200	UN
41597	Independent Store	Customer13	3800	UN
61532	Independent Store	Customer14	3300	UN
10260	Independent Store	Customer15	3000	UN
40648	Independent Store	Customer16	2500	UN
94749	Independent Store	Customer17	2100	UN
89942	Independent Store	Customer18	1100	UN
25838	Independent Store	Customer19	600	UN
74510	Independent Store	Customer20	200	UN

Source: Author (2019)

Figure 25 – Compact FN/PFN Function Modeling



Source: Author (2019)

Table 8 – Change Difficulty Level and Certification requirement

Category	Priority		Dificulty Level	Dificulty Category	Certifications required			
					Prototype	Test	Production	Homologation
Product	3	New product desing	5	High	x	x	x	x
		New product feature	3	Medium	-	x	x	x
		Product change impacting primary function	3	Medium	-	-	x	x
		Product change impacting secondary function	1	Low	-	-	-	x
		Documentation update	1	Low	-	-	-	-
Process	3	New assembly line	5	High	x	x	x	x
		Major change on assembly line	4	High	-	x	x	x
		Process parameter change	2	Medium	-	-	x	x
		Impact on overral production rate	2	Medium	-	-	x	x
		SOP adjustment	1	Low	-	-	-	x
Supplier	2	New supplier for the company	4	High	x	x	x	x
		New supplier for the product	3	Medium	-	x	x	x
		New compoment with current supplier	3	Medium	-	x	x	x
		New tool for current supplier	3	Medium	-	x	x	x
		Adjustment on current tool for supplier	2	Medium	-	-	x	x
		Documentation update	1	Low	-	-	-	-
Customer	2	Change on primary function specification	3	Medium	-	x	x	x
		Change on secondary function specification	2	Medium	-	-	x	x
		Customer interface change	2	Medium	-	-	x	x
		Transport or storage impact	1	Low	-	-	x	x
Institute	1	New certifying institute for the product	3	Medium	-	x	x	-
		New certificate with current institute	2	Medium	-	-	x	-
		Change on current certificate specification	1	Low	-	-	x	-

Source: Author (2019)

Table 9 – Compact FN/PFN model TOP10 Quality problems

TOP10 Quality problems		
Ranking	Product	Process
1	Weak welding between compressor and condenser	Weld temperature stability problem
2	Leakeage on plastic evaporator and pipe connection	Broken pipe during connection to plastic evaporator
3	Loose thermostat	Incorrect position on pipe positioner
4	Front panel color degradation (yellow)	Tap fitting dificulty
5	Broken tap	Cover broken during assembly
6	Cover color degradation (yellow)	Solid contamination obstructing pipe
7	Leakeage on tap and pipe connection	Sponge hose incorrect position
8	Oxidation on compressor base	Incorrect compressor voltage assembly
9	Evaporator support bend	Torque excess on condenser screw
10	Broken thermostat cover	Cable clip broken during assembly

Ranking	Supplier	Customer
1	Front panel color homogeneity	Water cooling capacity on high temperature regions
2	Cover color homogeneity	Vibration on drip tray
3	Side structure burr	Starting noise
4	Thermostat cover clip size	Side structure cleanning dificulty
5	Tap´s starter thickness	Side structure heating
6	Tap´s o-ring rubber quality	Cold water volume
7	Thermostat lenght (shorter)	Long time to freeze water
8	Compressor starting device not starting	Maintenance dificulty
9	Connection cable lentgh (shorter)	Function noise
10	Incorrect compressor	High weight

Source: Author (2019)

Figure 25 presents a function modeling for Compact FN/PFN model based on product catalog information and appliances knowledge and Table 8 defines company standards regarding change difficulty level based on certifications requirement created using the information from in loco research company on this regard. Table 9 is a list of Top 10 quality problems that company is supposed to have in order to apply the templates and that was generated based on appliances knowledge to be used during simulated cases analysis and Table 10 are the company standards for change management defined using market best practices.

Table 10 – Company standards for change management

Engineering standards	
Standard tolerance for plastic parts	+/- 0,5mm
Standard tolerance for metallic parts	+/- 0,2mm
Standard tolerance for tubes dimension	+/- 0,3mm
Standard tolerance for paper dimensions	+/- 1mm
Standard tolerance for others	-0,5% / +2,0%
Standard acceptable weight variance	-2,0% / +0,5%

Business Standards	
Maximum Business Case Score	20
Maximum Technical Score	22
Maximum TIP Score	50
Maximun FTE (qty)	6
Minimum Payback (annual)	2,0
Payback impact LOW (annual)	<0,5
Payback impact MEDIUM (annual)	0,5 < x < 1,0
Payback impact HIGH (annual)	1,0 < x < 2,0
Payback priority score	5
Impact score HIGH	2
Impact score MEDIUM	1
Impact score LOM	0
Atractiveness Level – Level 5 score	1
Atractiveness Level – Level 4 score	10
Atractiveness Level – Level 3 score	100
Atractiveness Level – Level 2 score	1000
Atractiveness Level – Level 1 score	10000
Priority score result HIGH	< 50
Priority score result MEDIUM	50 < x < 2500
Priority score result LOW	> 2500

Table 10 – Company standards for change management (cont.)

Criteria for FAST Track	
Maximum Business Case Score	10
Maximum Technical Score	13
Maximum TIP Score	25
Maximum FTE (qty)	3
Minimum Payback	0,5

Source: Author (2019)

Considering Table 2 to Table 10 and Figure 25 is possible to simulate the ECM methodology applied on IBBL Compact FN/PFN model.

5.2SIMULATED APPLICATION CASES

To exemplify the framework, three simulated cases are proposed as illustrated on Board 28. Those cases were considered to explore all alternatives for the framework: fast track, full track and process shut down. With these cases is possible to understand the possible scenarios that using the framework may implicate and how to cope with them.

The analysis performed is credible and based on real cases but all the information is simulated and decision taken are based on item 5.1.2 that defines company information to support ECM framework application.

Board 28 – Simulated cases definition

ID	**Case**	**Affected part**	**Requester area**	**Case details**
1	High number of welding rework between compressor and static condenser due to small size of connection tube on static condenser	Static Condenser	Manufacturing - Assembly	Current Situation Tube size: 12mm Current static condenser cost: R$ 12,75 Rework index at welding station: 35% Average reworked units: 140 units / day Average rework cost (material add + labor dedication): R$ 2,09 / unit Static condenser total buy: R$ 1.373.175,00 /year

Board 28 – Simulated cases definition (cont.)

				Proposed solution Tube size: 14mm New static condenser cost: R$ 12,95 New expected rework index at welding station: 3% Number of expected reworked units reduced: 128 units / day Expected cost reduction: R$ 267,52 / day or R$5885,44 / month Static condenser total buy: R$ 1.394.715,00 /year Total cost reduction: R$ 49.085,28 /year
2	Approve new compressor supplier to reduce 7% in compressor cost (dual source for the item)	Compressor	Procurement - Compressor	Current Situation Single supplier: Compressor1 Compressor cost: R$23,50 / unit Compressor volume: 100% Compressor1 Compressor total buy: R$2.530.950,00 /year Proposed solution Two suppliers: Compressor1 and Compressor2 Compressor cost: R$23,50 for Compressor1 and R$20,20 for Compressor2 Compressor volume: 50% Compressor1 and 50% Compressor2 Compressor total buy: R$ 2.353.245,00 /year (R$ 177.705,00 reduction - 7%)

Board 28 – Simulated cases definition (cont.)

3	Upgrade current plastic evaporator item for Product4 plastic evaporator model in order to standardize plastic evaporator on manufacturing	Plastic evaporator	Logistics	Current Situation Plastic evaporator ID: 3 Plastic evaporator cost: R$7,50 / unit Storage area: 62 m2 for ID 3 and 85 m2 for ID 58 Plastic evaporator total buy: R$ 807.750,00 /year Storage cost (month): R$ 64 /m2 Storage total cost: R$ 112.896,00 /year Proposed solution: Plastic evaporator ID: 58 (used on Product4) Plastic evaporator cost: R$7,72 /unit Storage area: 100 m2 for ID 85 Plastic evaporator total buy: R$ 831.444,00 /year Storage total cost: R$ 76.800,00 /year Cost reduction: R$ 12.402,00 /year

Source: Author (2019)

The costs estimated on the cases are based on commercially available information regarding parts cost and average market information.

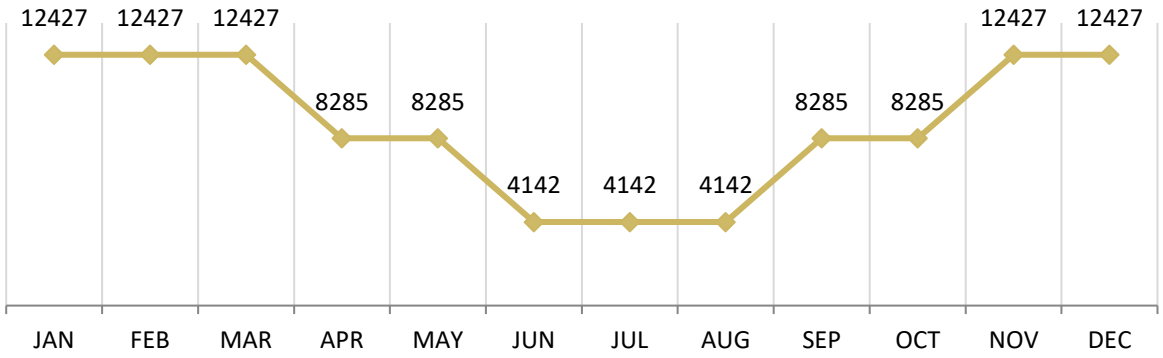
Besides that, other costs were estimated to serve as reference for business case analysis as illustrated in Table 11 and the production plan based on seasonality for year volume is as shown on Graphic 2.

Table 11 – Reference cost for cases business case analysis

Expense	**Cost (R$)**
Average project development	R$5000,00
Average manufacturing line adjustment (per Assembly Line)	R$1400,00
Average supplier tool change	R$0,00 (supplier cost)
Average institute certification cost (per Certificate)	R$7000,00

Source: Author (2019)

Graphic 2 – Production plan estimation based on seasonality



Source: Author (2019)

With this information, the business case for each situation can be evaluated.

For change identification, a standard ID will be considered for the simulated cases on the format YYYYMMDD – HHMM considering the date and the time the change was requested. Each company can define a specific ID standard.

The names for employee and e-mail addresses are fictional and created to be used on the simulated case and are not related to any real employee on IBBL Company.

5.3SIMULATED APPLICATION RESULTS

Considering the cases described in item 5.2 and the framework presented on Chapter 4, the detailed application of the framework is simulated on items 5.3.1, 5.3.2 and 5.3.3

5.3.1Simulated Case 1

5.3.1.1Engineering Change need phase

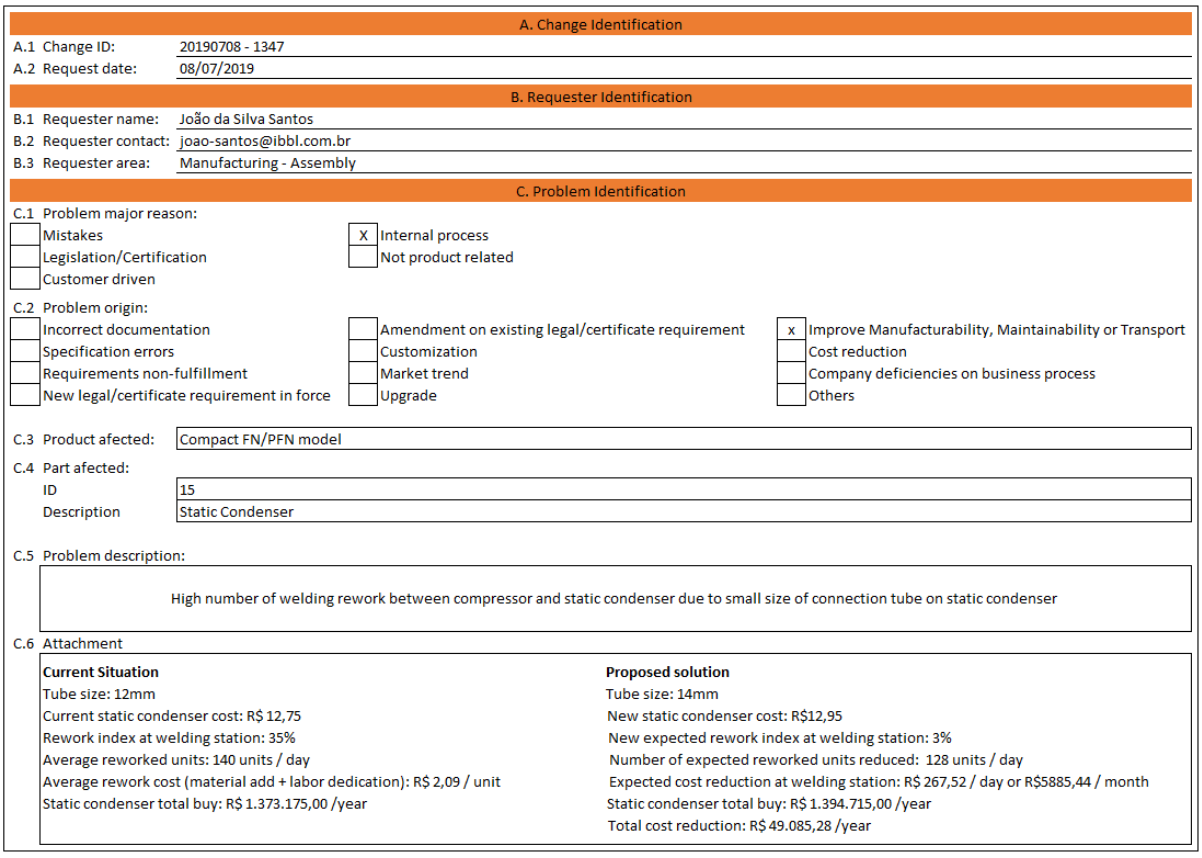
The first step in the ECM flow is to identify the engineering change need. In this simulated case, the problem illustrated on Board 28 is “High number of welding rework between compressor and static condenser due to small size of connection tube on static condenser”. The change required is to increase 2mm on the static condenser tube size.

To support the proper record of this need and to start the change process, a problem report is required. The template for the Problem Report supports this request. Figure 26 shows the TPR for Case 1.

This template reflects the change need considering the parameters defined by the company. The change ID is according described on item 5.2 as standard defined by the company for change identification YYYYMMDD – HHMM and the request date is the date the request is being issued. In this simulated case, the date is considered as the date the research simulated the case.

The requester identification used fictional name for employee and e-mail address to serve as example and the requester area is according the case description from Board 28.

Figure 26 – Template for Problem Report – Simulated Case 1



A. Change Identification

A.1 Change ID: 20190708 - 1347
A.2 Request date: 08/07/2019

B. Requester Identification

B.1 Requester name: João da Silva Santos
B.2 Requester contact: joao-santos@ibbl.com.br
B.3 Requester area: Manufacturing - Assembly

C. Problem Identification

C.1 Problem major reason:

[ ]	Mistakes	[X]	Internal process
[ ]	Legislation/Certification	[ ]	Not product related
[ ]	Customer driven		

C.2 Problem origin:

[ ]	Incorrect documentation	[ ]	Amendment on existing legal/certificate requirement	[x]	Improve Manufacturability, Maintainability or Transport
[ ]	Specification errors	[ ]	Customization	[ ]	Cost reduction
[ ]	Requirements non-fulfillment	[ ]	Market trend	[ ]	Company deficiencies on business process
[ ]	New legal/certificate requirement in force	[ ]	Upgrade	[ ]	Others

C.3 Product afected: Compact FN/PFN model

C.4 Part afected:
ID: 15
Description: Static Condenser

C.5 Problem description:

High number of welding rework between compressor and static condenser due to small size of connection tube on static condenser

C.6 Attachment

Current Situation	**Proposed solution**
Tube size: 12mm	Tube size: 14mm
Current static condenser cost: R$ 12,75	New static condenser cost: R$12,95
Rework index at welding station: 35%	New expected rework index at welding station: 3%
Average reworked units: 140 units / day	Number of expected reworked units reduced: 128 units / day
Average rework cost (material add + labor dedication): R$ 2,09 / unit	Expected cost reduction at welding station: R$ 267,52 / day or R$5885,44 / month
Static condenser total buy: R$ 1.373.175,00 /year	Static condenser total buy: R$ 1.394.715,00 /year
	Total cost reduction: R$ 49.085,28 /year

Source: Author (2019)

The problem major reason definition requires some analysis over the change requested and is a decision from the requester when filling the template. In this simulated case, considering the request aims to reduce process rework, the reasons “Legislation/Certification”

“Customer driven” and “Not product related” can be disregarded, and the decision is between “Mistakes” and “Internal process”. Although both could be applied, “Mistakes” are more related to corrections on documents or products that were released incorrectly, while “Internal process” refers to change on the product to improve internal process index. Therefore, the simulated case 1 reason is more aligned with “Internal process” problem and this was marked on item C.1 from TPR.

The problem origin also requires analysis to identify the alternative most related to the problem and is a decision made by the requester. In this case, the item “Improve Manufacturability, Maintainability or Transport” clearly describes the change goal of reducing rework. This was marked on item C.2 from TPR.

The product affected will always be Compact FN/PFN model because is the product used as reference for this study. However, in real cases, it´s important to properly identify the product that requires the change. The part affected is as defined on the case description on Board 28.

The problem description and the details on attachment also come from the case identification illustrated on Board 28. It´s important for real cases to clearly describe those items otherwise the next steps of the change evaluation can´t be properly executed.

With the problem report completed, the change process receives an ID and can be evaluated through the change process steps. With ECM need properly identified and the Problem Report as a document to start the engineering change, the step “Engineering Change Need” phase is completed and the next stage on the ECM flow is the “Technical and Financial feasibility evaluation”.

5.3.1.2Technical and Financial feasibility evaluation phase

After problem report creation, as illustrated on Figure 16 from Chapter 4, the next step is evaluation of the problem report by CAI for Feasibility. At this step, the information from the problem report will be evaluated to ensure it´s completed to allow the next steps of the process.

In this simulated case, the change need is clearly defined and all the analysis regarding possible gains and impact are described on attachment from item C.6 at TPR. Considering the

CAI for Feasibility experience, the information on TPR is enough to proceed and the request is technically feasible. For this reason, the CAI for feasibility creates the business case on Figure 27.

On TBC, the items “A. Change Identification” and “C. Problem Identification” come from the problem report. The evaluation starts at item “D. Problem Analysis.”

The product affected will always be Compact FN/PFN model because is the product used as reference for this study. In the real cases, it´s important that CAI for Feasibility checks other company products to verify if they use the same impacted part or same impacted process. If any other product besides the one identified by the requester on Problem Report is impacted, it should also be listed on item D.1 from TBC.

Figure 27 – Template for Business Case – Simulated Case 1

A. Change Identification	
A.1 Change ID:	20190708 - 1347
A.2 Request date:	08/07/2019
C. Problem Identification	
C.3 Product afected:	Compact FN/PFN model
C.4 Part afected:	
ID	15
Description	Static Condenser
C.5 Problem description:	
High number of welding rework between compressor and static condenser due to small size of connection tube on static condenser	
D. Problem Analysis	
D.1 List of total product afected:	
Compact FN/PFN model	
D.2 Suppliers affected:	
Refrigeration1 ; Refrigeration2	
D.3 Customers afected:	
Customer1 ; Customer2 ; Customer3 ; Customer4 ; Customer5 ; Customer6 ; Customer7 ; Customer8 ; Customer9 ; Customer10 ; Customer11 ; Customer12 ; Customer13 ; Customer14 ; Customer15 ; Customer16 ; Customer17 ; Customer18 ; Customer19 ; Customer20	
D.4 Company sites afected:	
Site1 - Assembly Line 1; Site1 - Assembly Line 2; Site2 - Assembly Line 5; Site4 - Assembly Line 9; Site5 - Assembly Line 11;	
D.5 Legal/Institutes affected:	
Institute1 - Certificate 1 ; Institute1 - Certificate 2 ; Institute1 - Certificate 3 ; Institute2 - Certificate 6 ; Institute2 - Certificate 7	
D.6 Product Subsystems affected:	
Structure ; Water Transport ; Water cooler ; Electrical connections ; Transport	

Figure 27 – Template for Business Case – Simulated Case 1 (cont.)

E. Cost Identification

E.1	Cost impact per unit:	R$ 0,46 (total year reduction divided by total year production)		
E.2	Volume:			
	Month 1	3976	Month 7	1325
	Month 2	3976	Month 8	1325
	Month 3	3976	Month 9	2651
	Month 4	2651	Month 10	2651
	Month 5	2651	Month 11	3976
	Month 6	1325	Month 12	3976
E.3	CAPEX:	Not necessary		
E.4	OPEX:	R$5000 (average project development cost)		
E.5	Direct Labor:	Not necessary		
E.6	Payback:	0,10		

F. Business Case

F.1	Supplier impact:					
		High	x	Medium		Low	New tool for current supplier
F.2	Customer :					
		High		Medium	x	Low	No impact
F.3	Company impact:					
		High	x	Medium		Low	Process parameter change
F.4	Legal/Institutes impact:					
		High		Medium	x	Low	No impact
F.5	Product subsystems impact:					
		High		Medium	x	Low	Product change impacting secondary function
F.6	Payback impact:					
		High		Medium	x	Low	Lower than 0,5

BUSINESS CASE SCORE:	5

Source: Author (2019)

The list of suppliers, customers, company sites, legal/institutes and product subsystem affected all come from definitions to support the ECM framework described on item 5.1.2. The suppliers refers to Supplier Matrix for the impacted part that is “Static Condenser.” The customer refers to the Customer List for the product. The company sites affected are as illustrated on Manufacturing Map for the product. The legal/institutes affected consider the

certification the product have according the Certification Map. The subsystems affected are the subsystems that affected part is related according the Correlation Matrix.

The cost identification also requires analysis from the CAI for Feasibility. In this simulated case, the total cost reduction estimated by the requester is R$ 49.085,28 per year and the annual production for the product according the Customer List from item 5.1.2 is 107700 units. Therefore, the cost reduction for each produced unit will be R$ 0,46. This value is included on item E.1 from TBC.

The impacted volume in the case is 32% of total product volume because 35% of the units are reworked and a 3% rate will remain requiring the rework, despite the change. 32% of the products will no longer be reworked, making this the volume of impacted products. The distribution among months on item E.2 from TBC is 32% of production distribution from Graphic 9.

The CAPEX required in this case is to change the supplier tool is afforded by the supplier according to Table 11. The project does not require any CAPEX investment as a result. The OPEX is an average project development cost that is R$5000 according to Table 11. There is no direct labor impact because the change will neither remove any employee from the company nor require any employee to be hired. This information is filled on items E.3, E.4 and E.5 from TBC.

The payback is calculated by dividing the total cost for the change (that is this case is R$5000 for the project development) by the total annual gain (R$ 49.085,28) that results in 0,10 as reported on item E.6 for TBC.

The business case impact evaluation is based on company standard and F.1, F.2, F.3, F.4 and F.5 are assessed based on Table 8 – Change Difficulty Level and Certification requirement. To identify which category on the table is related to the change is part of CAI for feasibility skills. In this case, changing the tube size will require a new tool for the current supplier and will not impact the customer. This is due to the fact the static condenser is an internal part and the customer does not have interface with it, it will promote a process parameter change on the welding station, it does not have any relation to legal/institutes because it will not affect any product specification; and it will impact the product on secondary function because the static condenser is part of the system that refrigerates water.

The payback impact on F.6 is evaluated according to business standard from Table 10 – Company standards for change management.

The business case score is calculated by the sum of the impacts multiplied by the priority on each category. The priority for F.1, F.2, F.3, F.4 and F.5 is as defined on Table 8 – Change Difficulty Level and Certification requirement and the priority for F.6, as well as the impact for all the items is as defined by the business standard from Table 10 – Company standards for change management. In this simulated case, the calculation is as illustrated on Table 12.

Table 12 – Business case score calculation – Simulated Case 1

	Impact	**Priority**	**Product**
Supplier impact	1	2	2
Customer impact	0	2	0
Company impact	1	3	3
Legal/Institutes impact	0	1	0
Product subsystems impact	0	3	0
Payback impact	0	5	0
SUM			5

Source: Author (2019)

After the TBC is completed, the CAI for Feasibility creates the Change Report using the Template for Change Report. For this simulated case, the TCR is on Figure 28.

On the TCR, the item “A. Change Identification” and “C. Problem identification” are form TPR and item “F. Business Case” with business case score is from TBC. The CAI for Feasibility analysis starts on item “G. Proposed Solution.”

Considering the skills required, the CAI for feasibility evaluates the technical solution for the problem requiring the change. On this simulated case, the solution proposed on the request is to increase 2mm on the tube size for the static condenser was accepted as a solution for the problem. In other cases, a different solution, such as changing the static condenser model for another part used on a different product could also be applied.

Considering the technical solution, the CAI for Feasibility identifies to which category each certification requires based on Table 8 – Change Difficulty Level and Certification requirement. Since the solution is the one proposed on the change, this analysis was already made for a business case evaluation and changing the tube size will require a new tool for the current supplier. This will not impact the customer because the static condenser is an internal

part and the customer does not have interface with it. This will promote a process parameter change on welding station without any relation to legal/institutes because it will not affect any product specification. Rather, it will impact the product on its secondary function because the static condenser is part of the system that refrigerates water. With these categories, the required certifications are mapped on item G.2 from TCR.

Figure 28 – Template for Change Request – Simulated Case 1

A. Change Identification

A.1 Change ID:	20190708 - 1347
A.2 Request date:	08/07/2019

C. Problem Identification

C.3 Product afected:	Compact FN/PFN model
C.4 Part afected:	
ID	15
Description	Static Condenser

C.5 Problem description:

High number of welding rework between compressor and static condenser due to small size of connection tube on static condenser

F. Business Case

BUSINESS CASE SCORE: 5

G. Proposed Solution

G.1 Technical solution:

Accepted the solution proposed by requester to increase 2mm on tube lenth for static condenser

G.2 Certifications required:

	Prototype		Test		Production		Homologation	
Product							x	Product change impacting secondary function
Process					x	Process parameter change	x	Process parameter change
Supplier			x	New tool for current supplier	x	New tool for current supplier	x	New tool for current supplier
Customer		No impact		No impact		No impact		No impact
Institute		No impact		No impact		No impact		No impact

G.3 Resource Allocation required:

Impacted Area		FTE (qty)
Project Development	x	0,3
Manufacturing Assembly	x	0,1
Procurement	x	0,1
Supplier Quality	x	0,1

G.4 Technical Challenge:

	Level 1		Level 2	x	Level 3		Level 4		Level 5

TECHNICAL SCORE: 12

Source: Author (2019)

The resource allocation is also a part of CAI for Feasibility skills. This decision is made based on experience. In this case, considering the change on the static condenser part, it was identified that the project would require a partial FTE from the project development team,

manufacturing assembly, and the Procurement and Supplier Quality. The resources here are divided by company areas and may differ from company to company.

The technical challenge on item G.4 is defined by the highest level identified on Table 8 – Change Difficulty Level and Certification requirement. In this case, the Level 3 is defined because the “New tool for current supplier” is level 3 of difficulty, while “Process parameter change” is level 2 and “Product change impacting secondary function” is level 1. Customer and Institute are not impacted.

The technical score is defined by the sum of quantity of certifications required, quantity of impacted areas and the technical challenge grade considering Level 1 is grade 0, Level 2 is grade 1, Level 3 is grade 2, Level 4 is grade 3 and Level 5 is grade 4. In this case there are 6 certifications required, 4 impacted areas and grade 2. The sum is 6 + 4 + 2 resulting on a technical score of 12.

Considering the TCR completed, next step of the ECM process is the CAI for Analysis to evaluate the Change Request and approve it. At this step the CAI for Analysis skills will be used to ensure the information on TCR is accurate and the change can go to next ECM phase. With the change request approved, it concludes the “Technical and Financial feasibility evaluation” phase. The next stage on the ECM flow is the “Impact propagation analysis.”

5.3.1.3Impact propagation analysis phase

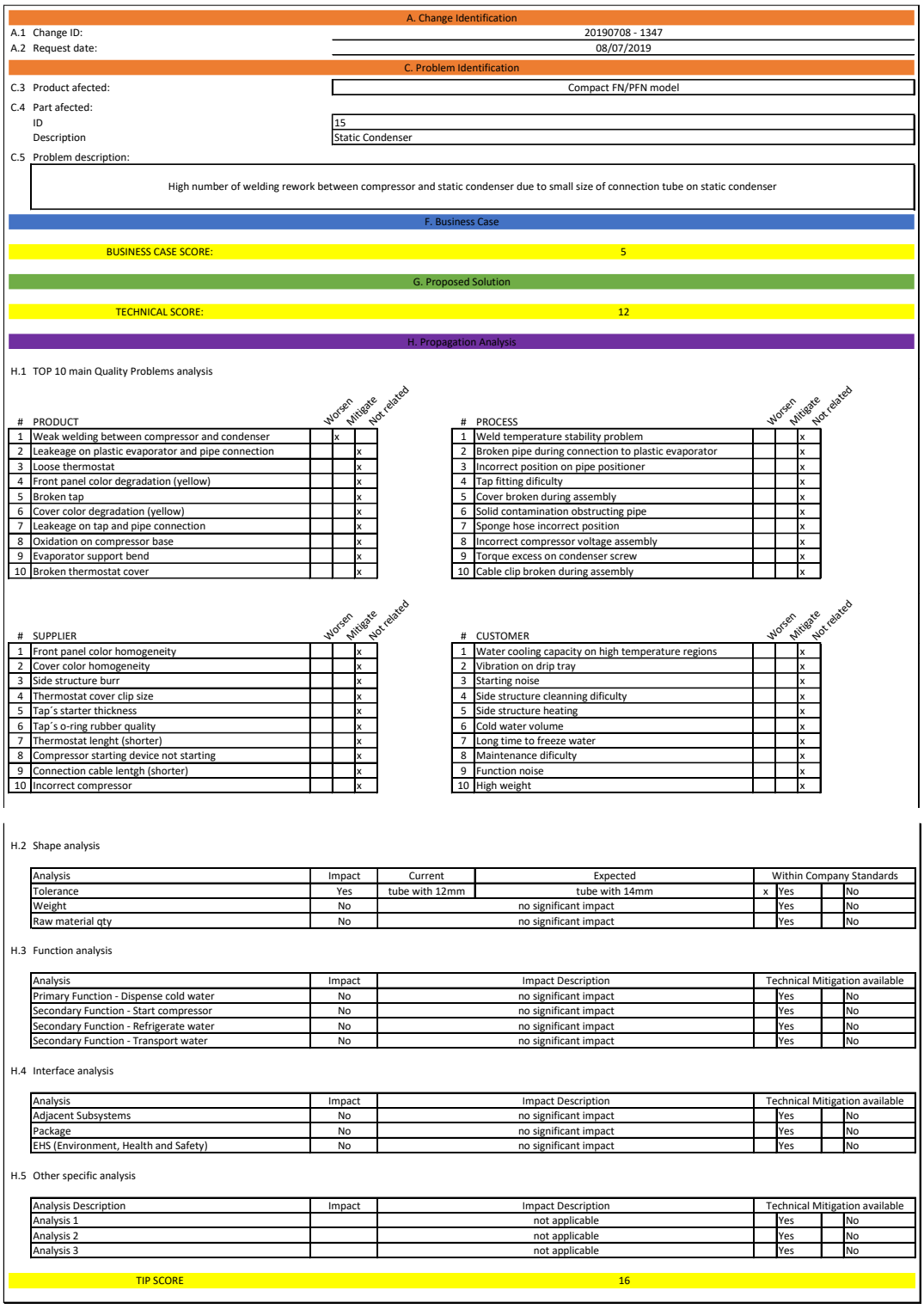
To analyze impact propagation for the change, the CAI for Analysis will arrange multiple meetings with experts on different areas and fill the Template for Impact propagation. For this case, the TIP is on Figure 29.

On the TIP, the item “A. Change Identification” and “C. Problem identification” are from TPR, item “F. Business Case” with business case score is from TBC and item “G. Proposed Solution” with a technical score from TCR. The CAI for Analysis evaluation starts with item “H. Propagation Analysis.”

The main quality problems are defined by the company on item 5.1.2 and the CAI for Analysis responsibility is to identify if the proposed change will impact any of the listed problems. Using CAI for skill analysis and input from experts identified that increasing 2mm on tube size on the static condenser will mitigate “Weak welding between compressor and

condenser" because it will decrease the welding rework, making it possible for a better weld process. The other problems are not related to the static condenser tube size and will not be impacted by the change.

Figure 29 – Template for Impact Propagation – Simulated Case 1



A. Change Identification

A.1 Change ID:	20190708 - 1347
A.2 Request date:	08/07/2019

C. Problem Identification

C.3 Product afected:	Compact FN/PFN model
C.4 Part afected:	
ID	15
Description	Static Condenser

C.5 Problem description:

High number of welding rework between compressor and static condenser due to small size of connection tube on static condenser

F. Business Case

BUSINESS CASE SCORE: 5

G. Proposed Solution

TECHNICAL SCORE: 12

H. Propagation Analysis

H.1 TOP 10 main Quality Problems analysis

#	PRODUCT	Worsen	Mitigate	Not related
1	Weak welding between compressor and condenser		x	
2	Leakeage on plastic evaporator and pipe connection			x
3	Loose thermostat			x
4	Front panel color degradation (yellow)			x
5	Broken tap			x
6	Cover color degradation (yellow)			x
7	Leakeage on tap and pipe connection			x
8	Oxidation on compressor base			x
9	Evaporator support bend			x
10	Broken thermostat cover			x

#	PROCESS	Worsen	Mitigate	Not related
1	Weld temperature stability problem			x
2	Broken pipe during connection to plastic evaporator			x
3	Incorrect position on pipe positioner			x
4	Tap fitting dificulty			x
5	Cover broken during assembly			x
6	Solid contamination obstructing pipe			x
7	Sponge hose incorrect position			x
8	Incorrect compressor voltage assembly			x
9	Torque excess on condenser screw			x
10	Cable clip broken during assembly			x

#	SUPPLIER	Worsen	Mitigate	Not related
1	Front panel color homogeneity			x
2	Cover color homogeneity			x
3	Side structure burr			x
4	Thermostat cover clip size			x
5	Tap´s starter thickness			x
6	Tap´s o-ring rubber quality			x
7	Thermostat lenght (shorter)			x
8	Compressor starting device not starting			x
9	Connection cable lentgh (shorter)			x
10	Incorrect compressor			x

#	CUSTOMER	Worsen	Mitigate	Not related
1	Water cooling capacity on high temperature regions			x
2	Vibration on drip tray			x
3	Starting noise			x
4	Side structure cleanning dificulty			x
5	Side structure heating			x
6	Cold water volume			x
7	Long time to freeze water			x
8	Maintenance dificulty			x
9	Function noise			x
10	High weight			x

H.2 Shape analysis

Analysis	Impact	Current	Expected	Within Company Standards			
Tolerance	Yes	tube with 12mm	tube with 14mm	x	Yes		No
Weight	No	no significant impact			Yes		No
Raw material qty	No	no significant impact			Yes		No

H.3 Function analysis

Analysis	Impact	Impact Description	Technical Mitigation available			
Primary Function - Dispense cold water	No	no significant impact		Yes		No
Secondary Function - Start compressor	No	no significant impact		Yes		No
Secondary Function - Refrigerate water	No	no significant impact		Yes		No
Secondary Function - Transport water	No	no significant impact		Yes		No

H.4 Interface analysis

Analysis	Impact	Impact Description	Technical Mitigation available			
Adjacent Subsystems	No	no significant impact		Yes		No
Package	No	no significant impact		Yes		No
EHS (Environment, Health and Safety)	No	no significant impact		Yes		No

H.5 Other specific analysis

Analysis Description	Impact	Impact Description	Technical Mitigation available			
Analysis 1		not applicable		Yes		No
Analysis 2		not applicable		Yes		No
Analysis 3		not applicable		Yes		No

TIP SCORE 16

Source: Author (2019)

The shape analysis is also conducted by the CAI for Analysis and supported by experts during alignment meetings, if necessary. In this case, increasing 2mm on tube size will impact tolerance chain, but the impact is within company standards as defined on Table 10 – Company standards for change management. Weight and raw material quantity are not significantly impacted by the change because 2mm on tube size is not relevant in terms of weight and raw material increase.

The function analysis and interface analysis is also conducted by the CAI for Analysis and supported by experts during alignment meetings, if necessary. These analyses also do not show significant impact. Other analyses are not required for this simulated case. This happens because the change is on a specific part that despite composing the subsystem impacting water cooler, increasing the tube by 2mm is increasing the tube size by 16%, which is not technically relevant in terms of cooling capacity. Therefore, neither primary nor secondary functions are impacted. The change will not interfere with other subsystems and does not impact the package because it is internal to the product and is not proposing any material change nor process standard that could generate any impact on Environment, Health or Safety.

With this, the TIP score can be calculated by the sum of business score, technical score and propagation analysis score. The propagation analysis score is defined as the sum for the points on item “H. Propagation analysis” such as illustrated on Table 13.

Table 13 – Points on item “H. Propagation Analysis”

Detail	**Score**
Quality Problem Worsen	1
Quality Problem Mitigated	-1
Quality Problem Not related	0
Shape analysis without impact	0
Shape analysis impact within company standards	0
Shape analysis impact without company standards	1
Function/Interface/Other analysis wihtout impact	0
Function/Interface/Other analysis impact with Technical Mitigation available	0
Function/Interface/Other analysis impact without Technical Mitigation available	1

Source: Author (2019)

For this case, the TIP is the sum of 5 (business case score) + 12 (technical score) + (-1) (quality problem mitigation) resulting in TIP as 16. With TIP score, the “Impact propagation analysis” phase is concluded. The next stage on the ECM flow is the “Change Implementation”.

5.3.1.4Change Implementation phase

The first step on change implementation is the approval for change execution. Considering the TCR and TIP score, the CAI for analysis will compare business standard with change results in order to define if it will be Full track or Fast track. In this case, the Table 10 – Company standards for change management – defines that the change can be Fast track if the business case score is lower than 10, the technical score is lower than 13 and the TIP score is lower than 25. The simulated case 1 meets all these requirements with business case score 5, technical score 12 and TIP score 16.

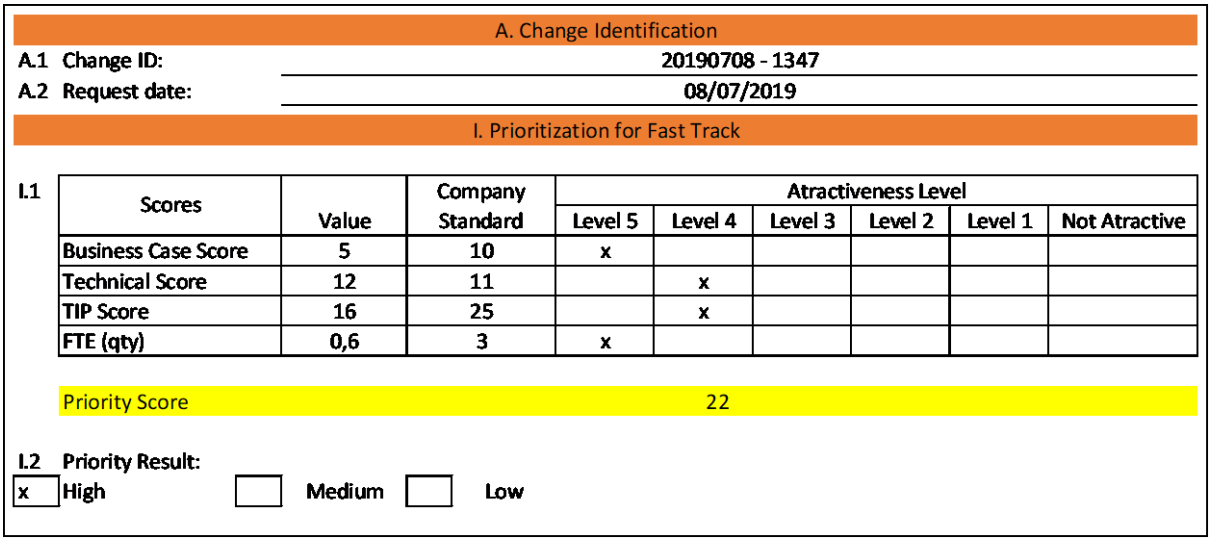
To be considered Fast track it is also required that the FTE quantity is lower than 3 and the payback is lower than 0,5. These criteria are also met by simulated case 1 with FTE quantity 0,6 and payback 0,10. Therefore, simulated case 1 will be conducted as Fast Track. The TPFast is on Figure 30.

On the TPFast, the item “A. Change Identification” is from TPR and the CAI for Analysis evaluation starts with item “I. Prioritization for Fast Track”. The value for the business case score, technical score, TIP score and FTE (qty) are from TIP and TCR, while the company standard is as defined by Table 10 – Company standards for change management. The attractiveness level is defined by the CAI for Analysis based on skills, and the priority score is the sum of attractiveness considering the values defined also on Table 10 – Company standards for change management.

For this simulated case, the attractiveness for business case score was considered Level 5, for technical score was considered Level 4, for TIP Score Level 4, and for FTE (qty) was considered Level 5. The priority score is the sum of 1 + 10 + 10 + 1 (as attractiveness level score from business standard) and results on 22.

According Table 10 – Company standards for change management, the priority score is lower than 50, leading the result to be HIGH.

Figure 30 – Template for Fast Track – Simulated Case 1



A. Change Identification

A.1 Change ID: 20190708 - 1347

A.2 Request date: 08/07/2019

I. Prioritization for Fast Track

I.1

Scores	Value	Company Standard	Atractiveness Level					
			Level 5	Level 4	Level 3	Level 2	Level 1	Not Atractive
Business Case Score	5	10	x					
Technical Score	12	11		x				
TIP Score	16	25		x				
FTE (qty)	0,6	3	x					
Priority Score			22					

I.2 Priority Result:

[x] High [ ] Medium [ ] Low

Source: Author (2019)

On TCN from Figure 31, all information originates on a previous template. The PMO only consolidates the information on this template and defines the person to be assignee for the change execution. In this case, the name is fictional to serve as reference.

The assignee on TCN will prepare a change implementation plan using the TCP. This plan minimally considers the required certifications identified on TCN, but also includes activities required by the company process to ensure the change execution. The plan is created based on CAII skills and experience.

For this case, the plan was divided into 3 implementation phases as illustrated on Figure 32. Since the plan is based on CAII skills and experience, a different plan results for each different CAII defined. The plan definition is hard to be standardized and relies on the correct definition of CAII.

After TCP is completed, the CAII starts process implementation based on the plan and considers the company process to execute the planned activities. When the implementation is completed, the CAII submits the change for audit and is released by CAIII.

The CAIII fills the TCA to check and audit the major deliverables from TCP. The CAIII needs to identify main deliverables and minimally ensure the required certifications are completed and approved. For this reason, specific CAIII skills are required. For this case, the TCA is on Figure 33.

On the TCA, the items “A. Change Identification” and “C. Problem identification” are from TPR, and item “G. Proposed Solution” with technical score is from TCR. The CAII evaluation starts with item “L. Audit.” In this case, the audit list considered the deliverables Supplier Test Certification, Supplier Production Certification, Process Production Certification, Drawings Release and New Product Cost. All deliverables were expected by CAIII experience. The comments are included for further reference and results are marked as “Approved.”

Figure 31 – Template for Change Notice – Simulated Case 1

A. Change Identification	
A.1 Change ID:	20190708 - 1347
A.2 Request date:	08/07/2019

C. Problem Identification	
C.3 Product afected:	Compact FN/PFN model
C.4 Part afected:	
ID	15
Description	Static Condenser

C.5 Problem description:

High number of welding rework between compressor and static condenser due to small size of connection tube on static condenser

F. Business Case	
BUSINESS CASE SCORE:	5

G. Proposed Solution

G.1 Technical solution:

Accepted the solution proposed by requester to increase 2mm on tube lenth for static condenser

G.2 Certifications required:

	Prototype		Test		Production		Homologation	
Product							x	Product change impacting secondary function
Process					x	Process parameter change	x	Process parameter change
Supplier			x	New tool for current supplier	x	New tool for current supplier	x	New tool for current supplier
Customer		No impact		No impact		No impact		No impact
Institute		No impact		No impact		No impact		No impact

G.3 Resource Allocation required:

Impacted Area		FTE (qty)
Project Development	x	0,3
Manufacturing Assembly	x	0,1
Procurement	x	0,1
Supplier Quality	x	0,1

TECHNICAL SCORE:	12

H. Propagation Analysis

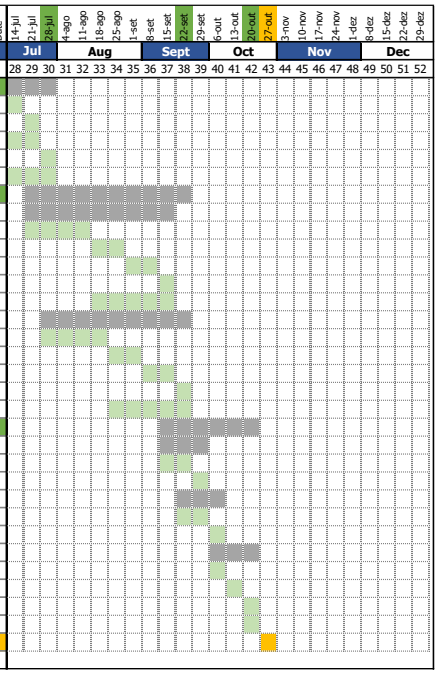
TIP SCORE	16
Assingee:	Maria Simone dos Anjos

Source: Author (2019)

Figure 32 – Template for Change Plan – Simulated Case 1

20190708 - 1347 - Maria Simone dos Anjos

Nº	DESCRIPTION	RESPONSIBLE
	Phase 1 - Planning	
1	**Align project steps with supplier - Refrigeration1**	**Project manager**
2	**Align project steps with supplier - Refrigeration2**	**Project manager**
3	**Define production certification window - Site1 - Assembly Line 1**	**Project manager**
4	**Validate similarity approval for other impacted sites / assembly line**	**Process specialist**
5	**Update drawings for new specification**	**Project manager**
	Phase 2 - Test Phase	
6	**Supplier Test Certification - Refrigeration1**	
	Develop new tool	Supplier
	Evaluate samples from new tool	Supplier Quality Specialist
	Produce test batch	Supplier
	Validate test certification	Supplier Quality Specialist
	Negociate new product cost	Procurement Specialist
7	**Supplier Test Certification - Refrigeration2**	
	Develop new tool	Supplier
	Evaluate samples from new tool	Supplier Quality Specialist
	Produce test batch	Supplier
	Validate test certification	Supplier Quality Specialist
	Negociate new product cost	Procurement Specialist
	Phase 3 - Production Phase	
8	**Supplier Production Certification - Refrigeration1**	
	Produce production batch	Supplier
	Validate Production certification	Supplier Quality Specialist
9	**Supplier Production Certification - Refrigeration2**	
	Produce production batch	Supplier
	Validate Production certification	Supplier Quality Specialist
10	**Process Production Certification - Site1 - Assembly line 1**	
	Procduce batch using Refrigeration1 parts	Manufacturing specialist
	Procduce batch using Refrigeration2 parts	Manufacturing specialist
	Validate Production certification	Manufacturing specialist
11	**Release drawings with new specification**	**Project manager**
	Project Implementation Completed	



Source: Author (2019)

Figure 33 – Template for Change Audit – Simulated Case 1

A. Change Identification

A.1 Change ID: 20190708 - 1347

A.2 Request date: 08/07/2019

C. Problem Identification

C.3 Product afected: Compact FN/PFN model

C.4 Part afected:

ID 15

Description Static Condenser

C.5 Problem description:

High number of welding rework between compressor and static condenser due to small size of connection tube on static condenser

G. Proposed Solution

G.1 Technical solution:

Accepted the solution proposed by requester to increase 2mm on tube lenth for static condenser

L. Audit

Main Deliverables	Delivered				Comments
Suplier Test Certification	x	Yes		No	Refrigeration1 and Refrigeration2
Supplier Production Certification	x	Yes		No	Refrigeration1 and Refrigeration2
Process Production Certification	x	Yes		No	Site1 - Assembly Line 1 and Similarity approval for other impacted sites
Drawings release	x	Yes		No	ok
New product cost	x	Yes		No	ok
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	

Final Result: Approved

Source: Author (2019)

The audit and release process concludes the “Change Implementation” phase. The next stage on the ECM flow is the “Not relevant impacts validation.”

5.3.1.5Not relevant impacts validation phase

When the change notice is completed, the CAII evaluates that no relevant impacts occurred after the change by creating a plan to homologate the results. The TH minimally contains the Homologation certifications required by the change.

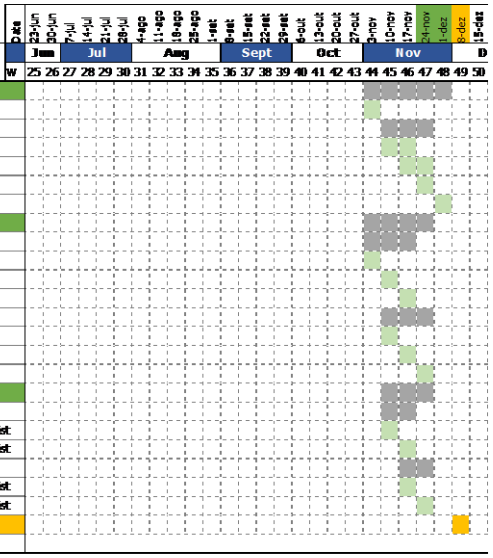
Similar to change plan, the homologation plan is based on CAII skills, experience and different plan results for each different CAII defined. The plan definition is hard to standardize and relies on correct definition of CAII. For this case, the TH is on Figure 34.

The final definition regarding impact final evaluation is decided by CAII after homologation activities are completed and all results are according expected. In this case, the final impact evaluation was no unexpected impact was identified.

Figure 34 – Template for Homologation – Simulated Case 1

20190708 - 1347 - Maria Simone dos Anjos

Nº	DESCRIPTION	RESPONSIBLE
	Phase 1 - Product Homologation	
1	Select 10 samples from different batches produced with new specification	Project Manager
2	Execute performance tests	
	Cooling capacity test - 10 samples	Lab responsible
	Water volume test - 10 sampels	Lab responsible
	Transpot test - 10 samples	Lab responsible
3	Validade homologation results	Project Manager
	Phase 2 - Process Homologation	
4	Site 1 - Assembly Line 1	
	Review welding rework index	Process Specialist
	Review line performance index (productivity, quality, OEE etc)	Process Specialist
	Validate homologation results	Process Specialist
5	Sites approved by similarity	
	Review welding rework index	Process Specialist
	Review line performance index (productivity, quality, OEE etc)	Process Specialist
	Validate homologation results	Process Specialist
	Phase 3 - Supplier Homologation	
6	Refrigeration1	
	Review quality index	Supplier Quality Specialist
	Validate homologation results	Supplier Quality Specialist
7	Refrigeration2	
	Review quality index	Supplier Quality Specialist
	Validate homologation results	Supplier Quality Specialist
	Project Homologation Completed	



Impact Final Evaluation:	
	Yes
x	No

Source: Author (2019)

Since there is no evidence of impact, the ECM process is completed and the change is concluded.

5.3.2Simulated Case 2

5.3.2.1Engineering Change need phase

The first step on the ECM flow is to identify the engineering change need. In this simulated case, the problem illustrated on Board 28 is “Approve new compressor supplier to reduce 7% in compressor cost (dual source for the item).” The change required is to develop and approve Compressor2 as the supplier for the product with a 50% volume share.

To support the proper record of this need and to start the change process, a problem report is required, and the Template for Problem Report supports this request. The Figure 35 shows the TPR for Case 2.

Figure 35 – Template for Problem Report – Simulated Case 2

A. Change Identification

A.1 Change ID: 20190717 - 1825
A.2 Request date: 17/07/2019

B. Requester Identification

B.1 Requester name: Carlos Menezes
B.2 Requester contact: carlos-menezes@ibbl.com.br
B.3 Requester area: Procurement - Compressor

C. Problem Identification

C.1 Problem major reason:

[ ]	Mistakes	[ ]	Internal process
[ ]	Legislation/Certification	[ ]	Not product related
[x]	Customer driven		

C.2 Problem origin:

[ ]	Incorrect documentation	[ ]	Amendment on existing legal/certificate requirement	[ ]	Improve Manufacturability, Maintainability or Transport
[ ]	Specification errors	[ ]	Customization	[x]	Cost reduction
[ ]	Requirements non-fulfillment	[ ]	Market trend	[ ]	Company deficiencies on business process
[ ]	New legal/certificate requirement in force	[ ]	Upgrade	[ ]	Others

C.3 Product afected: Compact FN/PFN model

C.4 Part afected:
ID: 19
Description: Compressor

C.5 Problem description:
Approve new compressor supplier to reduce 7% in compressor cost (dual source for the item)

C.6 Attachment

Current Situation	Proposed solution
Single supplier: Compressor1	Two suppliers: Compressor1 and Compressor2
Compressor cost: R$23,50 / unit	Compressor cost: R$23,50 for Compressor1 and R$20,20 for Compressor2
Compressor volume: 100% Compressor1	Compressor volume: 50% Compressor1 and 50% Compressor2
Compressor total buy: R$2.530.950,00 /year	Compressor total buy: R$ 2.353.245,00 /year (R$ 177.705,00 reduction - 7%)

Source: Author (2019)

This template reflects the change need considering the parameters defined by the company. The change ID is described on item 5.2 as standard defined by the company for

change identification YYYYMMDD – HHMM. The request date is the date the request is being issued. In this simulated case, the date is considered as the date the research is simulated the case.

The requester identification used a fictional name for employee and e-mail address to serve as example. The requester area is according to the case description from Board 28.

As mentioned for Simulated Case 1, the major problem is a decision from the requester when filling the template. In this simulated case, considering the request aims to reduce cost by introducing a new supplier with 50% volume share, the reason “Customer driven” is the best option to indicate the reason for the request. This was marked on item C.1 from TPR.

The problem origin also requires analysis to identify the alternative most related to the problem, and is a decision made by the requester. “Cost reduction” is clearly the driven goal for the request and was marked on item C.2 from TPR.

Same as adopted on Simulated Case 1, the product affected will always be Compact FN/PFN model because it is the product used as reference for this study. The part affected is as defined on the case description on Board 28.

The problem description and the details on attachment also come from the case identification illustrated on Board 28. It is important to reinforce that for real cases, to clearly describe those items is essential to proceed with the next steps of the change evaluation.

With the problem report completed, the change process receives an ID and can be evaluated through the change process steps. With ECM need properly identified and the Problem Report as a document to start the engineering change, the step “Engineering Change Need” phase is completed, and the next stage on the ECM flow is the “Technical and Financial feasibility evaluation.”

5.3.2.2Technical and Financial feasibility evaluation phase

After problem report creation, as illustrated on Figure 16 from Chapter 4, the next step is evaluation of problem report by CAI for Feasibility. At this step, the information from problem report will be evaluated to ensure it is completed to allow for the next steps of the process.

In this simulated case, the change need is clearly defined and all the analysis regarding possible gains and impact are described on attachment from item C.6 at TPR. Considering the CAI for Feasibility experience, the information on TPR is enough to proceed and the request is

technically feasible. For this reason, the CAI for feasibility creates the business case on Figure 36.

Figure 36 – Template for Business Case – Simulated Case 2

A. Change Identification	
A.1 Change ID:	20190717 - 1825
A.2 Request date:	17/07/2019

C. Problem Identification	
C.3 Product afected:	Compact FN/PFN model
C.4 Part afected:	
ID	19
Description	Compressor

C.5 Problem description:

Approve new compressor supplier to reduce 7% in compressor cost (dual source for the item)

D. Problem Analysis

D.1 List of total product afected:

Compact FN/PFN model

D.2 Suppliers affected:

Compressor1

D.3 Customers afected:

Customer1 ; Customer2 ; Customer3 ; Customer4 ; Customer5 ; Customer6 ; Customer7 ; Customer8 ; Customer9 ; Customer10 ; Customer11 ; Customer12 ; Customer13 ; Customer14 ; Customer15 ; Customer16 ; Customer17 ; Customer18 ; Customer19 ; Customer20

D.4 Company sites afected:

Site1 - Assembly Line 1; Site1 - Assembly Line 2; Site2 - Assembly Line 5; Site4 - Assembly Line 9; Site5 - Assembly Line 11;

D.5 Legal/Institutes affected:

Institute1 - Certificate 1 ; Institute1 - Certificate 2 ; Institute1 - Certificate 3 ; Institute2 - Certificate 6 ; Institute2 - Certificate 7

D.6 Product Subsystems affected:

Structure ; Water cooler ; Electrical connections

E. Cost Identification

E.1 Cost impact per unit:	R$1,64 (7% reduction on compressor cost for average year volume)

E.2 Volume:

Month 1	12426	Month 7	4142
Month 2	12426	Month 8	4142
Month 3	12426	Month 9	8284
Month 4	8284	Month 10	8284
Month 5	8284	Month 11	12426
Month 6	4142	Month 12	12426

Figure 36 – Template for Business Case – Simulated Case 2 (cont.)

E.3 CAPEX:	Not necessary			
E.4 OPEX:	R$5000 (average project development cost) + R$35000 (5 Institute certifications)			
E.5 Direct Labor:	Not necessary			
E.6 Payback:	0,23			
F. Business Case				
F.1 Supplier impact:				
x High		Medium	Low	New supplier for the company
F.2 Customer :				
High		Medium	x Low	No impact
F.3 Company impact:				
High	x Medium		Low	Process parameter change
F.4 Legal/Institutes impact:				
High	x Medium		Low	New certificate with current institute
F.5 Product subsystems impact:				
High	x Medium		Low	Product change impacting primary function
F.6 Payback impact:				
High		Medium	x Low	Lower than 0,5
BUSINESS CASE SCORE:	11			

Source: Author (2019)

On TBC, the items “A. Change Identification” and “C. Problem Identification” come from the problem report and the evaluation starts at item “D. Problem Analysis.”

The product affected will always be Compact FN/PFN model because it is the product used as reference for this study. However, in real cases, as mentioned on Simulated Case 1, it is important that CAI for Feasibility checks other company products to verify if they use the same impacted part or same impacted process. If any other product besides the one identified by the requester on Problem Report is impacted, it should also be listed on item D.1 from TBC.

The list of suppliers, customers, company sites, legal/institutes and product subsystem affected all come from definitions to support the ECM framework as described on item 5.1.2. The suppliers refer to Supplier Matrix for the impacted part that is “Static Condenser.” The customer refers to the Customer List for the product. The company sites affected are as described on Manufacturing Map for the product. The legal/institutes affected consider the certification the product have according to the Certification Map. The subsystems affected are the subsystems that affected part are related according to the Correlation Matrix. In Simulated Case 2, the information for items D.1, D.2, D.3, D.4 and D.5 are the same as Simulated Case 1 because the product is the same while D.6 varies according to the affected part.

The cost identification also requires analysis from the CAI for Feasibility. In this simulated case, the total cost reduction estimated by the requester is R$ 177.705,00 per year and the annual production for the product according the Customer List from item 5.1.2 is 107700 units. Therefore, the cost reduction for each produced unit will be R$ 1,65. This value is included on item E.1 from TBC.

The impacted volume in the case is all produced products because Compressor2 supplier will be responsible for 50% of volumes, but the cost reduction will apply to the total buy for the item. This will lead to a cost reduction for all units. The distribution among months on item E.2 from TBC is the total production distribution from Graphic 9.

The project does not require any CAPEX investment because the new supplier will be similar to the current one and no changes on the manufacturing assembly line nor supplier tool is necessary. The OPEX is an average project development cost is R$5000 and the product certifications on Institute is R$7000 according to Table 11. The certificate and the product has 5 certifications, for a total of R$35000. There is no direct labor impact because the change will neither remove any employee from the company nor require any employee to be hired. This information is filled on items E.3, E.4 and E.5 from TBC.

The payback is calculated by dividing the total cost for the change (that is, this case is R$40000) by the total annual gain (R$ 177.705,00), that results in 0,23 as reported on item E.6 for TBC.

The business case impact evaluation is based on company standard, and F.1, F.2, F.3, F.4 and F.5 are assessed based on Table 8 – Change Difficulty Level and Certification requirement. To identify which category on the table is related to the change is part of CAI for feasibility skills. In this case, approving a new supplier for the compressor will require a development of a new supplier for the company. This will not impact the customer because the compressor is an internal part and the customer does not have interface with it. This will promote a process parameter change by including a second source for compressor and will require a new certificate with the current supplier at legal/institutes. This will impact the product on primary function because the compressor is essential to water cooling.

The payback impact on F.6 is evaluated according to business standard from Table 10 – Company standards for change management.

As explained in Simulated Case 1, the business case score is calculated by the sum of the impacts multiplied by the priority on each category. The priority for F.1, F.2, F.3, F.4 and F.5 is as defined on Table 8 – Change Difficulty Level and Certification requirement, and the priority for F.6 as well as the impact for all the items are as defined by the business standard from Table 10 – Company standards for change management. The calculation is illustrated on Table 14 for this stimulated case.

Table 14 – Business case score calculation – Simulated Case 2

	Impact	**Priority**	**Product**
Supplier impact	2	2	4
Customer impact	0	2	0
Company impact	1	3	3
Legal/Institutes impact	1	1	1
Product subsystems impact	1	3	3
Payback impact	0	5	0
SUM			11

Source: Author (2019)

After the TBC is completed, the CAI for Feasibility creates the Change Report using the Template for Change Report. For this simulated case, the TCR is on Figure 37.

On the TCR, the item “A. Change Identification” and “C. Problem identification” are form TPR, and item “F. Business Case” with business case score is from TBC. The CAI for Feasibility analysis starts on item “G. Proposed Solution.”

Considering the skills required, the CAI for feasibility evaluates the technical solution for the problem requiring the change. The solution proposed in the request is to approve new compressor supplier to reduce 7% in compressor cost was accepted as solution for the problem of this stimulated case.

Considering the technical solution, the CAI for Feasibility identifies to which category each certification requires based on Table 8 – Change Difficulty Level and Certification requirement. In this case, since the solution is the one proposed on the change, this analysis was already made for the business case evaluation. Approving a new supplier for the compressor will require a development of a new supplier for the company. This will not impact the customer because the compressor is an internal part and the customer does not have interface with it. This will promote a process parameter change by including a second source for compressor. It will also require a new certificate with the current supplier at legal/institutes and will impact the

product on primary function because the compressor is essential to water cooling. With these categories, the required certifications are mapped on item G.2 from TCR.

Figure 37 – Template for Change Request – Simulated Case 2

A. Change Identification

A.1 Change ID:	20190717 - 1825
A.2 Request date:	17/07/2019

C. Problem Identification

C.3 Product afected:	Compact FN/PFN model
C.4 Part afected:	
ID	19
Description	Compressor

C.5 Problem description:

Approve new compressor supplier to reduce 7% in compressor cost (dual source for the item)

F. Business Case

BUSINESS CASE SCORE:	11

G. Proposed Solution

G.1 Technical solution:

Develop new supplier for compressor validating that all major characteristics are not impacted by the change (cooling capacity, energy efficiency, noise, maximun product weight, compressor size)

G.2 Certifications required:

	Prototype		Test		Production		Homologation	
Product					x	Product change impacting primary function	x	Product change impacting primary function
Process					x	Process parameter change	x	Process parameter change
Supplier	x	New supplier for the company	x	New supplier for the company	x	New supplier for the company	x	New supplier for the company
Customer		No impact		No impact		No impact		No impact
Institute					x	New certificate with current institute		

G.3 Resource Allocation required:

Impacted Area		FTE (qty)
Project Development	x	0,3
Manufacturing Assembly	x	0,1
Procurement	x	0,2
Supplier Quality	x	0,2
Product engineering	x	0,3
Institute certification	x	0,3

G.4 Technical Challenge:

	Level 1		Level 2		Level 3	x	Level 4		Level 5

TECHNICAL SCORE:	18

Source: Author (2019)

The resource allocation is also part of CAI for Feasibility skills and the decision is made based on experience. In this case, considering the development of a new compressor

supplier, it was identified that the project would require a partial FTE from project development team, manufacturing assembly, Procurement, Supplier Quality, Product Engineer and Institutes certification. The resources here are divided by company areas and may differ from company to company.

The technical challenge on item G.4 is defined by the highest level identified on Table 8 – Change Difficulty Level and Certification requirement. In this case, the Level 4 is defined because the "New supplier for the company" is level 4 of difficulty, while "Process parameter change" is level 2, "Product change impacting primary function" is level 3 and "New certificate with current institute" is level 2. Customer is not impacted.

The technical score is defined by the sum of quantity of certifications required, quantity of impacted areas and the technical challenge grade as described on Simulated Case 1 (Level 1 is grade 0, Level 2 is grade 1, Level 3 is grade 2, Level 4 is grade 3 and Level 5 is grade 4). In this case, there are 9 certifications required, 6 impacted areas and grade 3, the sum is 9 + 6 + 3, resulting on a technical score of 18.

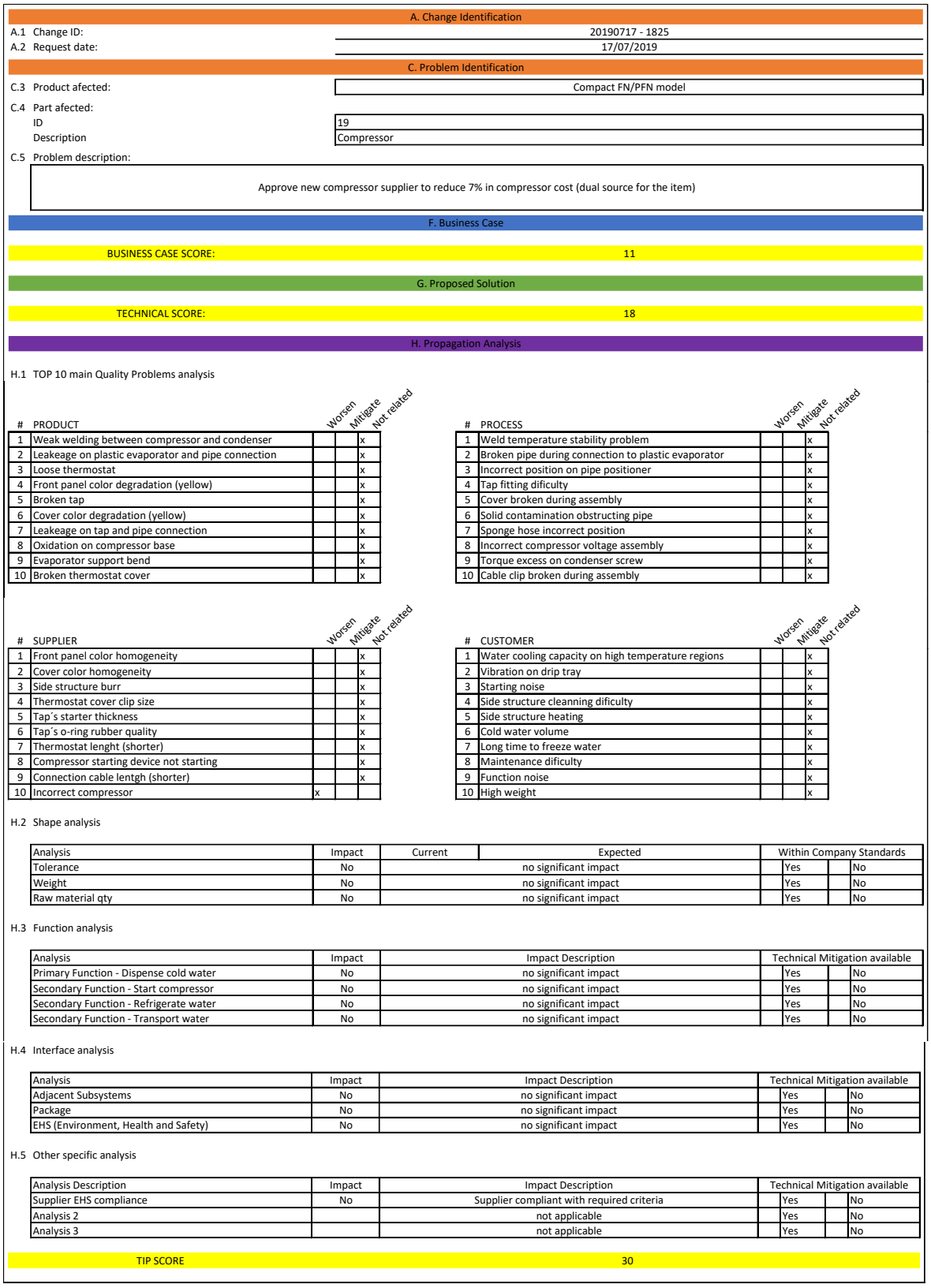
Considering the TCR completed, the next step of the ECM process is the CAI for Analysis to evaluate the Change Request and approve it. The CAI for Analysis skills will be used to ensure the information on TCR is accurate and the change can go to next ECM phase. With the change request approved, it concludes the "Technical and Financial feasibility evaluation" phase and the next stage on the ECM flow is the "Impact propagation analysis."

5.3.2.3Impact propagation analysis phase

To analyze impact propagation for the change, the CAI for Analysis will arrange multiple meetings with experts on different areas and fill the Template for Impact propagation. The TIP is on Figure 38 for this case.

On the TIP, items "A. Change Identification" and "C. Problem identification" are from TPR, item "F. Business Case" with business case score is from TBC, and item "G. Proposed Solution" with technical score is from TCR. The CAI for Analysis evaluation starts with item "H. Propagation Analysis."

Figure 38 – Template for Impact Propagation – Simulated Case 2



A. Change Identification

A.1 Change ID:	20190717 - 1825
A.2 Request date:	17/07/2019

C. Problem Identification

C.3 Product afected:	Compact FN/PFN model
C.4 Part afected:	
ID	19
Description	Compressor

C.5 Problem description:

Approve new compressor supplier to reduce 7% in compressor cost (dual source for the item)

F. Business Case

BUSINESS CASE SCORE:	11

G. Proposed Solution

TECHNICAL SCORE:	18

H. Propagation Analysis

H.1 TOP 10 main Quality Problems analysis

#	PRODUCT	Worsen	Mitigate	Not related
1	Weak welding between compressor and condenser			x
2	Leakeage on plastic evaporator and pipe connection			x
3	Loose thermostat			x
4	Front panel color degradation (yellow)			x
5	Broken tap			x
6	Cover color degradation (yellow)			x
7	Leakeage on tap and pipe connection			x
8	Oxidation on compressor base			x
9	Evaporator support bend			x
10	Broken thermostat cover			x

#	PROCESS	Worsen	Mitigate	Not related
1	Weld temperature stability problem			x
2	Broken pipe during connection to plastic evaporator			x
3	Incorrect position on pipe positioner			x
4	Tap fitting dificulty			x
5	Cover broken during assembly			x
6	Solid contamination obstructing pipe			x
7	Sponge hose incorrect position			x
8	Incorrect compressor voltage assembly			x
9	Torque excess on condenser screw			x
10	Cable clip broken during assembly			x

#	SUPPLIER	Worsen	Mitigate	Not related
1	Front panel color homogeneity			x
2	Cover color homogeneity			x
3	Side structure burr			x
4	Thermostat cover clip size			x
5	Tap´s starter thickness			x
6	Tap´s o-ring rubber quality			x
7	Thermostat lenght (shorter)			x
8	Compressor starting device not starting			x
9	Connection cable lentgh (shorter)			x
10	Incorrect compressor	x		

#	CUSTOMER	Worsen	Mitigate	Not related
1	Water cooling capacity on high temperature regions			x
2	Vibration on drip tray			x
3	Starting noise			x
4	Side structure cleanning dificulty			x
5	Side structure heating			x
6	Cold water volume			x
7	Long time to freeze water			x
8	Maintenance dificulty			x
9	Function noise			x
10	High weight			x

H.2 Shape analysis

Analysis	Impact	Current	Expected	Within Company Standards	
Tolerance	No	no significant impact		Yes	No
Weight	No	no significant impact		Yes	No
Raw material qty	No	no significant impact		Yes	No

H.3 Function analysis

Analysis	Impact	Impact Description	Technical Mitigation available	
Primary Function - Dispense cold water	No	no significant impact	Yes	No
Secondary Function - Start compressor	No	no significant impact	Yes	No
Secondary Function - Refrigerate water	No	no significant impact	Yes	No
Secondary Function - Transport water	No	no significant impact	Yes	No

H.4 Interface analysis

Analysis	Impact	Impact Description	Technical Mitigation available	
Adjacent Subsystems	No	no significant impact	Yes	No
Package	No	no significant impact	Yes	No
EHS (Environment, Health and Safety)	No	no significant impact	Yes	No

H.5 Other specific analysis

Analysis Description	Impact	Impact Description	Technical Mitigation available	
Supplier EHS compliance	No	Supplier compliant with required criteria	Yes	No
Analysis 2		not applicable	Yes	No
Analysis 3		not applicable	Yes	No

TIP SCORE	30

Source: Author (2019)

The main quality problems are defined by the company on item 8.1.2. The responsibility of CAI for Analysis is to identify if the proposed change will impact any of the listed problems. While using CAI for analysis skill and input from experts, it was identified that developing a new supplier for compressor will worsen “Incorrect compressor” because instead of 2 compressors items (Compressor1 110V, Compressor1 220V), the line would manufacture 4 compressors items (Compressor1 110V, Compressor1 220V, Compressor2 110V, Compressor2 220V). The other problems are not related to compressor supplier and will not be impacted by the change.

As explained on Simulated Case 1, the shape analysis is also conducted by the CAI for Analysis and supported by experts during alignment meetings if necessary. In this case, developing a new supplier for compressor with same characteristics will not significantly impact tolerance nor weigh and raw material because the part will be similar to the current one.

The function analysis and interface analysis are also conducted by the CAI for Analysis. These analyses supported by experts during alignment meetings if necessary. For this case, neither analysis shows significant impact. This happens because the change is on a specific part. Despite composing the subsystem impacting water cooler, the new compressor has the same characteristics as the current one and cannot impact neither the primary nor secondary functions. Besides that, the change will not interfere with other subsystems, does not impact package because it is internal to the product, and is not proposing any material change nor process standard that could generate any impact on Environment, Health or Safety.

A specific analysis regarding “Supplier EHS compliance” is required but since the new supplier is compliant with Environment, Health or Safety, there is no impact identified.

With this, the TIP score can be calculated by the sum of business score, technical score and propagation analysis score. The propagation analysis score is defined as the sum for the points on item “H. Propagation analysis” such as illustrated on Table 13 from Simulated Case 1.

For this case, the TIP is the sum of 11 (business case score) + 18 (technical score) + 1 (quality problem worsen) resulting in TIP as 30. The “Impact propagation analysis” phase is concluded and the next stage on the ECM flow is the “Change Implementation” with the TIP score.

5.3.2.4Change Implementation phase

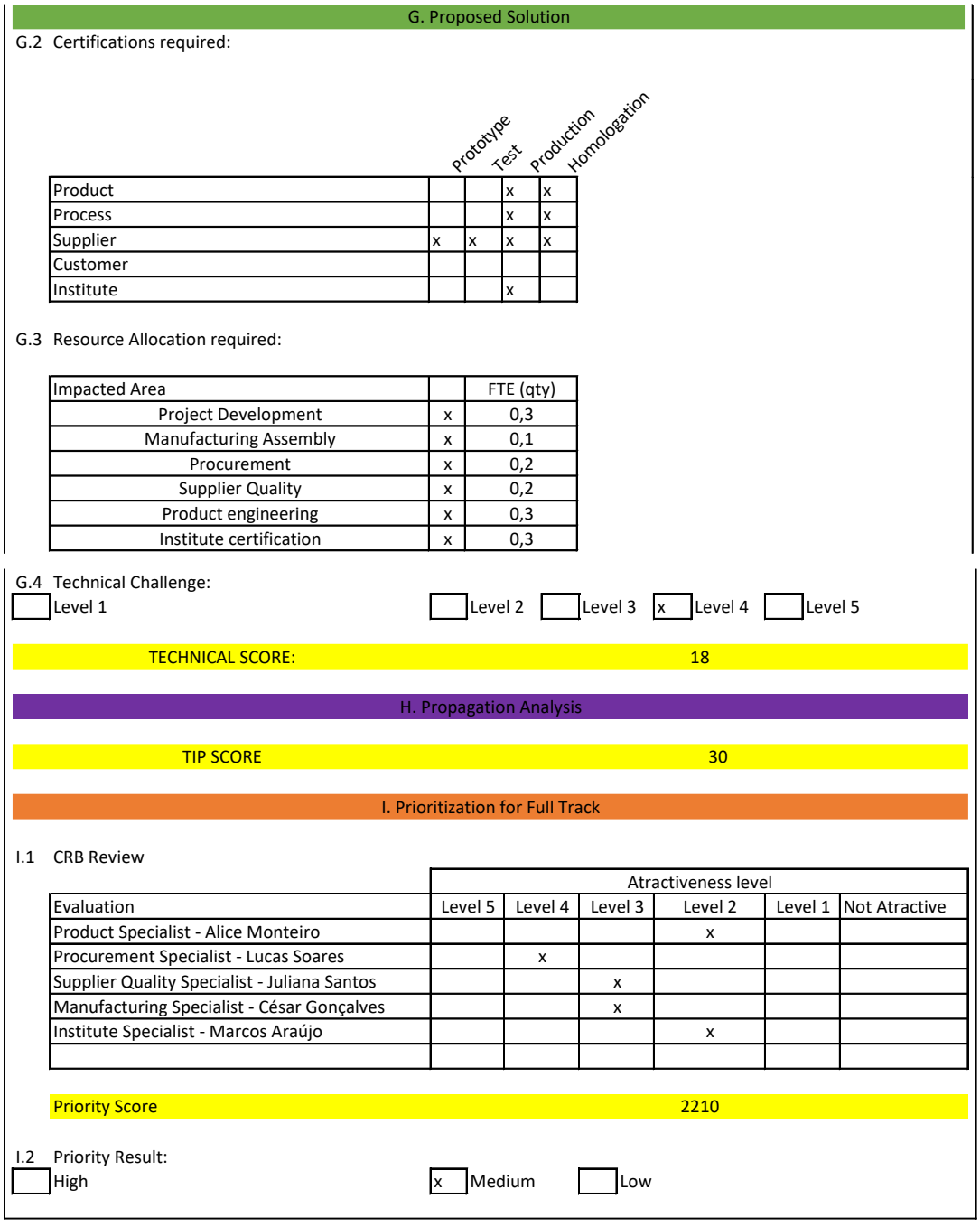
The first step in change implementation is the approval for change execution. Considering the TCR and TIP score, the CAI for analysis will compare business standard with change results in order to define if it will be Full track or Fast track. In this case, Table 10 – Company standards for change management — defines that the change can be Fast track if the business case score is lower than 10, the technical score is lower than 13 and the TIP score is lower than 25. The simulated case 2 exceed these requirements with business case score 11, technical score 18 and TIP score 30. Therefore, simulated case 2 will be conducted as Full Track. The TPFull is in Figure 39.

With TPFull completed, the PMO will prioritize the change to be executed. When the request is prioritized, the PMO creates the Change Notice that defines a CAII. The TCN for simulated case 2 is on Figure 40.

Figure 39 – Template for Full Track – Simulated Case 2

A. Change Identification			
A.1 Change ID:	20190717 - 1825		
A.2 Request date:	17/07/2019		
C. Problem Identification			
C.3 Product afected:	Compact FN/PFN model		
C.4 Part afected:			
ID	19		
Description	Compressor		
C.5 Problem description:			
Approve new compressor supplier to reduce 7% in compressor cost (dual source for the item)			
F. Business Case			
F.1 Supplier impact:			
[x] High	[ ] Medium	[ ] Low	
F.2 Customer :			
[ ] High	[ ] Medium	[x] Low	
F.3 Company impact:			
[ ] High	[x] Medium	[ ] Low	
F.4 Legal/Institutes impact:			
[ ] High	[x] Medium	[ ] Low	
F.5 Product subsystems impact:			
[ ] High	[x] Medium	[ ] Low	
F.6 Payback impact:			
[ ] High	[ ] Medium	[x] Low	
BUSINESS CASE SCORE:	11		

Figure 39 – Template for Full Track – Simulated Case 2 (cont.)



G. Proposed Solution

G.2 Certifications required:

	Prototype	Test	Production	Homologation
Product			x	x
Process			x	x
Supplier	x	x	x	x
Customer				
Institute			x	

G.3 Resource Allocation required:

Impacted Area		FTE (qty)
Project Development	x	0,3
Manufacturing Assembly	x	0,1
Procurement	x	0,2
Supplier Quality	x	0,2
Product engineering	x	0,3
Institute certification	x	0,3

G.4 Technical Challenge:

[ ] Level 1 [ ] Level 2 [ ] Level 3 [x] Level 4 [ ] Level 5

TECHNICAL SCORE:	18

H. Propagation Analysis

TIP SCORE	30

I. Prioritization for Full Track

I.1 CRB Review

	Atractiveness level					
Evaluation	Level 5	Level 4	Level 3	Level 2	Level 1	Not Atractive
Product Specialist - Alice Monteiro				x		
Procurement Specialist - Lucas Soares		x				
Supplier Quality Specialist - Juliana Santos			x			
Manufacturing Specialist - César Gonçalves			x			
Institute Specialist - Marcos Araújo				x		

Priority Score	2210

I.2 Priority Result:

[ ] High [x] Medium [ ] Low

Source: Author (2019)

On the TPFull, the item “A. Change Identification” and “C. Problem identification” are from TPR, item “F. Business Case” with business case score is from TBC, item “G. Proposed Solution” is from TCR and item “H. Propagation Analysis” is from TIP. The CAI for Analysis evaluation starts with item “I. Prioritization for Full Track.”

The CRB participant list is defined by CAI for Analysis based on impacted areas and previous experience. In this simulated case, the names are fictional to serve as reference.

The attractiveness level is defined by each participant of CRB based on own skills and the priority score is the sum of attractiveness considering the values defined on Table 10 – Company standards for change management.

For this simulated case, the attractiveness defined by the product specialist was level 2, by procurement specialist was level 4, by supplier quality specialist and manufacturing specialist was level 3, and for institute specialist was level 2. Considering the change will increase product complexity and require new institute certification. The level 2 rate defined by product and institute specialist is justified. Procurement is highly attractive because it will decrease total purchasing costs for the compressor, manufacturing, and supplier quality. Perspective is neither attractive nor unattractive, therefore the rate 3 is explained.

The priority score is the sum of 1000 + 10 + 100 + 100 + 1000 (as attractiveness level score from business standard), resulting in 2210. According Table 10 - Company standards for change management—the priority score is between 50 and 2500. Therefore, the result is MEDIUM.

On TCN from Figure 40, all information originates on a previous template already submitted on the process. The PMO only consolidates the information on this template and defines the person as an assignee for the change execution. In this case, the name is fictional to serve as reference.

The assignee on TCN will prepare a change implementation plan using the TCP. As described on Simulated case 1, this plan minimally considers the required certifications identified on TCN, but also includes activities required by the company process to ensure the change execution. The plan is created based on CAII skills and experience.

For this case, the plan was divided into 4 implementation phases as illustrated on Figure 41. As highlighted on Simulated case 1, the plan is based on CAII skills and experience and is difficult to standardize.

Figure 40 – Template for Change Notice – Simulated Case 2

A. Change Identification

A.1 Change ID:	20190717 - 1825
A.2 Request date:	17/07/2019

C. Problem Identification

C.3 Product afected:	Compact FN/PFN model
C.4 Part afected:	
ID	19
Description	Compressor

C.5 Problem description:

Approve new compressor supplier to reduce 7% in compressor cost (dual source for the item)

F. Business Case

BUSINESS CASE SCORE:	11

G. Proposed Solution

G.1 Technical solution:

Develop new supplier for compressor validating that all major characteristics are not impacted by the change (cooling capacity, energy efficiency, noise, maximun product weight, compressor size)

G.2 Certifications required:

	Prototype		Test		Production		Homologation	
Product					x	Product change impacting primary function	x	Product change impacting primary function
Process					x	Process parameter change	x	Process parameter change
Supplier	x	New supplier for the company	x	New supplier for the company	x	New supplier for the company	x	New supplier for the company
Customer		No impact		No impact		No impact		No impact
Institute					x	New certificate with current institute		

G.3 Resource Allocation required:

Impacted Area		FTE (qty)
Project Development	x	0,3
Manufacturing Assembly	x	0,1
Procurement	x	0,2
Supplier Quality	x	0,2
Product engineering	x	0,3
Institute certification	x	0,3

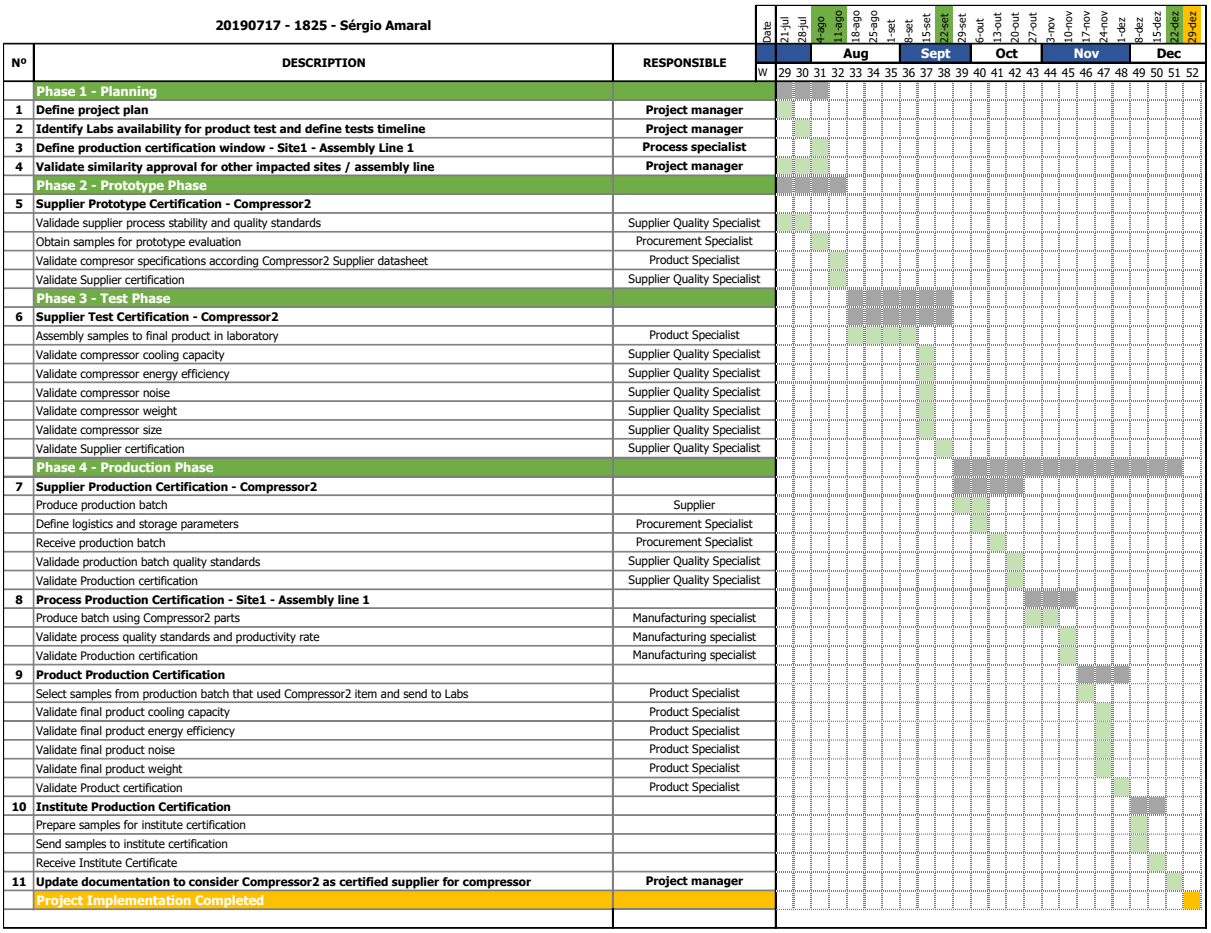
TECHNICAL SCORE:	18

H. Propagation Analysis

TIP SCORE	30
Assingee:	Sérgio Amaral

Source: Author (2019)

Figure 41 – Template for Change Plan – Simulated Case 2



20190717 - 1825 - Sérgio Amaral			Date	21-jul	28-jul	4-ago	11-ago	18-ago	25-ago	1-set	8-set	15-set	22-set	29-set	6-out	13-out	20-out	27-out	3-nov	10-nov	17-nov	24-nov	1-dez	8-dez	15-dez	22-dez	29-dez
						Aug						Sept			Oct				Nov					Dec			
Nº	DESCRIPTION	RESPONSIBLE	W	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
	Phase 1 - Planning																										
1	**Define project plan**	**Project manager**																									
2	**Identify Labs availability for product test and define tests timeline**	**Project manager**																									
3	**Define production certification window - Site1 - Assembly Line 1**	**Process specialist**																									
4	**Validate similarity approval for other impacted sites / assembly line**	**Project manager**																									
	Phase 2 - Prototype Phase																										
5	**Supplier Prototype Certification - Compressor2**																										
	Validade supplier process stability and quality standards	Supplier Quality Specialist																									
	Obtain samples for prototype evaluation	Procurement Specialist																									
	Validate compresor specifications according Compressor2 Supplier datasheet	Product Specialist																									
	Validate Supplier certification	Supplier Quality Specialist																									
	Phase 3 - Test Phase																										
6	**Supplier Test Certification - Compressor2**																										
	Assembly samples to final product in laboratory	Product Specialist																									
	Validate compressor cooling capacity	Supplier Quality Specialist																									
	Validate compressor energy efficiency	Supplier Quality Specialist																									
	Validate compressor noise	Supplier Quality Specialist																									
	Validate compressor weight	Supplier Quality Specialist																									
	Validate compressor size	Supplier Quality Specialist																									
	Validate Supplier certification	Supplier Quality Specialist																									
	Phase 4 - Production Phase																										
7	**Supplier Production Certification - Compressor2**																										
	Produce production batch	Supplier																									
	Define logistics and storage parameters	Procurement Specialist																									
	Receive production batch	Procurement Specialist																									
	Validade production batch quality standards	Supplier Quality Specialist																									
	Validate Production certification	Supplier Quality Specialist																									
8	**Process Production Certification - Site1 - Assembly line 1**																										
	Produce batch using Compressor2 parts	Manufacturing specialist																									
	Validate process quality standards and productivity rate	Manufacturing specialist																									
	Validate Production certification	Manufacturing specialist																									
9	**Product Production Certification**																										
	Select samples from production batch that used Compressor2 item and send to Labs	Product Specialist																									
	Validate final product cooling capacity	Product Specialist																									
	Validate final product energy efficiency	Product Specialist																									
	Validate final product noise	Product Specialist																									
	Validate final product weight	Product Specialist																									
	Validate Product certification	Product Specialist																									
10	**Institute Production Certification**																										
	Prepare samples for institute certification																										
	Send samples to institute certification																										
	Receive Institute Certificate																										
11	**Update documentation to consider Compressor2 as certified supplier for compressor**	**Project manager**																									
	Project Implementation Completed																										

Source: Author (2019)

After TCP is completed, the CAII prepares the TCPA to submit for CIB (Change Implementation Board) approval. The participants on CIB can be the same as CRB or different members according to company policy or CAII experience. For this simulated case, it was considered that the same participants on CRB were defined as CIB members. The TCPA approved document can be found in Figure 42.

On the TCPA, the item "A. Change Identification" and "C. Problem identification" are from TPR, item "G. Proposed Solution" is from TCR, the main dates on item "J. Proposed Change Plan" are from TCP, and the CIB is according as defined by company policy or CAII experience.

With TCPA approved by CIB, the CAII starts process implementation based on the plan and considers company process to execute the planned activities. When the implementation is completed, the CAII submits the change for audit and release by CAIII.

Figure 42 – Template for Change Plan approval – Simulated Case 2

A. Change Identification

A.1 Change ID: 20190717 - 1825
A.2 Request date: 17/07/2019

C. Problem Identification

C.3 Product afected: Compact FN/PFN model

C.4 Part afected:
ID: 19
Description: Compressor

C.5 Problem description:

Approve new compressor supplier to reduce 7% in compressor cost (dual source for the item)

G. Proposed Solution

G.1 Technical solution:

Develop new supplier for compressor validating that all major characteristics are not impacted by the change (cooling capacity, energy efficiency, noise, maximun product weight, compressor size)

J. Proposed Change Plan

J.1 Main Dates:

Project Plan	Date
Phase 1 - Planning	04/08/2019
Phase 2 - Prototype Phase	11/08/2019
Phase 3 - Test Phase	22/09/2019
Phase 4 - Production Phase	22/12/2019
Project Implementation Completed	29/12/2019

J.2 Change Implementation Board (CIB):

Member	Approval
Product Specialist - Alice Monteiro	Yes
Procurement Specialist - Lucas Soares	Yes
Supplier Quality Specialist - Juliana Santos	Yes
Manufacturing Specialist - César Gonçalves	Yes
Institute Specialist - Marcos Araújo	Yes

J.3 General Comments

Source: Author (2019)

The CAIII fills the TCA to check and audit the major deliverables from TCP. As explained on Simulated Case 1, the CAIII needs to identify main deliverables and minimally ensure the required certifications are completed and approved. For this reason, specific CAIII skills are required. The TCA can be found in Figure 43.

On the TCA, items “A. Change Identification” and “C. Problem identification” are from TPR, and item “G. Proposed Solution” with technical score is from TCR. The CAII evaluation starts with item “L. Audit.” In this case, the audit list considered the deliverables, Supplier Prototype Certification - Compressor2, Supplier Test Certification - Compressor2, Supplier Production Certification - Compressor2, Process Production Certification - Site1 - Assembly line 1, Product Production Certification, and Institute Production Certification. Updated documentation considers Compressor2 as certified supplier for compressor.

All deliverables were expected by CAIII experience. The comments are included for further reference. The result is marked as “Approved.”

Figure 43 – Template for Change Audit – Simulated Case 2

A. Change Identification

A.1 Change ID:	20190717 - 1825
A.2 Request date:	17/07/2019

C. Problem Identification

C.3 Product afected:	Compact FN/PFN model
C.4 Part afected:	
ID	19
Description	Compressor

C.5 Problem description:

Approve new compressor supplier to reduce 7% in compressor cost (dual source for the item)

G. Proposed Solution

G.1 Technical solution:

Develop new supplier for compressor validating that all major characteristics are not impacted by the change (cooling capacity, energy efficiency, noise, maximun product weight, compressor size)

L. Audit

Main Deliverables	Delivered				Comments
Supplier Prototype Certification - Compressor2	x	Yes		No	
Supplier Test Certification - Compressor2	x	Yes		No	
Supplier Production Certification - Compressor2	x	Yes		No	
Process Production Certification - Site1 - Assembly line 1	x	Yes		No	
Product Production Certification	x	Yes		No	
Institute Production Certification	x	Yes		No	
Update documentation to consider Compressor2 as certified supplier for compressor	x	Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	

Final Result: Approved

Source: Author (2019)

The audit and release process concludes the “Change Implementation” phase and the next stage on the ECM flow is the “Not relevant impacts validation”.

5.3.2.5Not relevant impacts validation phase

When the change notice is completed, the CAII evaluates the Not relevant impacts after the change by creating a plan to homologate the results. The TH minimally contains the Homologation certifications required by the change.

As explained on Simulated Case 1, similar to change plan, the homologation plan is based on CAII skills and experience. Results for each different CAII defined are considered a different plan. The plan definition is difficult to standardize and relies on the correct definition of CAII. For this case, the TH is in Figure 44.

Figure 44 – Template for Homologation – Simulated Case 2

20190717 - 1825 - Sérgio Amaral

Nº	DESCRIPTION	RESPONSIBLE
	Phase 1 - Product Homologation	
1	Select 10 samples from different batches produced with Compressor2	Project Manager
2	Execute performance tests	
	Cooling capacity test - 10 samples	Lab responsible
	Water volume test - 10 sampels	Lab responsible
	Noise test - 10 samples	Lab responsible
3	Validade homologation results	Project Manager
	Phase 2 - Process Homologation	
4	Site1 - Assembly Line 1	
	Review line performance index (productivity, quality, OEE etc)	Process Specialist
	Validate homologation results	Process Specialist
5	Sites approved by similarity	
	Review line performance index (productivity, quality, OEE etc)	Process Specialist
	Validate homologation results	Process Specialist
	Phase 3 - Supplier Homologation	
6	Compressor2	
	Review quality index	Supplier Quality Specialist
	Validate homologation results	Supplier Quality Specialist
	Project Homologation Completed	

Jan | Feb | Mar | Apr | Mai | Jun

W 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26

Impact Final Evaluation:

	Yes
x	No

Source: Author (2019)

The final definition regarding Impact final evaluation is decided by CAII after the homologation activities are completed and all results are according expected. In this case, the final impact evaluation was that no unexpected impact was identified,

Since there was no evidence of impact, the ECM process is completed and the change is concluded.

5.3.3Simulated Case 3

5.3.3.1Engineering Change need phase

The first step in the ECM flow is to identify the engineering change need. In this simulated case, the problem illustrated on Board 28 is "Upgrade current plastic evaporator item for Product4 plastic evaporator model in order to standardize plastic evaporator on manufacturing." The change required is to replace in BOM for Compact model FN/PFN plastic evaporator ID 3 by plastic evaporator ID 58.

To support the proper record of this need and to start the change process, a problem report is required. The Template for Problem Report supports this request. Figure 45 shows the TPR for Case 3.

Figure 45 – Template for Problem Report – Simulated Case 3

A. Change Identification

A.1 Change ID: 20190721 - 1607
A.2 Request date: 21/07/2019

B. Requester Identification

B.1 Requester name: Luzia Garcia
B.2 Requester contact: luzia-garcia@ibbl.com.br
B.3 Requester area: Logistics

C. Problem Identification

C.1 Problem major reason:

	Mistakes	x	Internal process
	Legislation/Certification		Not product related
	Customer driven		

C.2 Problem origin:

	Incorrect documentation		Amendment on existing legal/certificate requirement		Improve Manufacturability, Maintainability or Transport
	Specification errors		Customization		Cost reduction
	Requirements non-fulfillment		Market trend		Company deficiencies on business process
	New legal/certificate requirement in force	x	Upgrade		Others

C.3 Product afected: Compact FN/PFN model

C.4 Part afected:
ID: 3
Description: Plastic evaporator

C.5 Problem description:
Upgrade current plastic evaporator item for Product4 plastic evaporator model in order to standardize plastic evaporator on manufacturing

C.6 Attachment

Current Situation	Proposed solution
Plastic evaporator ID: 3	Plastic evaporator ID: 58 (used on Product4)
Plastic evaporator cost: R$7,50 / unit	Plastic evaporator cost: R$7,72 /unit
Storage area: 62 m2 for ID 3 and 85 m2 for ID 58	Storage area: 100 m2 for ID 85
Plastic evaporator total buy: R$ 807.750,00 /year	Plastic evaporator total buy: R$ 831.444,00 /year
Storage cost (month): R$ 64 /m2	Storage total cost: R$ 76.800,00 /year
Storage total cost: R$ 112.896,00 /year	Cost reduction: R$ 12.402,00 /year

Source: Author (2019)

This template reflects the change need considering the parameters defined by the company. The change ID is described on item 5.2 as standard as defined by the company for change identification YYYYMMDD – HHMM. The request date is the date the request is being issued. In this simulated case, the date is considered as the date the research simulated the case.

The requester identification used a fictional name for employee and e-mail address to serve as example. The requester area is according to the case description from Board 28.

As mentioned for Simulated Case 1, the major problem is a decision from the requester when filling the template. In this simulated case, the request aims to replace the current plastic evaporator ID 3 with plastic evaporator ID 58 to improve storage area. “Internal Process” is the best option to indicate the reason for the request. This was marked on item C.1 from TPR.

The problem origin also requires analysis to identify the alternative most related to the problem and is a decision made by the requester. In this case, “Upgrade” is more related to the problem because the change requests the replacement of a part used on another product. The part that is used to replace the current part is more advanced. This origin was marked on item C.2 from TPR. The option “Improve Manufacturability, Maintainability or Transport” could also be considered, but since the storage is not directly related to manufacturability, maintainability, or transport, the upgrade option suits better the purpose.

Same as adopted on Simulated Case 1, the product affected will always be Compact FN/PFN model because it is the product used as reference for this study. The part affected is as defined on the case description on Board 28.

The problem description and the details on attachment also come from the case identification illustrated on Board 28. It is important to reinforce that real cases clearly describe those items. It is essential to proceed with the next steps of the change evaluation.

With the problem report completed, the change process receives an ID and can be evaluated through the change process steps. With ECM need properly identified and the Problem Report as a document to start the engineering change, the step “Engineering Change Need” phase is completed. The next stage on the ECM flow is the “Technical and Financial feasibility evaluation”.

5.3.3.2Technical and Financial feasibility evaluation phase

After problem report creation, as illustrated on Figure 16 from Chapter 4, the next step is evaluation of problem report by CAI for Feasibility. At this step, the information from

problem report will be evaluated to ensure it is completed. This will allow for the next steps of the process.

In this simulated case, the change need is clearly defined and all the analysis regarding possible gains and impact are described in the attachment from item C.6 at TPR. Considering the CAI for Feasibility experience, the information on TPR is enough to proceed and the request is technically feasible. For this reason, the CAI for feasibility creates the business case in Figure 46.

On TBC, the items “A. Change Identification” and “C. Problem Identification” come from the problem report. The evaluation starts at item “D. Problem Analysis.”

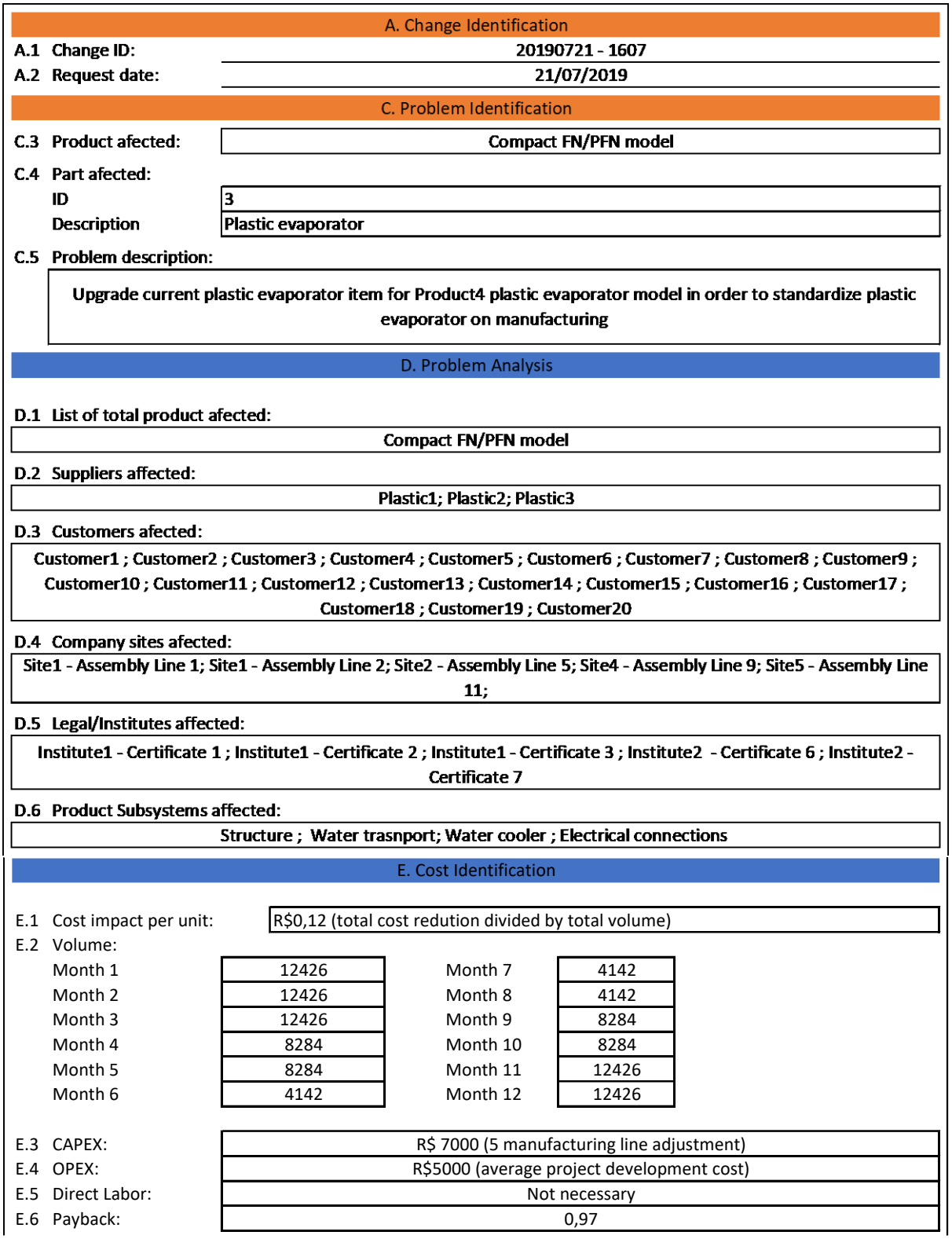
The product affected will. In real cases, however, it is important that CAI for Feasibility checks other company products to verify if they use the same impacted part or same impacted process. If any other product besides the one identified by the requester on Problem Report is impacted, it should also be listed on item D.1 from TBC.

The list of suppliers, customers, company sites, legal/institutes and product subsystem affected all come from definitions to support the ECM framework described on item 5.1.2. The suppliers refer to Supplier Matrix for the impacted part that is “Plastic Evaporator.” The customer refers to the Customer List for the product. The company sites affected are as described on Manufacturing Map for the product. The legal/institutes affected consider the certification the product have according the Certification Map. The subsystems affected are the subsystems that the affected part is related to according the Correlation Matrix. In Simulated Case 3, the information for items D.1, D.2, D.3, D.4 and D.5 are the same as Simulated Case 1 because the product is the same while D.6 varies according to the affected part.

The cost identification also requires analysis from the CAI for Feasibility. In this simulated case, the total cost reduction estimated by the requester is R$ 12.402,00 per year while the annual production for the product according to the Customer List from item 5.1.2 is 107700 units. Therefore, the cost reduction for each produced unit will be R$ 0,12. This value is included on item E.1 from TBC.

The impacted volume in the case is all produced products because the change will be valid for all units. The distribution among months on item E.2 from TBC is the total production distribution from Graphic 9.

Figure 46 – Template for Business Case – Simulated Case 3



A. Change Identification

A.1	Change ID:	20190721 - 1607
A.2	Request date:	21/07/2019

C. Problem Identification

C.3	Product afected:	Compact FN/PFN model
C.4	Part afected:	
	ID	3
	Description	Plastic evaporator

C.5 Problem description:

Upgrade current plastic evaporator item for Product4 plastic evaporator model in order to standardize plastic evaporator on manufacturing

D. Problem Analysis

D.1 List of total product afected:

Compact FN/PFN model

D.2 Suppliers affected:

Plastic1; Plastic2; Plastic3

D.3 Customers afected:

Customer1 ; Customer2 ; Customer3 ; Customer4 ; Customer5 ; Customer6 ; Customer7 ; Customer8 ; Customer9 ; Customer10 ; Customer11 ; Customer12 ; Customer13 ; Customer14 ; Customer15 ; Customer16 ; Customer17 ; Customer18 ; Customer19 ; Customer20

D.4 Company sites afected:

Site1 - Assembly Line 1; Site1 - Assembly Line 2; Site2 - Assembly Line 5; Site4 - Assembly Line 9; Site5 - Assembly Line 11;

D.5 Legal/Institutes affected:

Institute1 - Certificate 1 ; Institute1 - Certificate 2 ; Institute1 - Certificate 3 ; Institute2 - Certificate 6 ; Institute2 - Certificate 7

D.6 Product Subsystems affected:

Structure ; Water trasnport; Water cooler ; Electrical connections

E. Cost Identification

E.1 Cost impact per unit: R$0,12 (total cost redution divided by total volume)

E.2 Volume:

Month 1	12426	Month 7	4142
Month 2	12426	Month 8	4142
Month 3	12426	Month 9	8284
Month 4	8284	Month 10	8284
Month 5	8284	Month 11	12426
Month 6	4142	Month 12	12426

E.3	CAPEX:	R$ 7000 (5 manufacturing line adjustment)
E.4	OPEX:	R$5000 (average project development cost)
E.5	Direct Labor:	Not necessary
E.6	Payback:	0,97

Figure 46 – Template for Business Case – Simulated Case 3 (cont.)

F. Business Case				
F.1 Supplier impact:				
	High		Medium	x Low	Documentation update
F.2 Customer :				
	High		Medium	x Low	No impact
F.3 Company impact:				
	High	x	Medium		Low	Impact on overral production rate
F.4 Legal/Institutes impact:				
	High		Medium	x Low	No impact
F.5 Product subsystems impact:				
	High	x	Medium		Low	Product change impacting primary function
F.6 Payback impact:				
	High	x	Medium		Low	Between 0,5 and 1,0
BUSINESS CASE SCORE:			11		

Source: Author (2019)

The project requires a CAPEX investment to adjust 5 manufacturing lines where the product is manufactured. Considering the cost per line on Table 11 – Reference cost for cases business case analysis – the total amount is R$7000. The OPEX is an average project development cost that according to Table 11 is R$5000. There is no direct labor impact because the change will neither remove any employee from the company nor require any employee to be hired. Institutes certifications are also not required in this case. This information is filled on items E.3, E.4 and E.5 from TBC.

The payback is calculated by dividing the total cost for the change (that is, this case is R$12.000) by the total annual gain (R$ 12.402,00), that results in 0,97 as reported on item E.6 for TBC.

The business case impact evaluation is based on company standard where F.1, F.2, F.3, F.4 and F.5 are assessed based on Table 8 – Change Difficulty Level and Certification requirement. To identify which category on the table is related to the change is part of CAI for feasibility skills. In this case, approving a new plastic evaporator will require a documentation update with the supplier to consider the ID change on this part. This will not impact the customer because the plastic evaporator is an internal part and the customer does not have interface with it. It will impact both an overall production rate due to part replacement as well

as the product on primary function because the plastic evaporator is essential to water cooling. It will not require any certificate change at legal/institutes.

The payback impact on F.6 is evaluated according to business standard from Table 10 – Company standards for change management.

As explained on Simulated Case 1, the business case score is calculated by the sum of the impacts multiplied by the priority on each category. The priority for F.1, F.2, F.3, F.4 and F.5 are as defined on Table 8 – Change Difficulty Level and Certification requirement. The priority for F.6, as well as the impact for all other items, is as defined by the business standard from Table 10 – Company standards for change management. The calculation is illustrated on Table 15 for this stimulated case.

Table 15 – Business case score calculation – Simulated Case 3

	Impact	**Priority**	**Product**
Supplier impact	0	2	0
Customer impact	0	2	0
Company impact	1	3	3
Legal/Institutes impact	0	1	0
Product subsystems impact	1	3	3
Payback impact	1	5	5
SUM			11

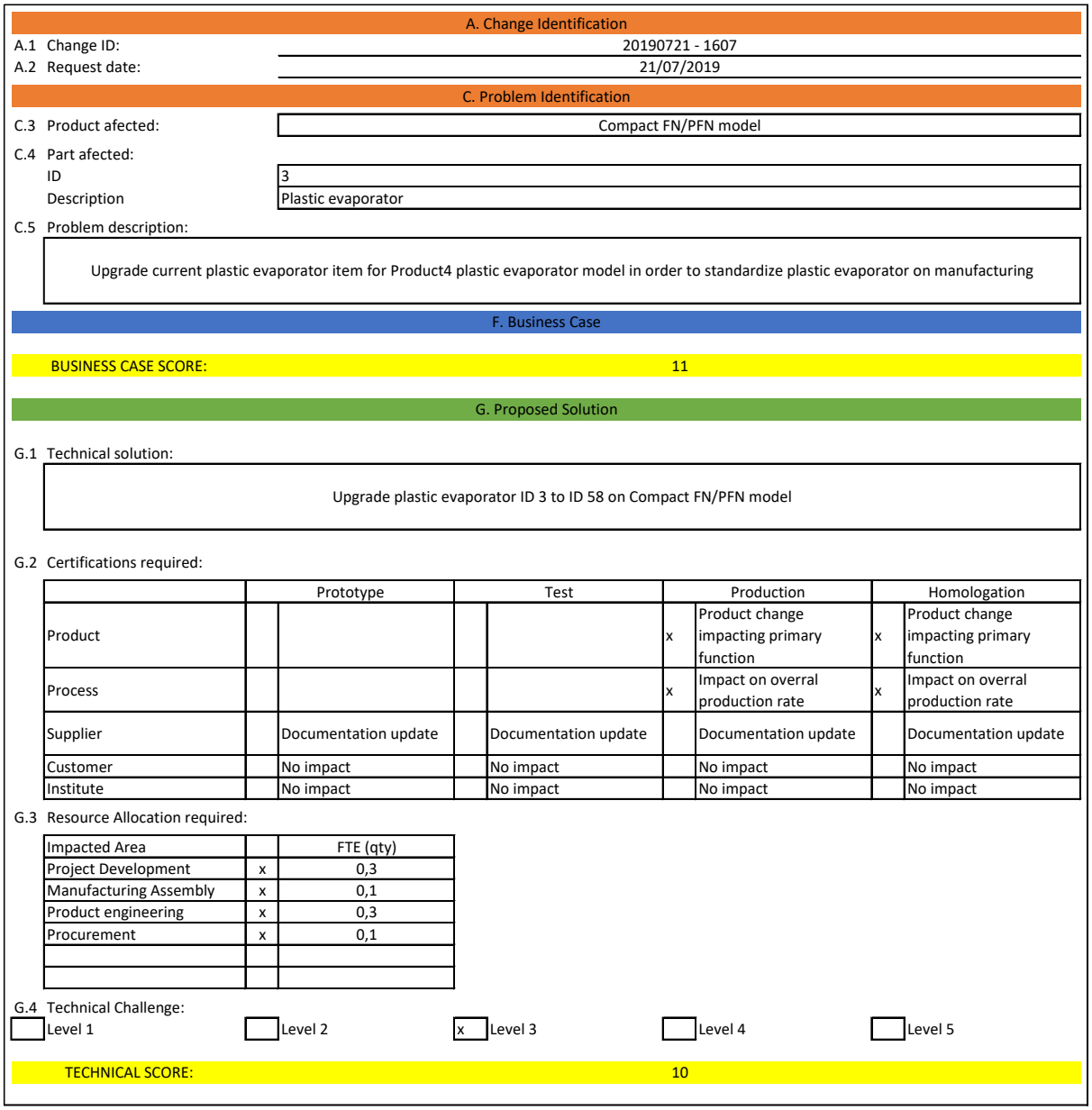
Source: Author (2019)

After the TBC is completed, the CAI for Feasibility creates the Change Report using the Template for Change Report. For this simulated case, the TCR is on Figure 47.

On the TCR, the items “A. Change Identification” and “C. Problem identification” are from TPR. Item “F. Business Case” with business case score is from TBC. The CAI for Feasibility analysis starts on item “G. Proposed Solution.”

Considering the skills required, the CAI for feasibility evaluates the technical solution for the problem requiring the change. On this simulated case, the solution proposed on the request to upgrade the current plastic evaporator item for the Product4 plastic evaporator model in order to standardize the plastic evaporator on manufacturing was accepted as solution for the problem.

Figure 47 – Template for Change Request – Simulated Case 3



A. Change Identification

A.1 Change ID:	20190721 - 1607
A.2 Request date:	21/07/2019

C. Problem Identification

C.3 Product afected:	Compact FN/PFN model
C.4 Part afected:	
ID	3
Description	Plastic evaporator

C.5 Problem description:

Upgrade current plastic evaporator item for Product4 plastic evaporator model in order to standardize plastic evaporator on manufacturing

F. Business Case

BUSINESS CASE SCORE: 11

G. Proposed Solution

G.1 Technical solution:

Upgrade plastic evaporator ID 3 to ID 58 on Compact FN/PFN model

G.2 Certifications required:

	Prototype		Test		Production		Homologation	
Product					x	Product change impacting primary function	x	Product change impacting primary function
Process					x	Impact on overral production rate	x	Impact on overral production rate
Supplier		Documentation update		Documentation update		Documentation update		Documentation update
Customer		No impact		No impact		No impact		No impact
Institute		No impact		No impact		No impact		No impact

G.3 Resource Allocation required:

Impacted Area		FTE (qty)
Project Development	x	0,3
Manufacturing Assembly	x	0,1
Product engineering	x	0,3
Procurement	x	0,1

G.4 Technical Challenge:

	Level 1		Level 2	x	Level 3		Level 4		Level 5

TECHNICAL SCORE: 10

Source: Author (2019)

Considering the technical solution, the CAI for Feasibility identifies to which category each certification requires based on Table 8 – Change Difficulty Level and Certification requirement. In this case, since the solution is the one proposed on the change, this analysis was already made for business case evaluation. It will require a documentation update with the supplier to consider the ID change on this part, impact an overall production rate due to part replacement, and impact the product during primary function because the plastic evaporator is

essential to water cooling. However, it will not impact the customer because the plastic evaporator is an internal part and customer don´t have interface with it. It also will not require any certificate change at legal/institutes. The required certifications are mapped on item G.2 from TCR for these categories.

The resource allocation is also part of CAI for Feasibility skills and the decision is made based on experience. The consideration for replacing a part ID from a different product identified the project would require a partial FTE from the project development team, manufacturing assembly, Procurement and Product Engineer. The resources here are divided by company areas and may differ from company to company.

The technical challenge on item G.4 is defined by the highest level identified on Table 8 – Change Difficulty Level and Certification requirement. In this case, Level 3 is defined because the "Product change impacting primary function" is level 3 of difficulty, while "Impact overall production rate" is level 2, and "Documentation update" is level 1. Customer and Institutes are not impacted.

The technical score is defined by the compilation of quantity of certifications required, quantity of impacted areas and the technical challenge grade as described on Simulated Case 1 (Level 1 is grade 0, Level 2 is grade 1, Level 3 is grade 2, Level 4 is grade 3 and Level 5 is grade 4). In this case, there are 4 certifications required, 4 impacted areas and grade 2, the sum is 4 + 4 + 2, resulting on a technical score of 10.

Considering the TCR completed, the next step of the ECM process is the CAI for Analysis to evaluate the Change Request and approve it. At this step, the CAI for Analysis skills will be used to ensure the information on TCR is accurate and the change can go to the next ECM phase. With the change request approved, the "Technical and Financial feasibility evaluation" phase can be concluded. The next stage on the ECM flow is the "Impact propagation analysis".

5.3.3.3Impact propagation analysis phase

To analyze impact propagation for the change, the CAI for Analysis will arrange multiple meetings with experts in different areas and fill the Template for Impact propagation. The TIP for this case can be found in Figure 48.

Figure 48 – Template for Impact Propagation – Simulated Case 3

A. Change Identification

A.1 Change ID:	20190721 - 1607
A.2 Request date:	21/07/2019

C. Problem Identification

C.3 Product afected:	Compact FN/PFN model
C.4 Part afected:	
ID	3
Description	Plastic evaporator

C.5 Problem description:

Upgrade current plastic evaporator item for Product4 plastic evaporator model in order to standardize plastic evaporator on manufacturing

F. Business Case

BUSINESS CASE SCORE: 11

G. Proposed Solution

TECHNICAL SCORE: 10

H. Propagation Analysis

H.1 TOP 10 main Quality Problems analysis

#	PRODUCT	Worsen	Mitigate	Not related
1	Weak welding between compressor and condenser			x
2	Leakeage on plastic evaporator and pipe connection		x	
3	Loose thermostat			x
4	Front panel color degradation (yellow)			x
5	Broken tap			x
6	Cover color degradation (yellow)			x
7	Leakeage on tap and pipe connection			x
8	Oxidation on compressor base			x
9	Evaporator support bend			x
10	Broken thermostat cover			x

#	PROCESS	Worsen	Mitigate	Not related
1	Weld temperature stability problem			x
2	Broken pipe during connection to plastic evaporator		x	
3	Incorrect position on pipe positioner			x
4	Tap fitting dificulty			x
5	Cover broken during assembly			x
6	Solid contamination obstructing pipe			x
7	Sponge hose incorrect position			x
8	Incorrect compressor voltage assembly			x
9	Torque excess on condenser screw			x
10	Cable clip broken during assembly			x

#	SUPPLIER	Worsen	Mitigate	Not related
1	Front panel color homogeneity			x
2	Cover color homogeneity			x
3	Side structure burr			x
4	Thermostat cover clip size			x
5	Tap´s starter thickness			x
6	Tap´s o-ring rubber quality			x
7	Thermostat lenght (shorter)			x
8	Compressor starting device not starting			x
9	Connection cable lentgh (shorter)			x
10	Incorrect compressor			x

#	CUSTOMER	Worsen	Mitigate	Not related
1	Water cooling capacity on high temperature regions			x
2	Vibration on drip tray			x
3	Starting noise			x
4	Side structure cleanning dificulty			x
5	Side structure heating			x
6	Cold water volume	x		
7	Long time to freeze water			x
8	Maintenance dificulty			x
9	Function noise			x
10	High weight			x

H.2 Shape analysis

Analysis	Impact	Current	Expected	Within Company Standards	
Tolerance	No	no significant impact		Yes	No
Weight	No	no significant impact		Yes	No
Raw material qty	No	no significant impact		Yes	No

H.3 Function analysis

Analysis	Impact	Impact Description	Technical Mitigation available			
Primary Function - Dispense cold water	Yes	Plastic evaporatir ID 58 has 2,8l water capacity while ID 3 has 3,2l		Yes	x	No
Secondary Function - Start compressor	No	no significant impact		Yes		No
Secondary Function - Refrigerate water	No	no significant impact		Yes		No
Secondary Function - Transport water	No	no significant impact		Yes		No

H.4 Interface analysis

Analysis	Impact	Impact Description	Technical Mitigation available			
Adjacent Subsystems	No	no significant impact		Yes		No
Package	No	no significant impact		Yes		No
EHS (Environment, Health and Safety)	No	no significant impact		Yes		No

H.5 Other specific analysis

Analysis Description	Impact	Impact Description	Technical Mitigation available			
Analysis 1		not applicable		Yes		No
Analysis 2		not applicable		Yes		No
Analysis 3		not applicable		Yes		No

TIP SCORE 21

Source: Author (2019)

On the TIP, items “A. Change Identification” and “C. Problem identification” are from TPR, item “F. Business Case” with business case score is from TBC, and item “G. Proposed Solution” with technical score is from TCR. The CAI for Analysis evaluation starts with item “H. Propagation Analysis.”

The main quality problems are defined by the company on item 5.1.2. The CAI for Analysis responsibility is to identify if the proposed change will impact any of the listed problems. Using CAI for analysis skill and input from experts, it was identified that doing an upgrade on the plastic evaporator from ID 3 to ID 58 will mitigate “Leakage on plastic evaporator and pipe connection” and “Broken pipe during connection to plastic evaporator.” This is because the ID 58 was developed to reduce these impacts on the product. On the other hand, this change will worsen the “Cold water volume” because the ID 58 specifications support less water volume than ID 3. The other problems are not related to the plastic evaporator and will not be impacted by the change.

As explained on Simulated Case 1, the shape analysis is also conducted by the CAI for Analysis and is supported by experts during alignment meetings if necessary. In this case, doing an upgrade on the plastic evaporator from ID 3 to ID 58 will not significantly impact tolerance, weigh, nor raw material because the parts are similar and used on similar products.

The function analysis and interface analysis is also conducted by the CAI for Analysis and supported by experts during alignment meetings if necessary. For this case, the only impact is on primary function due to water capacity difference between ID 3 and ID 58. Other aspects do not show significant impact. Besides that, the change will not interfere with other subsystems nor will they impact package because it is internal to the product and is not proposing any material change nor process standard that could generate any impact on Environment, Health or Safety. No other specific analysis is required.

With this, the TIP score can be calculated by the sum of business score, technical score and propagation analysis score. The propagation analysis score is defined as the sum for the points on item “H. Propagation analysis” such as illustrated on Table 13 from Simulated Case 1.

For this case, the TIP is the sum of 11 (business case score) + 10 (technical score) + 1 (quality problem worsen) + (-2) (quality problem mitigated) + 1 (primary function impacted without technical mitigation available), resulting in TIP as 21. With the TIP score, the “Impact propagation analysis” phase is concluded and the next stage on the ECM flow is the “Change Implementation.”

5.3.3.4Change Implementation phase

The first step on change implementation is the approval for change execution. Considering the TCR and TIP score, the CAI for analysis will compare business standard with change results in order to define if it will be Full track or Fast track. In this case, the Table 10 – Company standards for change management – defines that the change can be Fast track if the business case score is lower than 10, the technical score is lower than 13, and the TIP score is lower than 25. The Simulated Case 3 exceeds these requirements with business case score 11, despite technical score 10, and TIP score 21 within the target. Therefore, Simulated Case 3 will be conducted as Full Track. The TPFull is on Figure 49.

On the TPFull, items “A. Change Identification” and “C. Problem identification” are from TPR, item “F. Business Case” with business case score is from TBC, item “G. Proposed Solution” is from TCR, and item “H. Propagation Analysis” is from TIP. The CAI for Analysis evaluation starts with item “I. Prioritization for Full Track.”

The CRB participant list is defined by CAI for Analysis based on impacted areas and previous experience. In this simulated case, the names are fictional to serve as reference.

The attractiveness level is defined by each participant of CRB based on their own skills. The priority score is the sum of attractiveness considering the values defined on Table 10– Company standards for change management.

For this simulated case, the attractiveness defined by the product specialist as level 1, by the procurement and manufacturing specialist as level 2, and by the logistics specialist as level 4. Considering the change will impact product primary function without mitigation available, the level 1 attractiveness defined by the product is justified. For procurement, the product standardization may lead to supplier dependency, resulting in a manufacturing process adjustment. This will explain the level 2 while the change is highly attractive for logistics due to storage cost reduction. Therefore, a level 4 is the clear choice.

The priority score is the sum of 10000 + 1000 + 1000 + 10 (as attractiveness level score from business standard) and results in 12010. According to Table 10 – Company standards for change management – the priority score higher than 2500 is LOW priority.

Figure 49 – Template for Full Track – Simulated Case 3

A. Change Identification

A.1 Change ID: 20190721 - 1607

A.2 Request date: 21/07/2019

C. Problem Identification

C.3 Product afected: Compact FN/PFN model

C.4 Part afected:

ID: 3

Description: Plastic evaporator

C.5 Problem description:

Upgrade current plastic evaporator item for Product4 plastic evaporator model in order to standardize plastic evaporator on manufacturing

F. Business Case

F.1 Supplier impact:
[ ] High [ ] Medium [x] Low

F.2 Customer :
[ ] High [ ] Medium [x] Low

F.3 Company impact:
[ ] High [x] Medium [ ] Low

F.4 Legal/Institutes impact:
[ ] High [ ] Medium [x] Low

F.5 Product subsystems impact:
[ ] High [x] Medium [ ] Low

F.6 Payback impact:
[ ] High [x] Medium [ ] Low

BUSINESS CASE SCORE: 11

G. Proposed Solution

G.2 Certifications required:

	Prototype	Test	Production	Homologation
Product			x	x
Process			x	x
Supplier				
Customer				
Institute				

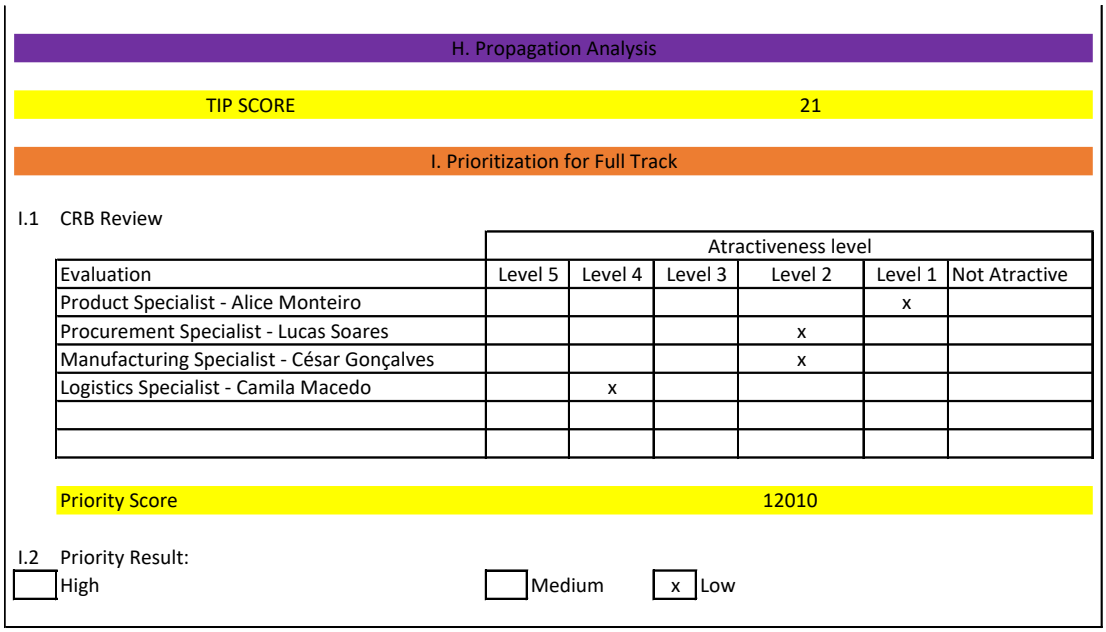
G.3 Resource Allocation required:

Impacted Area		FTE (qty)
Project Development	x	0,3
Manufacturing Assembly	x	0,1
Product engineering	x	0,3
Procurement	x	0,1

G.4 Technical Challenge:
[ ] Level 1 [ ] Level 2 [x] Level 3 [ ] Level 4 [ ] Level 5

TECHNICAL SCORE: 10

Figure 49 – Template for Full Track – Simulated Case 3 (cont.)



H. Propagation Analysis

TIP SCORE	21

I. Prioritization for Full Track

I.1 CRB Review

	Atractiveness level					
Evaluation	Level 5	Level 4	Level 3	Level 2	Level 1	Not Atractive
Product Specialist - Alice Monteiro					x	
Procurement Specialist - Lucas Soares				x		
Manufacturing Specialist - César Gonçalves				x		
Logistics Specialist - Camila Macedo		x				

Priority Score	12010

I.2 Priority Result:

[ ] High [ ] Medium [x] Low

Source: Author (2019)

With TPFull completed, the PMO will prioritize the change to be executed. When the request is prioritized, the PMO creates the Change Notice that defines a CAII. The TCN for Simulated Case 3 is on Figure 50.

On TCN from Figure 50, all information originates on a previous template already submitted on the process. The PMO only consolidates the information on this template and defines the person to be an Assignee for the change execution. In this case, the name is fictional to serve as reference.

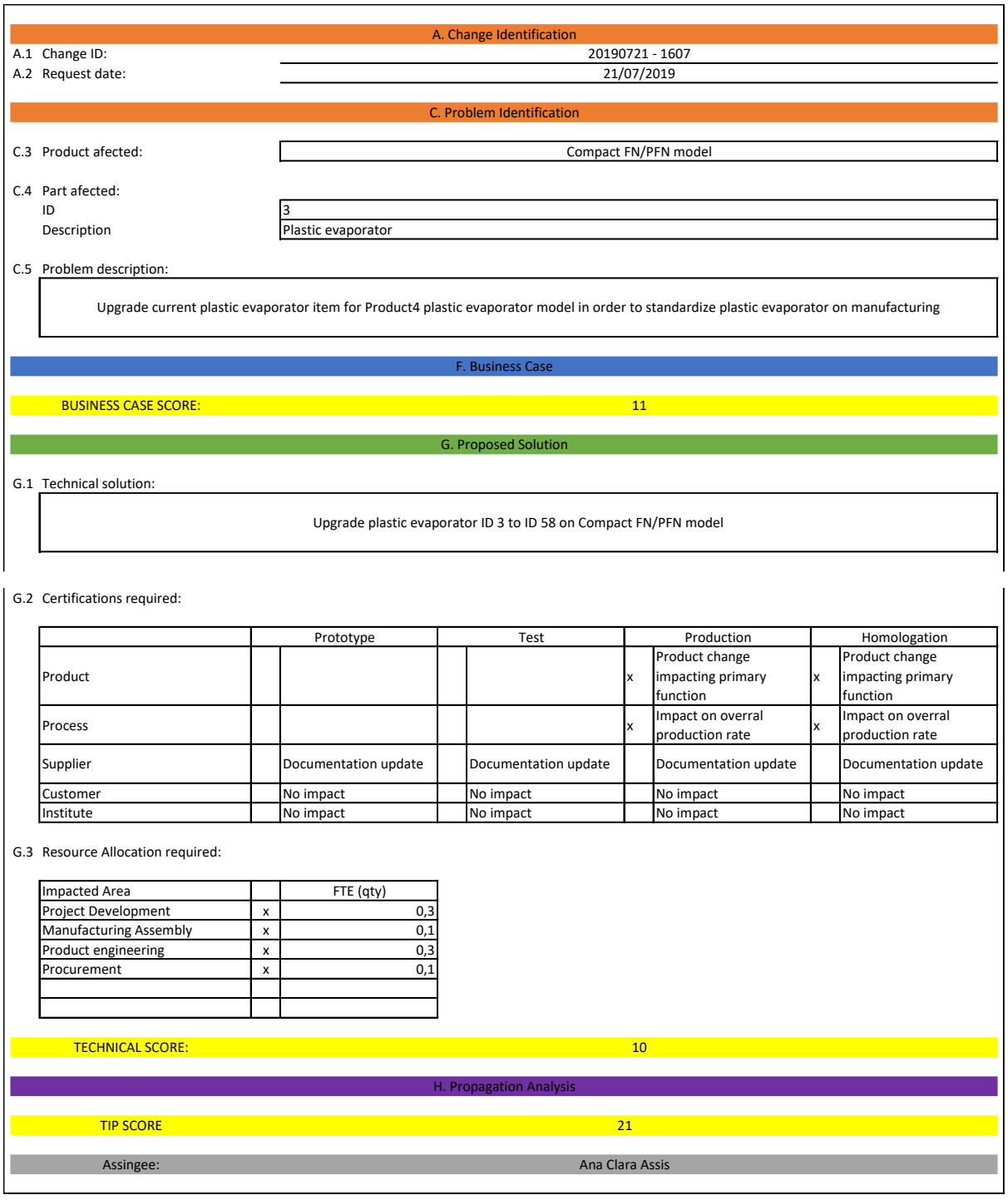
The assignee on TCN will prepare a change implementation plan using the TCP. As described on Simulated Case 1, this plan minimally considers the required certifications identified on TCN, but also includes activities required by the company process to ensure the change execution. The plan is created based on CAII skills and experience.

For this case, the plan was divided into 2 implementation phases as illustrated on Figure 51. As highlighted on Simulated Case 1, the plan is based on CAII skills and experience, and is difficult to standardize.

After TCP is completed, the CAII prepares the TCPA to submit for CIB (Change Implementation Board) approval. The participants on CIB can be the same as CRB or different members according to company policy or CAII experience. For this simulated case, it was

considered the same participants on CRB were defined as CIB members. The TCPA approved document is on Figure 51.

Figure 50 – Template for Change Notice – Simulated Case 3



A. Change Identification

A.1 Change ID:	20190721 - 1607
A.2 Request date:	21/07/2019

C. Problem Identification

C.3 Product afected:	Compact FN/PFN model
C.4 Part afected:	
ID	3
Description	Plastic evaporator

C.5 Problem description:

Upgrade current plastic evaporator item for Product4 plastic evaporator model in order to standardize plastic evaporator on manufacturing

F. Business Case

BUSINESS CASE SCORE: 11

G. Proposed Solution

G.1 Technical solution:

Upgrade plastic evaporator ID 3 to ID 58 on Compact FN/PFN model

G.2 Certifications required:

	Prototype		Test		Production		Homologation	
Product					x	Product change impacting primary function	x	Product change impacting primary function
Process					x	Impact on overral production rate	x	Impact on overral production rate
Supplier		Documentation update		Documentation update		Documentation update		Documentation update
Customer		No impact		No impact		No impact		No impact
Institute		No impact		No impact		No impact		No impact

G.3 Resource Allocation required:

Impacted Area		FTE (qty)
Project Development	x	0,3
Manufacturing Assembly	x	0,1
Product engineering	x	0,3
Procurement	x	0,1

TECHNICAL SCORE: 10

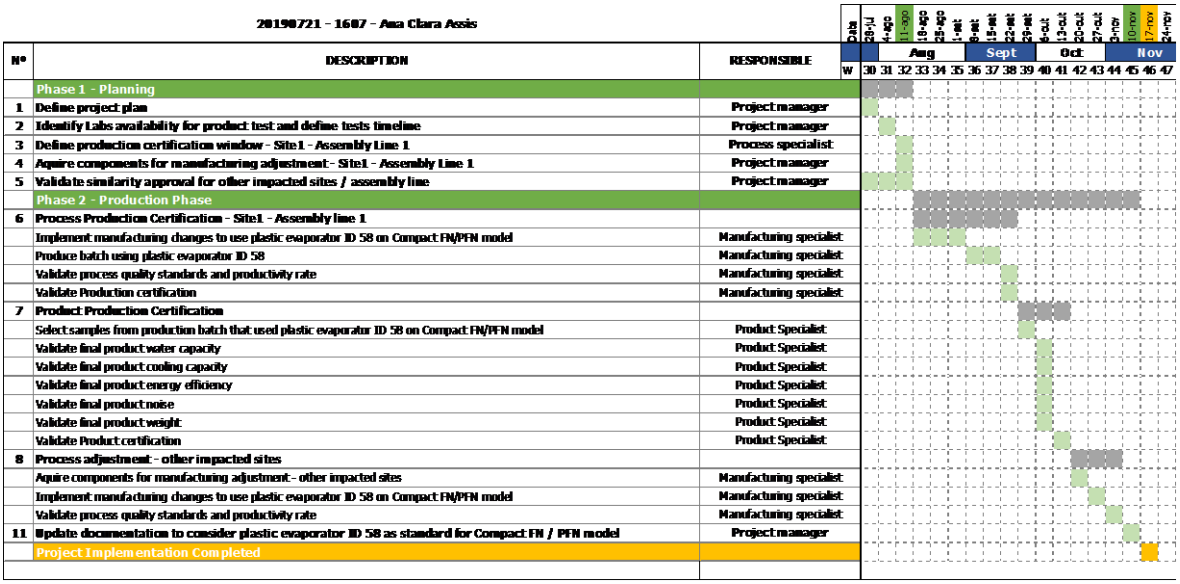
H. Propagation Analysis

TIP SCORE 21

Assingee: Ana Clara Assis

Source: Author (2019)

Figure 51 – Template for Change Plan – Simulated Case 3



20190721 - 1607 - Ana Clara Assis

Nº	DESCRIPTION	RESPONSIBLE
	Phase 1 - Planning	
1	Define project plan	Project manager
2	Identify Labs availability for product test and define tests timeline	Project manager
3	Define production certification window - Site1 - Assembly Line 1	Process specialist
4	Aquire components for manufacturing adjustment - Site1 - Assembly Line 1	Project manager
5	Validate similarity approval for other impacted sites / assembly line	Project manager
	Phase 2 - Production Phase	
6	Process Production Certification - Site1 - Assembly line 1	
	Implement manufacturing changes to use plastic evaporator ID 58 on Compact FN/PFN model	Manufacturing specialist
	Produce batch using plastic evaporator ID 58	Manufacturing specialist
	Validate process quality standards and productivity rate	Manufacturing specialist
	Validate Production certification	Manufacturing specialist
7	Product Production Certification	
	Select samples from production batch that used plastic evaporator ID 58 on Compact FN/PFN model	Product Specialist
	Validate final product water capacity	Product Specialist
	Validate final product cooling capacity	Product Specialist
	Validate final product energy efficiency	Product Specialist
	Validate final product noise	Product Specialist
	Validate final product weight	Product Specialist
	Validate Product certification	Product Specialist
8	Process adjustment - other impacted sites	
	Aquire components for manufacturing adjustment - other impacted sites	Manufacturing specialist
	Implement manufacturing changes to use plastic evaporator ID 58 on Compact FN/PFN model	Manufacturing specialist
	Validate process quality standards and productivity rate	Manufacturing specialist
11	Update documentation to consider plastic evaporator ID 58 as standard for Compact FN / PFN model	Project manager
	Project Implementation Completed	

Data 28-jul 4-ago 11-ago 18-ago 25-ago 1-set 8-set 15-set 22-set 29-set 6-out 13-out 20-out 27-out 3-nov 10-nov 17-nov 24-nov

Aug Sept Oct Nov

W 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47

Source: Author (2019)

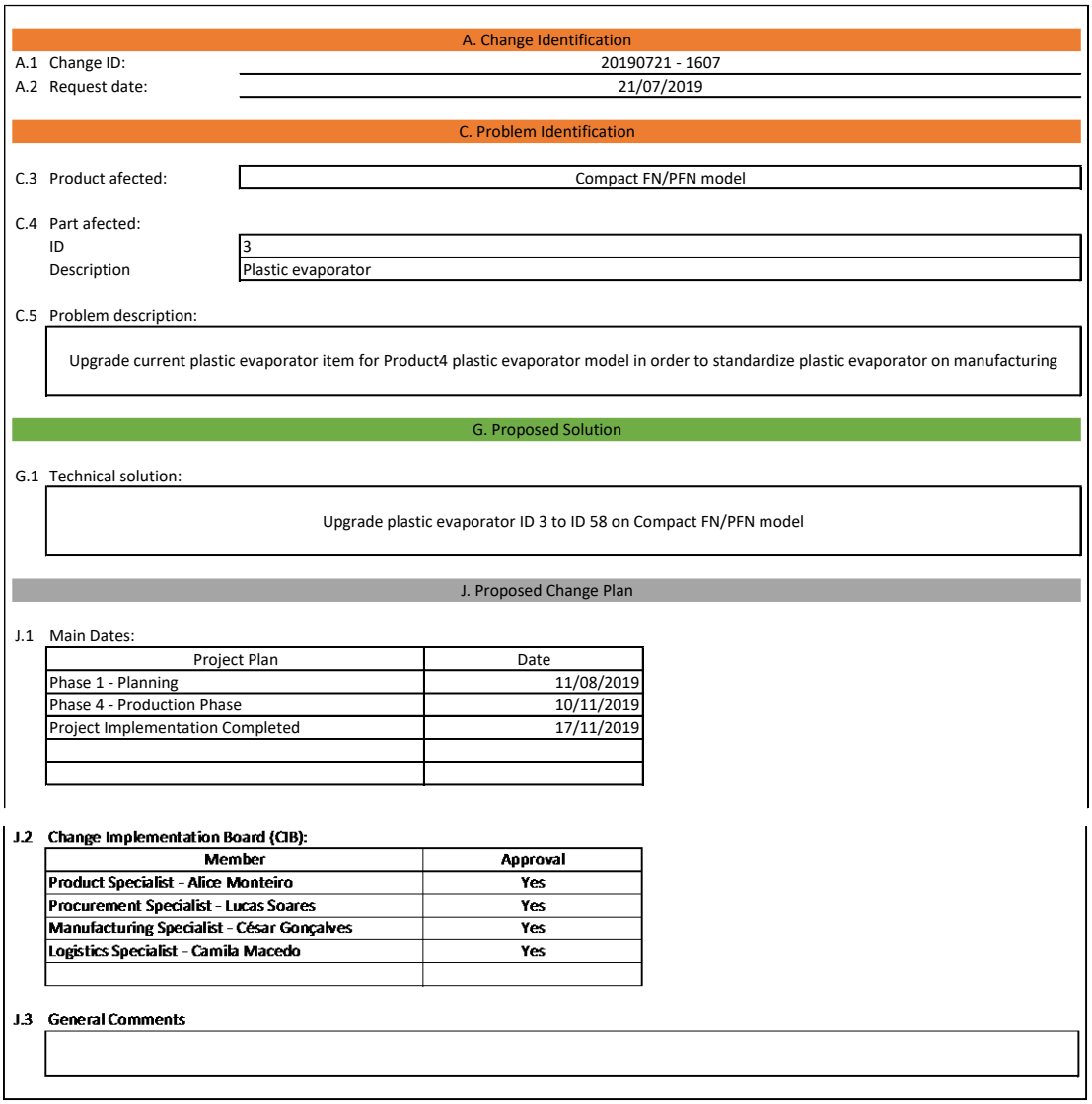
On the TCPA from Figure 52, items “A. Change Identification” and “C. Problem identification” are from TPR, item “G. Proposed Solution” is from TCR, the main dates on item “J. Proposed Change Plan” are from TCP, and the CIB is defined by company policy or CAII experience.

With TCPA approved by CIB, the CAII starts the process implementation based on the plan and considers company process to execute the planned activities. When the implementation is completed, the CAII submits the change for audit and is released by CAIII.

The CAIII fills the TCA to check and audit the major deliverables from TCP. As explained on Simulated Case 1, the CAIII needs to identify main deliverables and ensure the required certifications are completed and approved. For this reason, specific CAIII skills are required. The TCA for this case can be found in Figure 53.

On the TCA, items “A. Change Identification” and “C. Problem identification” are from TPR and item “G. Proposed Solution” with technical score is from TCR. The CAII evaluation starts with item “L. Audit.” In this case, the audit list considered the deliverables, Process Production Certification - Site1 - Assembly line 1, Product Production Certification, Process adjustment - other impacted sites, and Project Implementation Completed.

Figure 52 – Template for Change Plan approval – Simulated Case 3



A. Change Identification

A.1 Change ID: 20190721 - 1607

A.2 Request date: 21/07/2019

C. Problem Identification

C.3 Product afected: Compact FN/PFN model

C.4 Part afected:

ID: 3

Description: Plastic evaporator

C.5 Problem description:

Upgrade current plastic evaporator item for Product4 plastic evaporator model in order to standardize plastic evaporator on manufacturing

G. Proposed Solution

G.1 Technical solution:

Upgrade plastic evaporator ID 3 to ID 58 on Compact FN/PFN model

J. Proposed Change Plan

J.1 Main Dates:

Project Plan	Date
Phase 1 - Planning	11/08/2019
Phase 4 - Production Phase	10/11/2019
Project Implementation Completed	17/11/2019

J.2 Change Implementation Board (CIB):

Member	Approval
Product Specialist - Alice Monteiro	Yes
Procurement Specialist - Lucas Soares	Yes
Manufacturing Specialist - César Gonçalves	Yes
Logistics Specialist - Camila Macedo	Yes

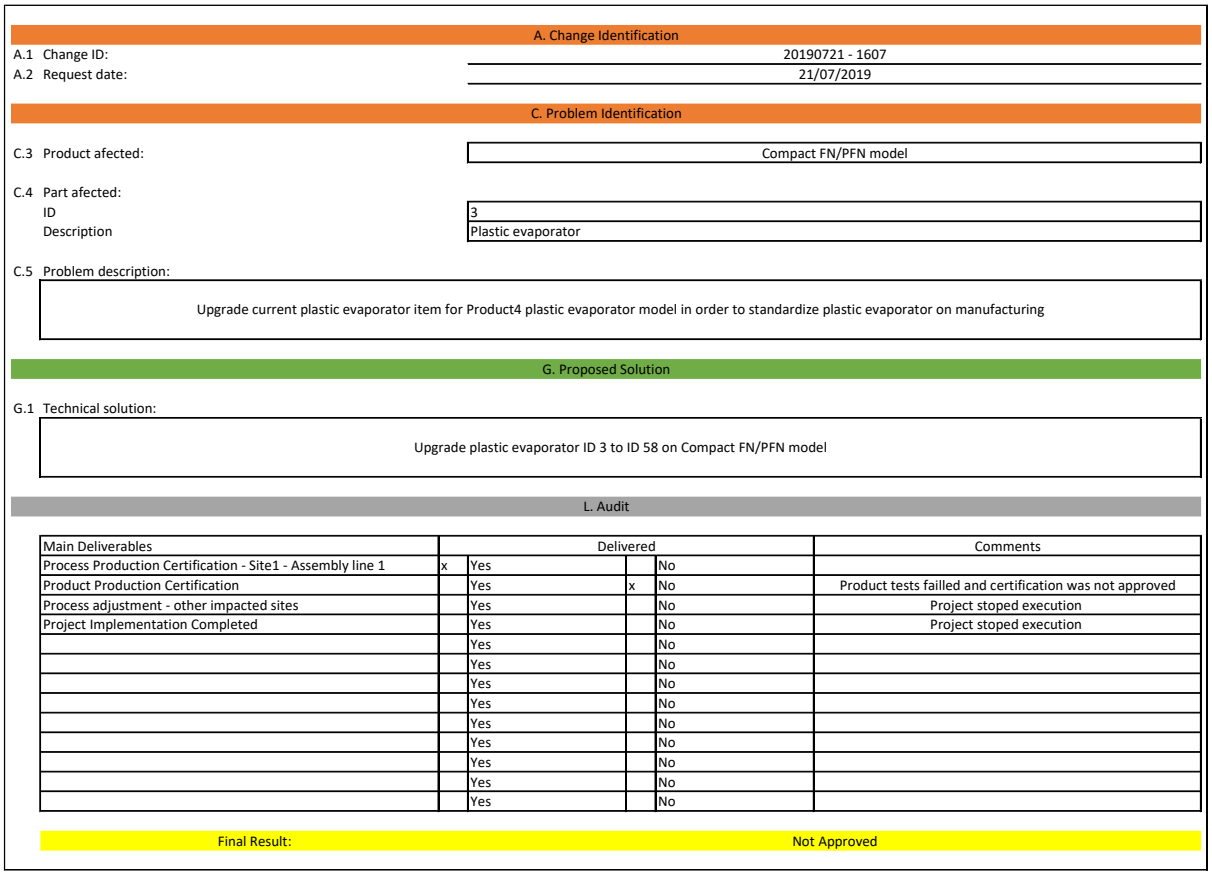
J.3 General Comments

Source: Author (2019)

Since the product tests failed and certification was not approved, the change will not be implemented and the result is marked as “Not Approved.”

In this case, it is necessary to follow the flow for process shut down as defined by Figure 22 - Proposed Framework and undo changes performed on documentation, such as drawings and BOM – Bill of Material, close the change notice, close the change request, close the problem report, and inform the requester identified on TPR item B.1 that the change will not be implemented.

Figure 53 – Template for Change Audit – Simulated Case 3



A. Change Identification

A.1 Change ID:	20190721 - 1607
A.2 Request date:	21/07/2019

C. Problem Identification

C.3 Product afected:	Compact FN/PFN model
C.4 Part afected:	
ID	3
Description	Plastic evaporator

C.5 Problem description:

Upgrade current plastic evaporator item for Product4 plastic evaporator model in order to standardize plastic evaporator on manufacturing

G. Proposed Solution

G.1 Technical solution:

Upgrade plastic evaporator ID 3 to ID 58 on Compact FN/PFN model

L. Audit

Main Deliverables	Delivered				Comments
Process Production Certification - Site1 - Assembly line 1	x	Yes		No	
Product Production Certification		Yes	x	No	Product tests failled and certification was not approved
Process adjustment - other impacted sites		Yes		No	Project stoped execution
Project Implementation Completed		Yes		No	Project stoped execution
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	

Final Result: Not Approved

Source: Author (2019)

The closure of change notice, change request and problem report finishes the change flow. There is no need for impact validation since the change was not implemented.

The ECM process is completed and the change is concluded as “not approved.”

5.4FRAMEWORK APPLICATION EVALUATION

The application results obtained in Chapter 5 and the templates from this study were submitted to ECM experienced professionals and researchers for feedback to ensure the best possible framework for ECM management.

The methodology used to submit the framework for evaluation was the questionnaire illustrated on Board 29, composed by both mandatory and optional questions. Associated to the

questionnaire, an explanation video was sent to respondents previous to the questions in order to present the ECM framework to be evaluated.

Board 29 – Questions used on ECM framework feedback questionnaire

Question ID	Question	Question Type	Possible Answer	Mandatory
1	How do you evaluate the ease of understanding of the framework presented?	Multiple choice	Very easy to understand; Easy to understand; Neither easy nor difficult to understand; Difficult to understand; Very difficult to understand	Yes
2	How do you evaluate the practical applicability of the framework presented?	Multiple choice	Highly applicable; Possibly applicable; Not applicable	Yes
3	How strong would you recommend to a company to use this framework for Engineering Change Management?	Rate (from 1 to 5)	1 - I would not recommend; 5 - I would strongly recommend	Yes
4	How long have you worked or studied Engineering Change Management?	Multiple choice	I never worked or studied Engineering Change Management until now; From 1 to 3 years; From 3 to 5 years; From 5 to 10 years; More than 10 years	Yes
5	Do you currently work with Engineering Change Management at a company?	Yes/No	Yes; No	Yes

Board 29 – Questions used on ECM framework feedback questionnaire (cont.)

6	Do you currently work with Engineering Change Management at a company?	Yes / No	Yes; No	Yes
7	Do you have any improvement suggestion for the framework presented? Please detail below	Open text	Open text	Yes
8	Name	Open text	Open text	No
9	Age	Open text	Open text	No
10	Profession	Open text	Open text	No
11	Current Company or University	Open text	Open text	No
12	Current position at company or University	Open text	Open text	No
13	Company or University location	Open text	Open text	No

Source: Author (2019)

The questionnaire together with the application cases were included on a free sharing file platform and the video was uploaded on a free sharing video stream. The video link was included on the questionnaire with instructions for respondents to watch the video before answering the questions. The video description contained the references used on the video and the link for the application cases file.

The original questionnaire, both the video images and audio details, as well as the links used to share the information are available in APPENDIX C.

The questionnaire was publicized on a professional social media platform using groups associated to ECM or related topics such as project management, product development and PLM listed as "Gerenciamento de projetos", "Women in New Product Development (WiNPD)","Product Management Professionals", "Business Improvement, Change Management, Corporate Culture & Performance Management", "PMO Experienced (Practicing Product, Project, and Program Managers)", "PM Community - Product/Portfolio/Program/Project Manager", "PLM Brasil", "Product Management", "Project Management Professionals PMP", "PMO - Project Management Office", "PMI Project,

Program and Portfolio Management: #1 group for career advancement" and "Project Manager Community - Best Group for Project Management" to announce the framework feedback request to more than 1.200.000 professionals on two different dates. People accepted as member on this professional social media groups are professionals that work with the group topic or has recognized knowledge about it, therefore are people with professional background on ECM or related topics.

To reach the academic public, a search was conducted on “Currículo Lattes” database using the words “ECM engineering” in both English and Portuguese to obtain 117 exclusive results for researchers related to engineering change management. The e-mail for each one of them was searched using Google Academics through papers published by those researchers. A direct e-mail was sent to identify electronic addresses, requesting the feedback for the framework. 45 deliveries failed and were returned, resulting in having 72 correct addresses. The list of people contacted is listed in APPENDIX D.

The answers received and the improvement resulted from the feedback are detailed in items 5.4.1 and 5.4.2, respectively.

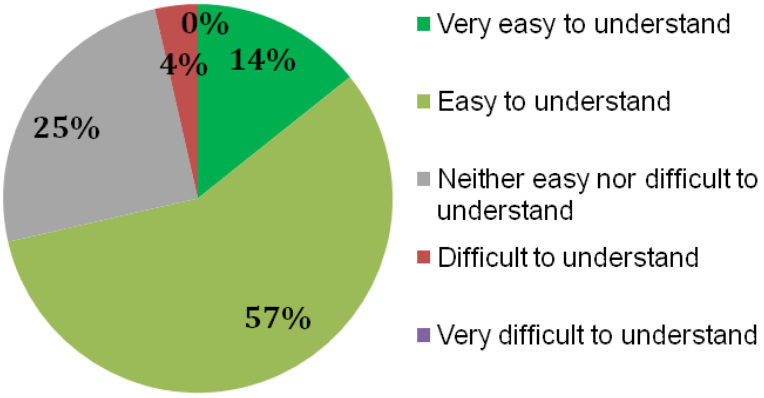
5.4.1Framework analysis by experienced ECM professionals and researchers

The questionnaire accepted answers during the month of September 2019 and resulted in 28 responses from different professionals and researchers on ECM.

The details on the mandatory responses are illustrated in Graphic 3 through Graphic 8. From optional responses, the age range is presented in Graph 9 and the professions list is in Table 16. The remaining data and the original responses are covered in APPENDIX E.

For the analysis, some answers in Portuguese were translated to English by the author. Comments containing more than one item were counted as 2 answers for summary purposes.

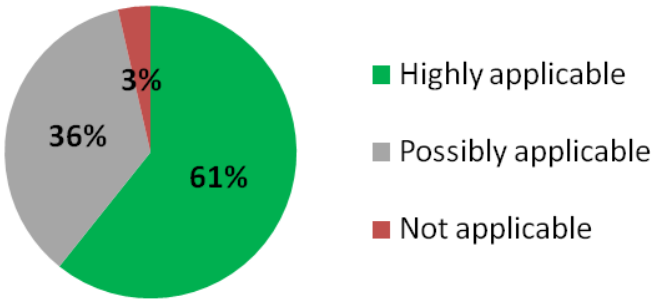
Graphic 3 – Result for question "How do you evaluate the ease of understanding of the framework presented?"



Source: Author based on ECM feedback questionnaire responses (2019)

On Graphic 3, it is possible to notice that more than 70% considered the framework "Easy" or "Very easy" to understand, and there were no answers that considered the framework "Very Difficult" to understand. This data validates the goal of the research, which is to present an ECM framework that professional can understand.

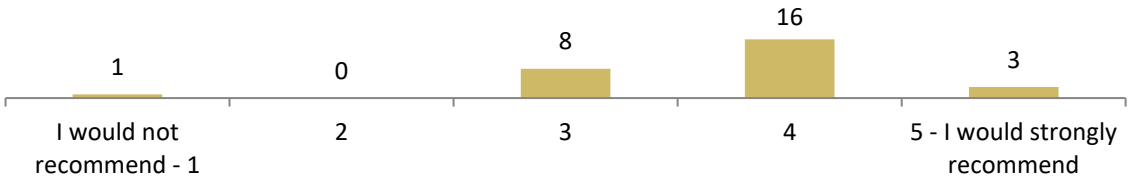
Graphic 4 – Result for question "How do you evaluate the practical applicability of the framework presented?"



Source: Author based on ECM feedback questionnaire responses (2019)

On Graphic 4, it is important to highlight that less than 4% considered the ECM framework "Not applicable." This data validates the goal of the research, which is to present an ECM framework that professionals can apply.

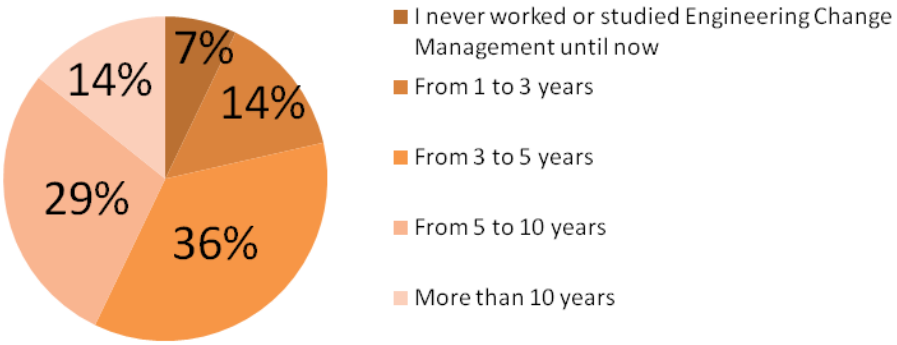
Graphic 5 – Result for question "How strong would you recommend to a company to use this framework for Engineering Change Management?"



Source: Author based on ECM feedback questionnaire responses (2019)

On Graphic 5, considering that scores 4 and 5 represent people favorable to use the framework and scores, 1, 2 and 3 are not favorable. From this, it is possible to state that 67% are favorable while 32% are not favorable. This means that there are twice as many people willing to use the framework than not willing to use it.

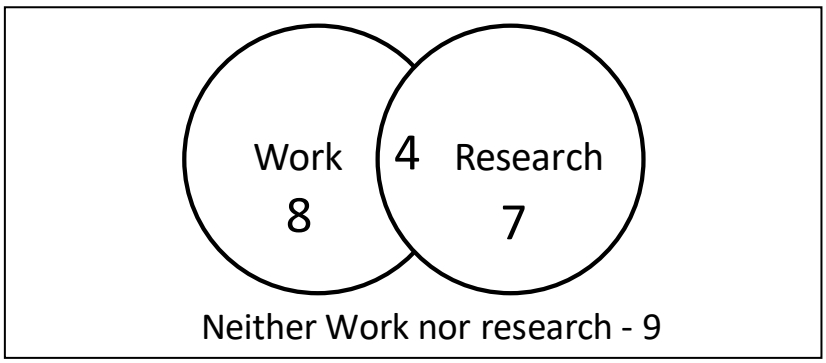
Graphic 6 – Result for question "How long have you worked or studied Engineering Change Management?"



Source: Author based on ECM feedback questionnaire responses (2019)

The result from Graphic 6 indicates that the questionnaire responses considered a wide range of experience and obtained answers from professionals that never worked with ECM for the previous 10 years. This validates the goal of this research to present an ECM framework with both professional and academic application.

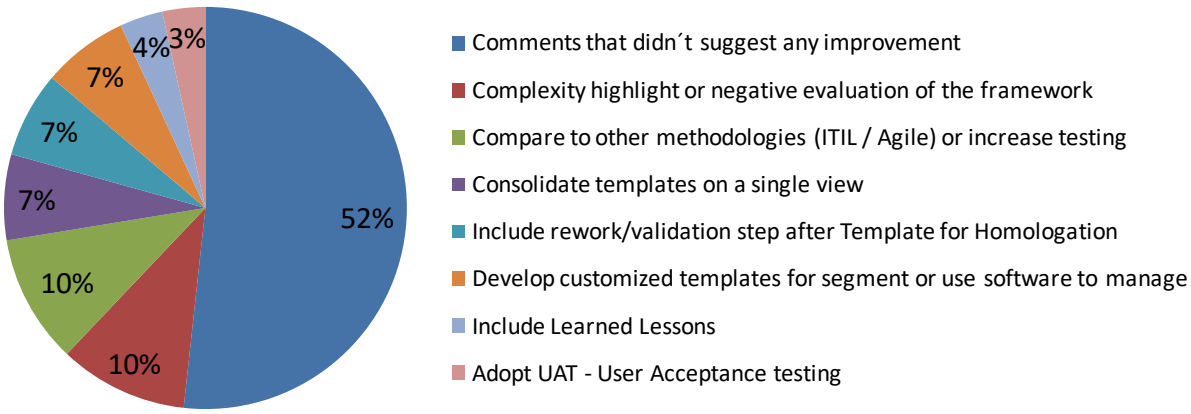
Graphic 7 – Result for question “Do you currently work with Engineering Change Management at a company?” and “Do you currently research Engineering Change Management at an University?”



Source: Author based on ECM feedback questionnaire responses (2019)

Graphic 7 indicates that both professional and academic experience was considered and that about 68% of respondents are currently working or researching ECM.

Graphic 8 – Result for question “Do you have any improvement suggestion for the framework presented? Please detail below”



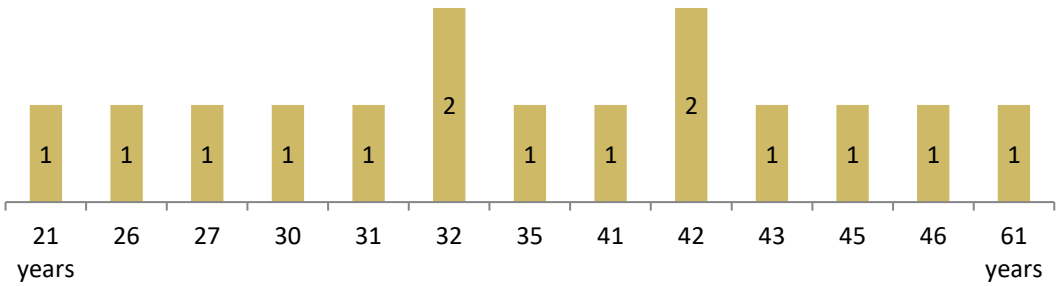
Source: Author based on ECM feedback questionnaire responses (2019)

On Graphic 8, it is possible to notice that more than 50% of answers did not suggest any improvement for the framework, even though the item was a mandatory question. This can be considered a favorable perspective over the proposed ECM Framework. Some of them included the comment “no,” an invalid character or an approval expression such as “good.” Only 10% highlighted complexity or gave a negative comment. 38% of comments can be

considered for ECM framework improvement or suggested for further studies. The answers from Graphic 8 will be detailed on item 5.4.2.

The result for age range illustrated in Graphic 9 considered a wide variation on age from 21 to 61 years. This reinforces that the framework can be understood as applied without restrictions on experience.

Graphic 9 – Result for question "Age:" excluding blank answers



Source: Author based on ECM feedback questionnaire responses (2019)

The respondent experience range detailed in Table 16 has the same aspect as the age range, allowing for a broad analysis with a variety of professions. This has achieved the goal of encompassing both professional and academic feedback.

Table 16 – Result for question "Profession:" excluding blank answers

Profession	Qty
Engineer	3
Product Engineer	2
Change Manager	1
Chemical Engineer	1
Sales Engineer	1
ITIL Manager	1
Master Degree Student	1
Product Manager	1
Production Engineer	1
Professor	1
R&D Engineer	1
Researcher	1
Senior IT Leader	1

Source: Author based on ECM feedback questionnaire responses (2019)

On Table 16, it is possible to note that results for the profession question indicate both company and university were covered on the questionnaire. There are multiple engineers professionals as well as researchers, professors and Master's degree students.

5.4.2Framework improvements opportunities

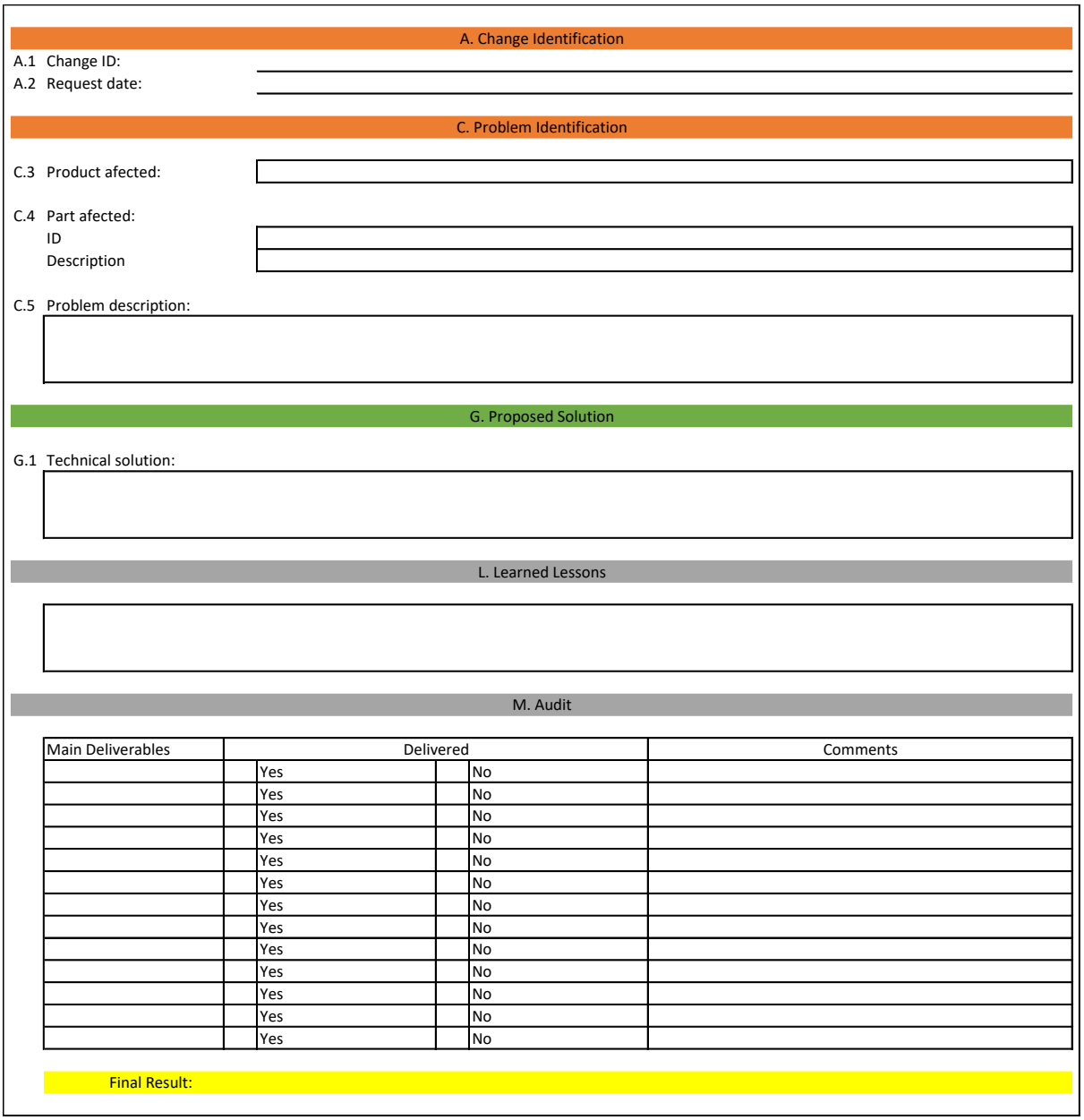
Considering the feedback from ECM Framework Feedback Questionnaire detailed in Graphic 8, it is possible to improve the framework to consolidate the templates in a single view, to include the rework/validation step after Template for Homologation, and to include a lessons learned session.

The first improvement is on TCA through including a lessons learned session to record major learnings from the change process. This would allow further studies by the company to deploy the best practices or to identify main blockers to the implementation. Figure 54, the updated version of TCA, is presented with a new session after item "G. Proposed Solution" dedicated the input of lessons learned before the change approval. The new session is called "L. Learned Lessons."

A new process called "Audit not relevant impact after change" was included on the proposed framework. It is to be executed by the CAIII with the support of a new template "Template for Homologation Approval" (THA) with the rework alternative. The updated proposed framework with the new process is illustrated in Figure 55 and the THA is illustrated in Figure 56.

The THA illustrated in Figure 56 considers two categories: "Change Identification" and "Problem identification" from TPR, and "Proposed solution" from TCR. The first new category "Homologation Audit" consolidates the main deliverables from TH and the evaluation from CAIII regarding the deliverables quality. The other new category, "Rework Analysis" indicates the need, or not, for rework on the change implementation. The CAIII evaluates the final result to consider the homologation "Approved" or "Not Approved' as the final decision.

Figure 54 – TCA updated version with Learned Lessons session



A. Change Identification

A.1 Change ID:

A.2 Request date:

C. Problem Identification

C.3 Product afected:

C.4 Part afected:

ID

Description

C.5 Problem description:

G. Proposed Solution

G.1 Technical solution:

L. Learned Lessons

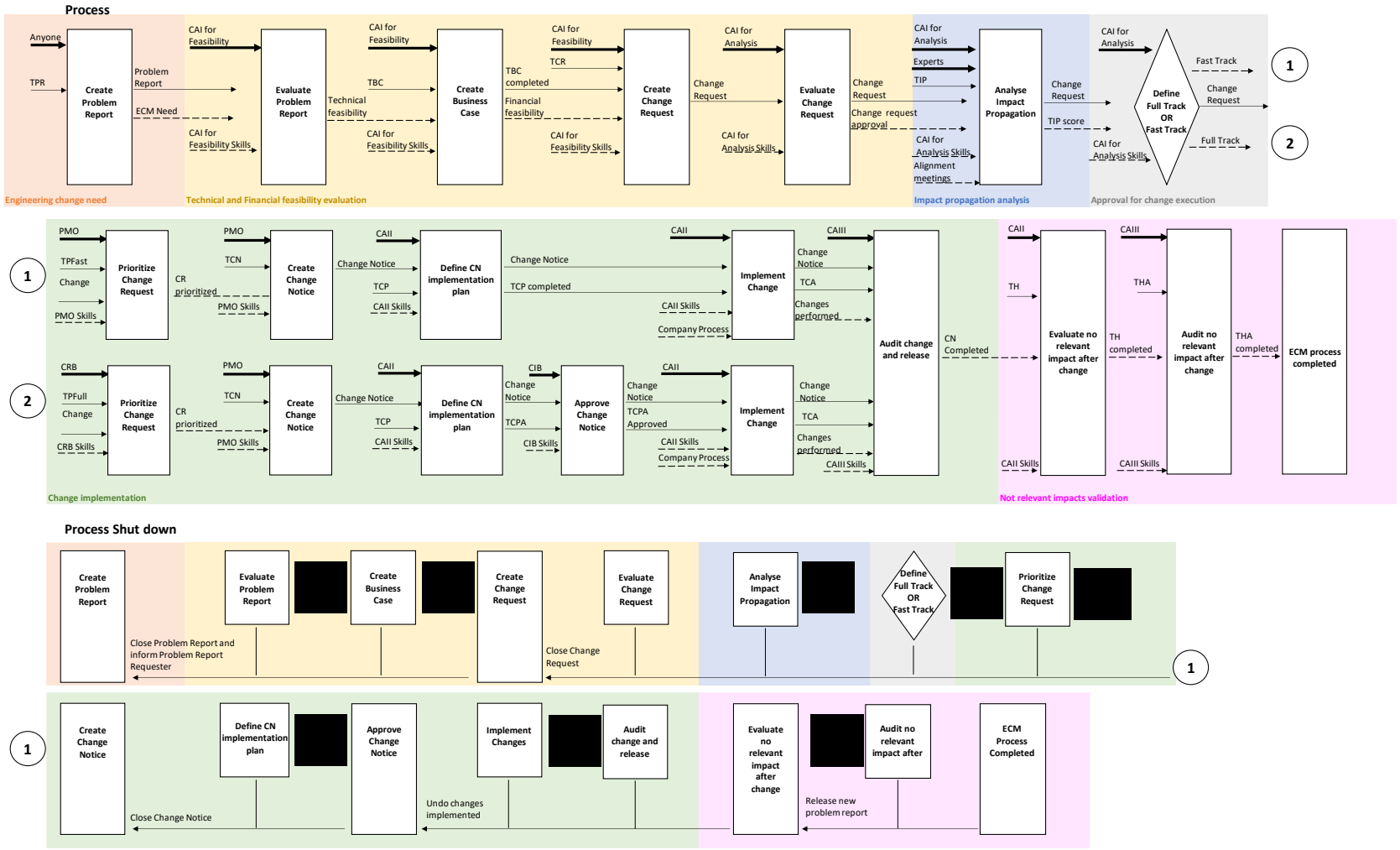
M. Audit

Main Deliverables	Delivered				Comments
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	

Final Result:

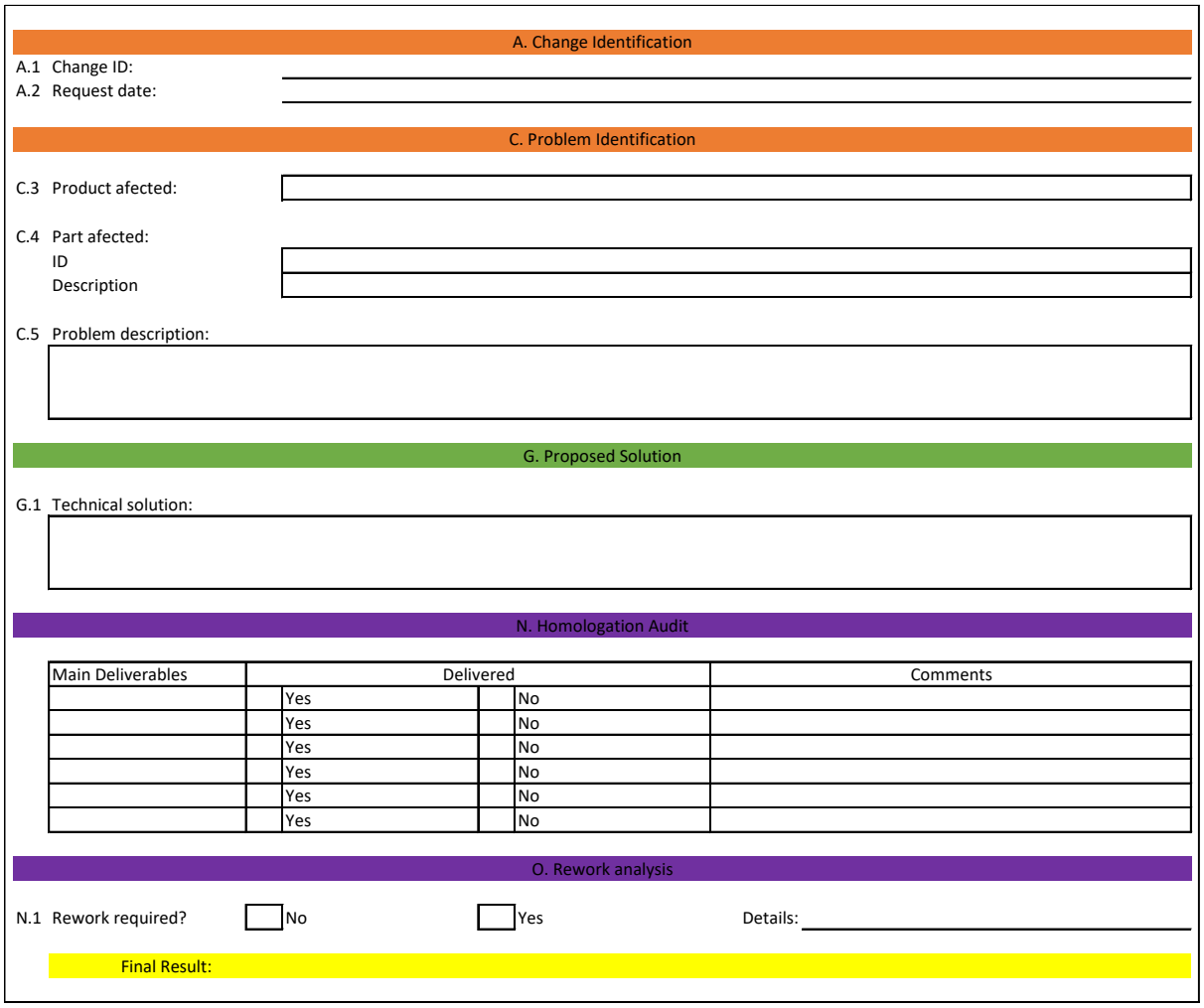
Source: Author (2019)

Figure 55 – Proposed framework updated



Source: Author (2019)

Figure 56 – Template for Homologation Approval (THA)



A. Change Identification

A.1 Change ID:

A.2 Request date:

C. Problem Identification

C.3 Product afected:

C.4 Part afected:

ID

Description

C.5 Problem description:

G. Proposed Solution

G.1 Technical solution:

N. Homologation Audit

Main Deliverables	Delivered				Comments
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	

O. Rework analysis

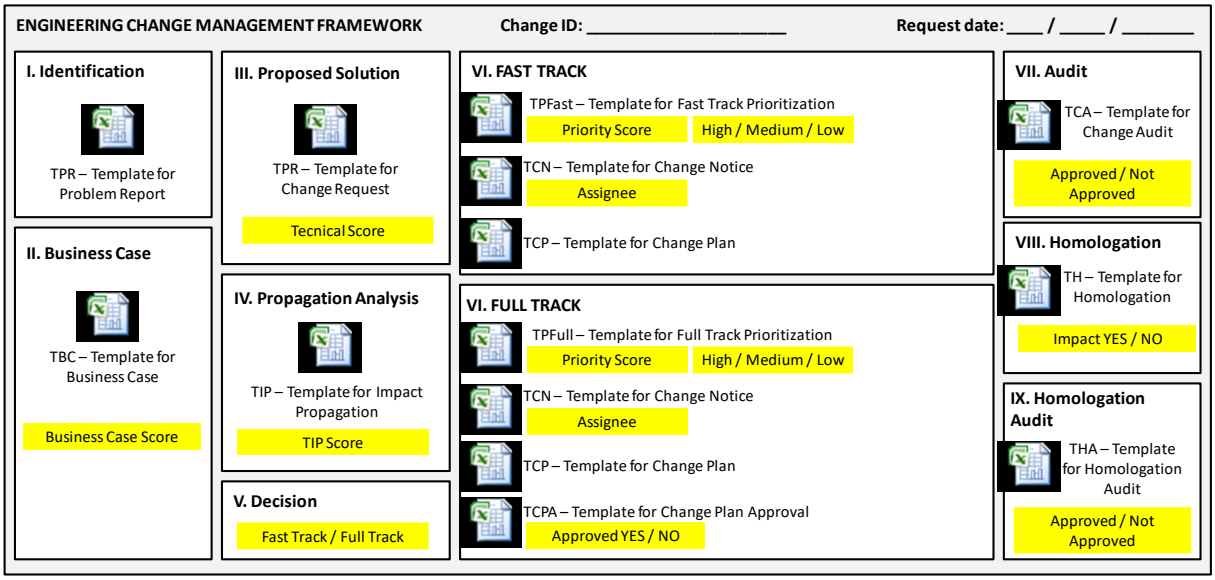
N.1 Rework required? No Yes Details:

Final Result:

Source: Author (2019)

The last improvement opportunity indicated by the feedback is to consolidate the proposed framework on a single view. Figure 57, a consolidated view of the framework templates divided according to macro steps on a CANVAS, can be used as dashboard to monitor the template delivered and the major decisions regarding the change.

Figure 57 – CANVAS for proposed framework



Source: Author (2019)

With these improvements, the framework can be considered completed and is finished to be used. Opportunities to deeper analyze the use of the framework, as well as new methodologies to be considered, are further studies alternatives.

6CONCLUSION

Engineering Change Management has seen increased interest within engineering research because managing properly the ECM is the key to adjust development process for producing customer variants and the solution to overcome hard competition on the marketplace. However, despite effective ECM is an important competitive advantage, a lack of structured studies is notable with six times less publication than other engineering related topics such as project management.

For this reason, this research conducted a study in which the first three chapters consider the introduction, the theoretical base with the state of the art ECM methodologies and tools and the method considering the bibliometric analysis, the systematic review and the in loco research results.

In Chapter 4 proposes the framework with its evaluation and limitations, while Chapter 5 presents the application of the proposed framework on three simulated cases as well as the evaluation of the framework application with improved version. At Chapter 6 lies the conclusion and further studies opportunities.

Considering the research questions and hypothesis, the Board 30 have the results for each problem presented by the study.

Board 30 – Research questions with results

ID	Problem	Hypothesis	Results
I	Are there main relevant documents to compose a theoretical referential on ECM control study?	Main relevant documents to compose a theoretical referential on ECM control study can be identified through a bibliometric analysis and a systematic review	62 documents aligned with research goal 12 documents selected as State of the Art Comparison between proposals (strength x weakness)
II	Which are the main ECM characteristics for products with multiple parts and sub-system assembly?	In loco research can identify main ECM characteristics for products with multiple parts and sub-system assembly.	5 major reasons for changes 9 ECM possible problems with consequences

Board 30 – Research questions with results (cont.)

ID	Problem	Hypothesis	Results
III	Which is the base for the best framework for ECM?	The best framework for ECM is based on current available academical knowledge associated to market best practices and professional applicability	ECM process flow and proposed framework with support templates
V	How to evaluate ECM framework?	Application results for proposed framework can be evaluated with ECM experienced professionals and researchers	Explanation video and questionnaire with 7 mandatory questions and 6 optional questions 28 responses from different professionals and researchers on ECM
IV	How to verify the ECM framework applicability?	Simulating the framework application on a commercial drinking fountain will verify the framework applicability	3 simulated cases applied to a commercial drinking fountain considering all framework possibilities (fast track, full track, shut down process)
VI	How to improve the ECM framework to get the best possible framework?	The best possible framework is the one based on academic knowledge associated with market best practices and professional applicability and improved by feedback from ECM experienced professionals and researchers	3 improvement opportunities applied to framework 5 opportunities for further studies based on research boundaries and suggestions from feedback

Source: author (2019)

The proposed framework after feedback is composed of 16 steps on its full track process and 15 on its fast track process, all of which are supported by 12 templates with a CANVAS for monitoring. Overall, the proposed framework was considered relevant by the questionnaire respondents.

For further studies, considering 3 comments of feedback from the questionnaire listed as “Compare to other methodologies (ITIL / Agile) or increase testing,” “Develop customized templates for segment or use software to manage” and “Adopt UAT - User Acceptance testing,” as well as the study boundaries listed in item 4.4, it is notable that multiple possibilities for further studies can be explored.

The first one is to increase testing because this research focused on presenting the methodology and to develop it on a simulated scenario. A real case application would contribute to endorsing professional applicability and consolidate this framework´s academic relevance.

The second opportunity is to adapt the framework for multiple types of companies, creating variants focused on specific segments and different manufacturing processes. Examples of this would be software development and made-to-order manufacturing, but not products with multiple parts and sub-system assembly produced or small sized production. These variants would allow comparison with other methodologies as mentioned for improvement opportunities suggested in the ECM framework feedback questionnaire.

Proposing a software to manage the framework as suggested on the ECM framework feedback questionnaire is also a possibility. However, this would request a different research focus on information technology tools and languages.

UAT – user acceptance testing – is common for software development. To adopt UAT, it is a valuable suggestion that would require a deeper study regarding how to delegate to requester the test on the required change. In the current framework, the acceptance testing is managed by the CAII as part of the implementation process, but to consider the user represented by the requester as responsible could be an interesting breakthrough thought worth exploring.

The last opportunity for further studies is to dedicate effort on defining how to execute risk management for fast track/full track decision, templates scores definition and not relevant impact validation.

With this, the study divided into 6 chapters presents a framework for the Engineering Change Management with practical implementation support through templates for products with multiple parts and sub-system assembly produced as high volume at a small-time rate.

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APPENDIX A – Bibliometric Analysis details

A.1 BIBLIOMETRIC ANALYSIS METHODOLOGY

a) STEP ONE

A general search using "ECM or Engineering Change Management" resulted in 33970 documents, according to Table 17. Those results involved multiple areas of studies, such as Biology, Medicine, Engineering, Material Sciences and Agricultural sciences.

Table 17 - General search on Scopus using "ECM or Engineering Change Management" for bibliometric analysis

SUBJECT AREA	Percentage
Biochemistry, Genetics and Molecular Biology	43,9%
Medicine	36,0%
Engineering	22,0%
Materials Science	12,4%
Agricultural and Biological Sciences	7,8%
Chemical Engineering	7,6%
Immunology and Microbiology	5,6%
Neuroscience	4,8%
Physics and Astronomy	4,7%
Undefined	0,2%
Others	29,4%

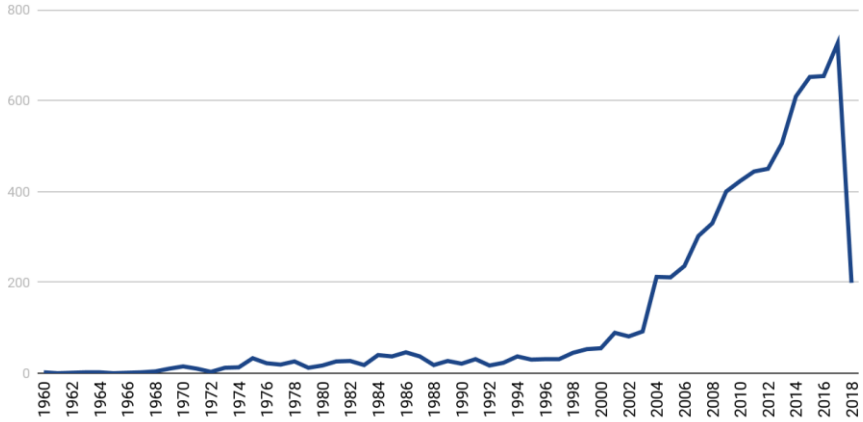
Source: Adapted by author using data from March 31st 2018 (2019)

Considering one document can refer to more than one subject area, the total percentage is superior to 100%. However, since the goal in this step is to establish to which topics the document relates to, this percentage exceeding 100% is expected.

B) STEP TWO

Since only topics related to Engineering are the focus of this research, a new search considering only this area resulted in 7472 documents. Their distribution through the years is illustrated on Graphic 10.

Graphic 10 - “ECM or Engineering Change Management” limited to Engineering study area



Source: Adapted by author using data from March 31 2018 (2019)

In Graphic 10, the increasing interest in the topic from 2002 and on is notable. This is consistent with Pikosz & Malmqvist (1998) affirming in late 90s that product lifecycle was decreasing, mainly due to hard competition. Engineering change was the key to fast adoption of changing customer needs. In the early 2000s, the ECM subject gained visibility.

In 2018, the number of publications is lower than in 2017 not because they decreased, but because only the first quarter of the year was considered. Projecting the first quarter number to the full year expectation results in almost 800 documents regarding the topic in Engineering for 2018.

When performing a detailed evaluation of the documents’ title and keywords, an unexpected outcome was noticed. Within the field of Engineering, the acronym ECM may not only refer to Engineering Change Management, but also to "ElectroChemical Machining,” “ElectroChemical Migration,” “Electrochemical Membrane,” “Electrochemical Metallization,” "ExtraCellular Matrix,” "Environmentally Conscious Manufacturing,” “Eco-Care-Matrix,” “Eco-design Concept Manual,” “Error Correction Model,” “Expectation Confirmation Model,” “Enterprise Content Management,” “Engine Control Module,” “Engine Condition Monitoring,” “Energy-Corrected Milk,” “Equivalent Circuit Model,” “Electronic Control Module,”

“Electrets Condenser Microphones,” “Engineering Chain Management,” “Equilibrium Constant Method,” and “Eddy Current Microscope.”

In order to avoid documents not related to Engineering Change Management, a review was conducted on steps 1 and 2 to remove ECM from the search during step 3.

C) STEP THREE

The results of reviewing of steps 1 and 2 to consider only Engineering Change Management and the area of Engineering can be found in Table 18.

Table 18 - General search on Scopus using “Engineering Change Management” for bibliometric analysis

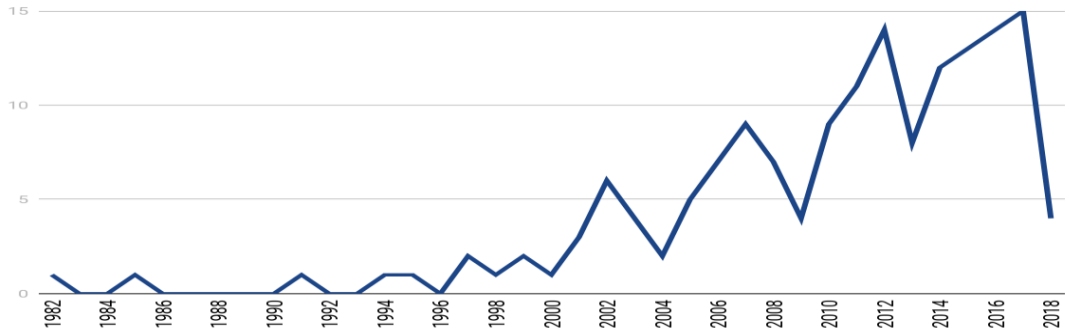
SUBJECT AREA	Percentage
Engineering	74,2%
Computer Science	43,2%
Business, Management and Accounting	19,7%
Decision Sciences	16,0%
Mathematics	16,0%
Social Sciences	3,8%
Others	7,9%

Source: Adapted by author using data from March 31st 2018 (2019)

Considering one document can refer to more than one subject area. The total percentage is superior to 100%, however, since the goal in this step is to establish which topics the document relates to, this percentage exceeding 100% is expected.

Removing ECM from the search, the study areas were narrowed down to exact sciences, such as Engineering, Computer and Mathematics. The biomedical sciences, such as Biology and Medicine were removed, indicating the documents are more related to product development. Despite that, focusing on Engineering is still necessary as shown in Graphic 11.

Graphic 11 - “Engineering Change Management” limited to Engineering study area



Source: Adapted by author using data from March 31st 2018 (2019)

In Graphic 11, the distribution of papers over the years indicate that removing ECM has also removed results from before 1980, which considering a comment from Padalkar & Gopinath (2016) that states from early ‘60s till early ‘80s, the focus for project management lied upon scheduling. Only from mid ‘80s and did a a shift toward an explanation for other phenomena than ECM studies starting in 1982 is reasonable.

The increased importance, noticed as publications have increased in the last eighteen years, can be associated with market scenario change as pointed out by Karthik & Reddy (2001). The point made was that manufacturers are pushed to produce a high quality product at the lowest cost with minimal lead-time, making change management of vital importance.

In 2018, the number of publications is lower than in 2017. This is not because it has decreased, but rather, because only first quarter of the year was considered. Projecting the first quarter number in comparison to the full year expectation results in about 16 documents regarding the topic in the field of Engineering for 2018.

D) STEP FOUR

In order to narrow down the 158 results from step 3, a series of cross-search was performed. Consideration of keywords identified as related to the main research purpose. The references are shown in Board 31.

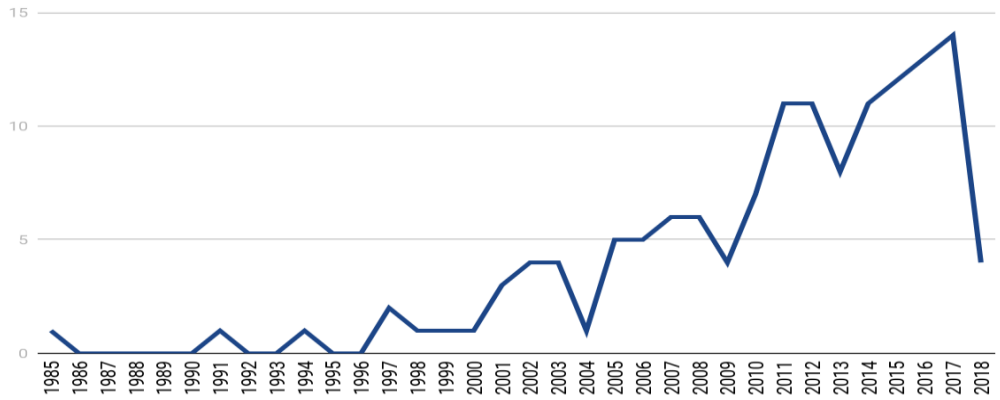
Board 31 - Cross search from step 3 to relevant keywords for bibliometric analysis

Keyword	Query	Results
Product	(TITLE-ABS-KEY("Engineering change management" and product) AND (LIMIT-TO (SUBJAREA,"ENGI")))	113
PMBOK	TITLE-ABS-KEY ("Engineering change management" AND pmbok)	0
SCRUM	(TITLE-ABS-KEY ("Engineering change management" AND scrum) AND (LIMIT-TO (SUBJAREA,"ENGI")))	0
CANVAS	TITLE-ABS-KEY ("Engineering change management" AND canvas)	0
Methodology	TITLE-ABS-KEY ("Engineering change management" AND methodology) AND (LIMIT-TO (SUBJAREA , "ENGI"))	14
Method	TITLE-ABS-KEY ("Engineering change management" AND method) AND (LIMIT-TO (SUBJAREA , "ENGI"))	55
Framework	TITLE-ABS-KEY ("Engineering change management" AND framework) AND (LIMIT-TO (SUBJAREA , "ENGI"))	24

Source: Adapted by author using data from March 31, 2018 (2019)

Board 31 obtained 137 documents as distributed over the years, according to Graphic 12.

Graphic 12 - “Engineering Change Management” and Keywords limited to Engineering study area



Source: Adapted by author using data from March 31, 2018 (2019)

The tendency in Graphic 12 is the same as in Graphic 11 because only 21 documents were removed once they did not have any relation to the keywords listed on Board 31. Therefore, there is no relevance to compose a theoretical referential on the ECM control study. The same is valid in relation to the comment about publications in 2018, where the full year expectation for publications would be 16.

E) STEP FIVE

Since the main relevant information is considered from the last 5 years, the appropriate string requires step 4 to be restricted from 2013 to 2018. This results in 62 documents being relevant to compose a theoretical referential on the ECM control study. The research string considering these limitations is illustrated in Board 32.

Board 32 - Research string for bibliometric analysis

Query	Results
((TITLE-ABS-KEY ("Engineering change management" AND product)) OR (TITLE-ABS-KEY ("Engineering change management" AND plm)) OR (TITLE-ABS-KEY ("Engineering change management" AND methodology)) OR (TITLE-ABS-KEY ("Engineering change management" AND method))) OR (TITLE-ABS-KEY ("Engineering change management" AND framework)) AND (LIMIT-TO (SUBJAREA , "ENGI")) AND (LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013))	62

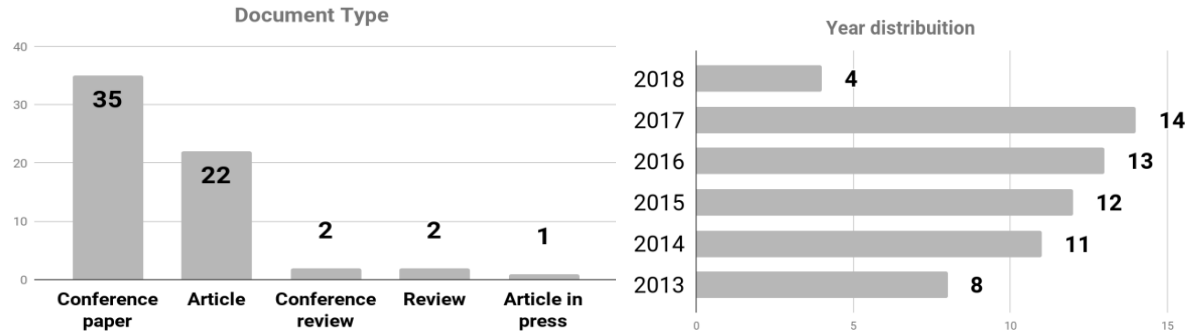
Source: Adapted by author from Scopus data from March 31, 2018 (2019)

The string from Board 32 concludes the bibliometric analysis methodology. The results can be found in Appendix A.2.

A.2 BIBLIOMETRIC ANALYSIS RESULTS

Considering the methodology for bibliometric analysis, the evaluation over the document type and year distribution is illustrated in Graphic 13.

Graphic 13 - Document type and Year distribution from bibliometric analysis

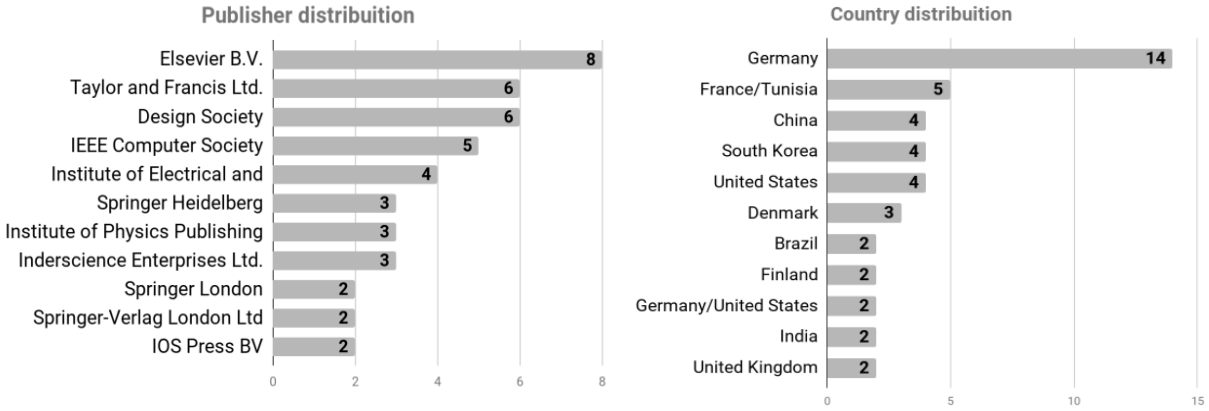


Source: Author based on Scopus data from March 31, 2018 (2019)

Graphic 13 indicates the increased importance of ECM when considering the trend of a higher number of publication over the last five years. Graphic 13 also indicates the increased importance of coherent when considering the industry competitiveness scenario. However, the theme is still stronger in conference papers, which account for over 56% of the responses total. This indicates the need for structured research on the topic.

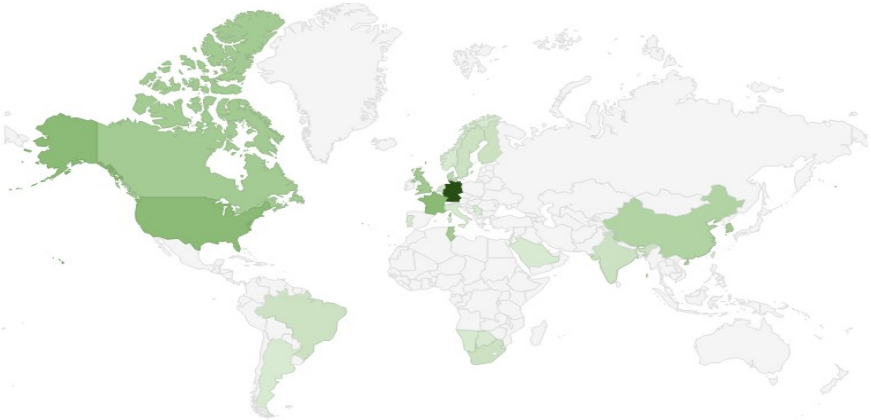
The main publisher and country were also evaluated and illustrated in Graphic 14. This evaluation indicates the concentration on a few publications and countries, which is common in topics with recent increased importance, such as ECM control. Eleven publishers responded for 71% of all documents, and five countries accumulate 50% of the total. This indicates that studies are centralized in a few institutions and need a worldwide spread. The map in Graphic 15 visualizes this concentration.

Graphic 14 - Main Publisher and Country from bibliometric analysis



Source: Author based on Scopus data from March 31, 2018 (2019)

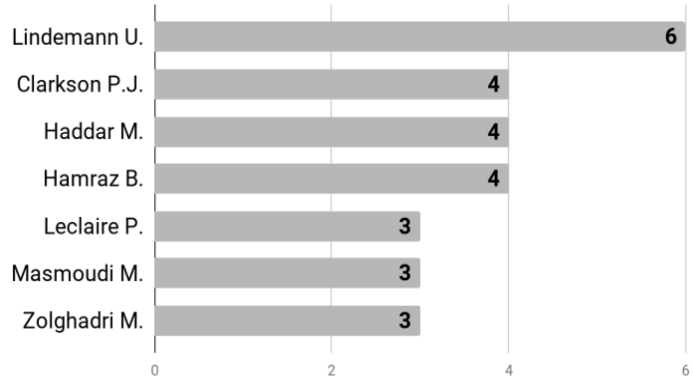
Graphic 15 - Country distribution map from bibliometric analysis



Source: Author based on Scopus data from March 31, 2018 (2019)

The same concentration pattern from Graphic 15 is presented when comparing authors and sources on Graphic 16 and Table 19. Nine sources respond for 61% of documents while 7 authors published 43% of the total reinforcing the idea that studies are centralized on few institutions.

Graphic 16 - Main authors (more than 2 publishes) from bibliometric analysis



Source: author based on Scopus data from March 31, 2018 (2019)

Table 19 - Main source with more than one publishing from bibliometric analysis

Source title	**Qty**
Proceedings of the International Conference on Engineering Design, ICED	8
Procedia CIRP	6
Research in Engineering Design	4
International Journal of Production Research	4
IEEE International Conference on Industrial Engineering and Engineering Management	4
Lecture Notes in Mechanical Engineering	3
IOP Conference Series: Materials Science and Engineering	3
Journal of Engineering Design	3
International Journal of Product Lifecycle Management	3
Computers in Industry	2
PICMET 2017 - Portland International Conference on Management of Engineering and Technology: Technology Management for the Interconnected World, Proceedings	2
Concurrent Engineering Research and Applications	2

Source: Author based on Scopus data from March 31, 2018 (2019)

Regarding keywords, the 62 documents present high similarity because the 13 keywords appear more than twice as showed in Board 33. Words “Engineering Change Management (ECM) and Product Lifecycle Management (PLM)” appear 6 times. Other pairs also repeat as shown in Board 34.

Board 33 - Keywords that appear more than twice from bibliometric analysis

Keyword	Qty
Engineering Change Management (ECM)	43
Change propagation	10
Product life cycle management (PLM)	9
Change management	6
Engineering Change	5
Decision making	4
Dependency	4

Keyword	Qty
Design management	4
Change prediction	3
Design Structure Matrix(DSM)	3
Engineering changes	3
Functional reasoning	3
Product data management	3

Source: author based on Scopus data from March 31, 2018

Board 34 - Main keywords combination (more than twice) from bibliometric analysis

Keyword 1	Keyword 2	Qty
Engineering Change Management (ECM)	Product life cycle management (PLM)	6
Engineering Change Management (ECM)	Change propagation	5
Engineering Change Management (ECM)	Engineering Change	5
Engineering Change Management (ECM)	Dependency	4
Engineering Change Management (ECM)	Change management strategy	3
Engineering Change Management (ECM)	Change Prediction	3
Engineering Change Management (ECM)	Decision making	3
Engineering Change Management (ECM)	Product data management	3

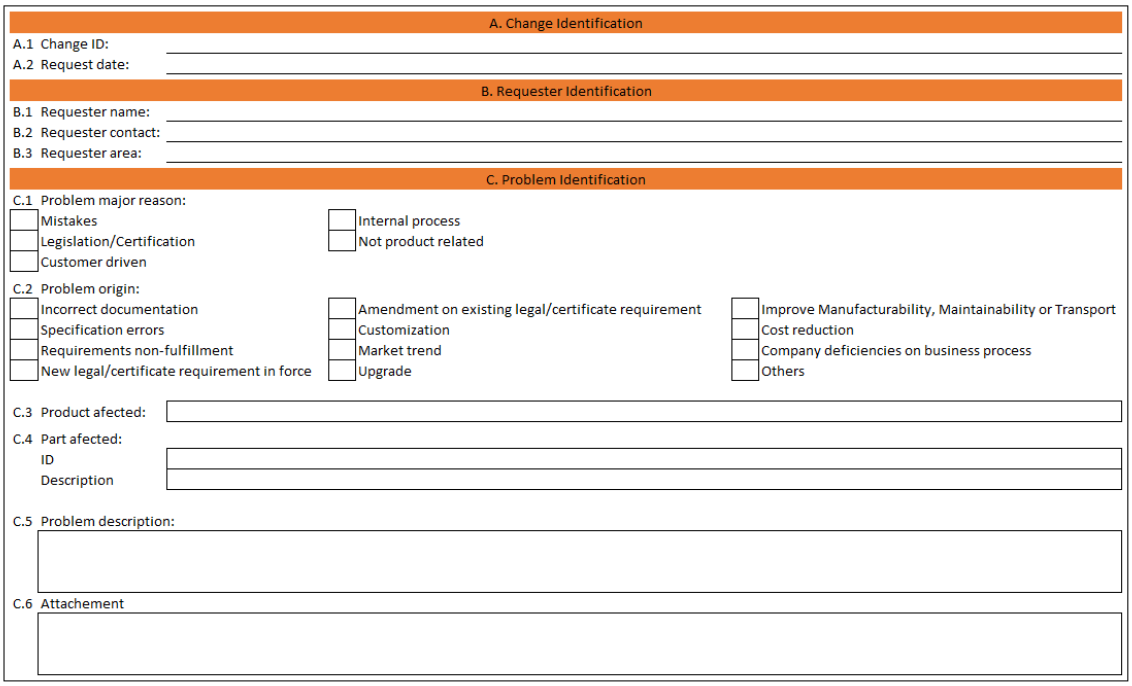
Source: author based on Scopus data from March 31, 2018

These results conclude the bibliometric analysis and the systematic review of the data as detailed in item 3.3.

APPENDIX B – Templates for ECM Framework

The templates requested during the framework execution are illustrated from Figure 58 to Figure 68.

Figure 58 – Template for Problem Report (TPR)



A. Change Identification

A.1 Change ID:

A.2 Request date:

B. Requester Identification

B.1 Requester name:

B.2 Requester contact:

B.3 Requester area:

C. Problem Identification

C.1 Problem major reason:

- ☐ Mistakes
- ☐ Legislation/Certification
- ☐ Customer driven
- ☐ Internal process
- ☐ Not product related

C.2 Problem origin:

- ☐ Incorrect documentation
- ☐ Specification errors
- ☐ Requirements non-fulfillment
- ☐ New legal/certificate requirement in force
- ☐ Amendment on existing legal/certificate requirement
- ☐ Customization
- ☐ Market trend
- ☐ Upgrade
- ☐ Improve Manufacturability, Maintainability or Transport
- ☐ Cost reduction
- ☐ Company deficiencies on business process
- ☐ Others

C.3 Product afected:

C.4 Part afected:

ID

Description

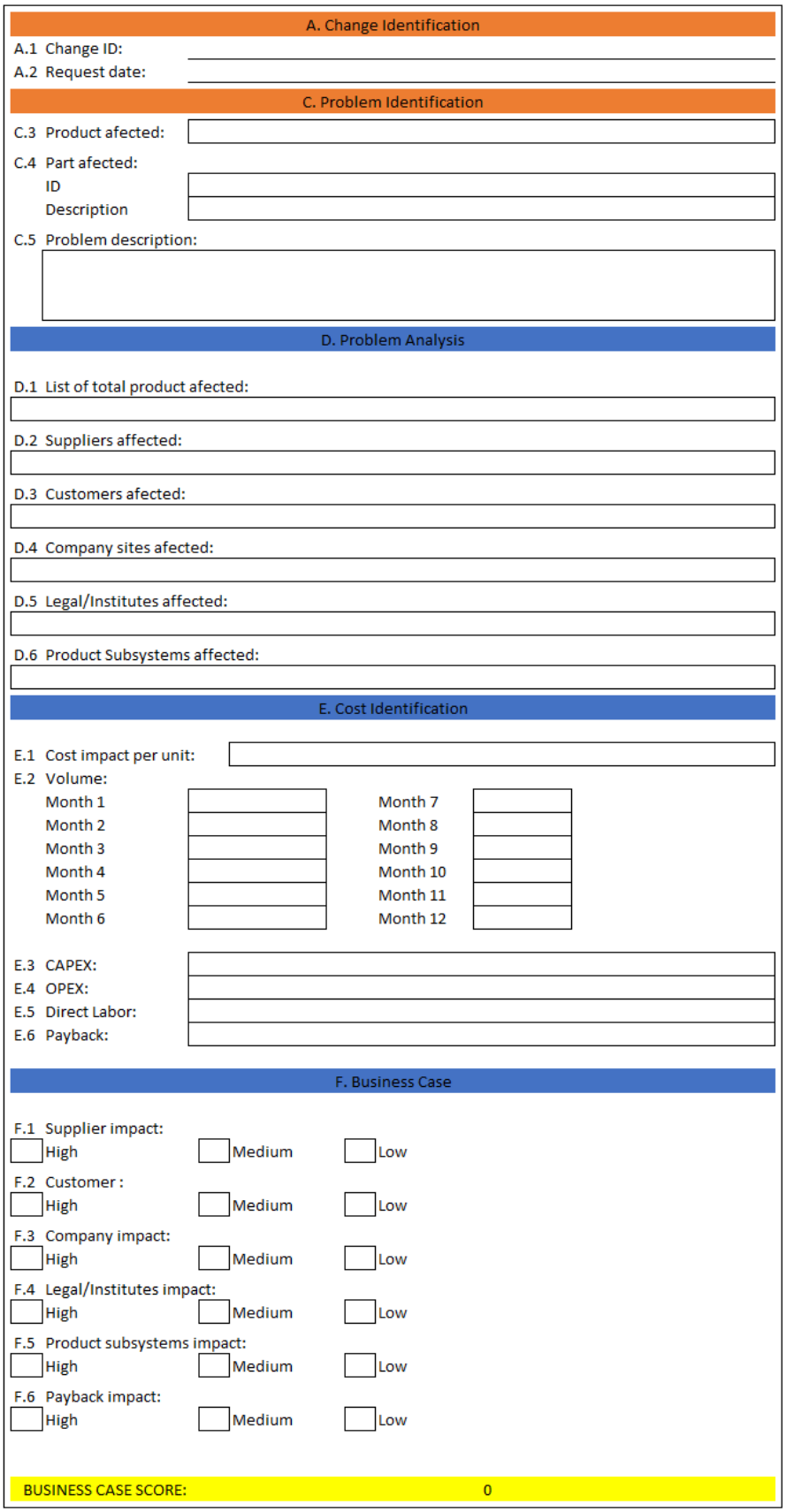
C.5 Problem description:

C.6 Attachement

Source: Author (2019)

For TPR, illustrated in Figure 58, three categories were considered as “Change Identification,” “Requester Identification,” and “Problem Identification” to support problem report creation. The items described in each category considered the results from the in loco research described in item 3.5, such as reasons for major problems their origins, as well as input from studies in Chapter 2.

Figure 59 - Template for Business Case (TBC)



A. Change Identification

A.1 Change ID:

A.2 Request date:

C. Problem Identification

C.3 Product afected:

C.4 Part afected:

ID

Description

C.5 Problem description:

D. Problem Analysis

D.1 List of total product afected:

D.2 Suppliers affected:

D.3 Customers afected:

D.4 Company sites afected:

D.5 Legal/Institutes affected:

D.6 Product Subsystems affected:

E. Cost Identification

E.1 Cost impact per unit:

E.2 Volume:

Month 1		Month 7	
Month 2		Month 8	
Month 3		Month 9	
Month 4		Month 10	
Month 5		Month 11	
Month 6		Month 12	

E.3 CAPEX:

E.4 OPEX:

E.5 Direct Labor:

E.6 Payback:

F. Business Case

F.1 Supplier impact: ☐ High ☐ Medium ☐ Low

F.2 Customer : ☐ High ☐ Medium ☐ Low

F.3 Company impact: ☐ High ☐ Medium ☐ Low

F.4 Legal/Institutes impact: ☐ High ☐ Medium ☐ Low

F.5 Product subsystems impact: ☐ High ☐ Medium ☐ Low

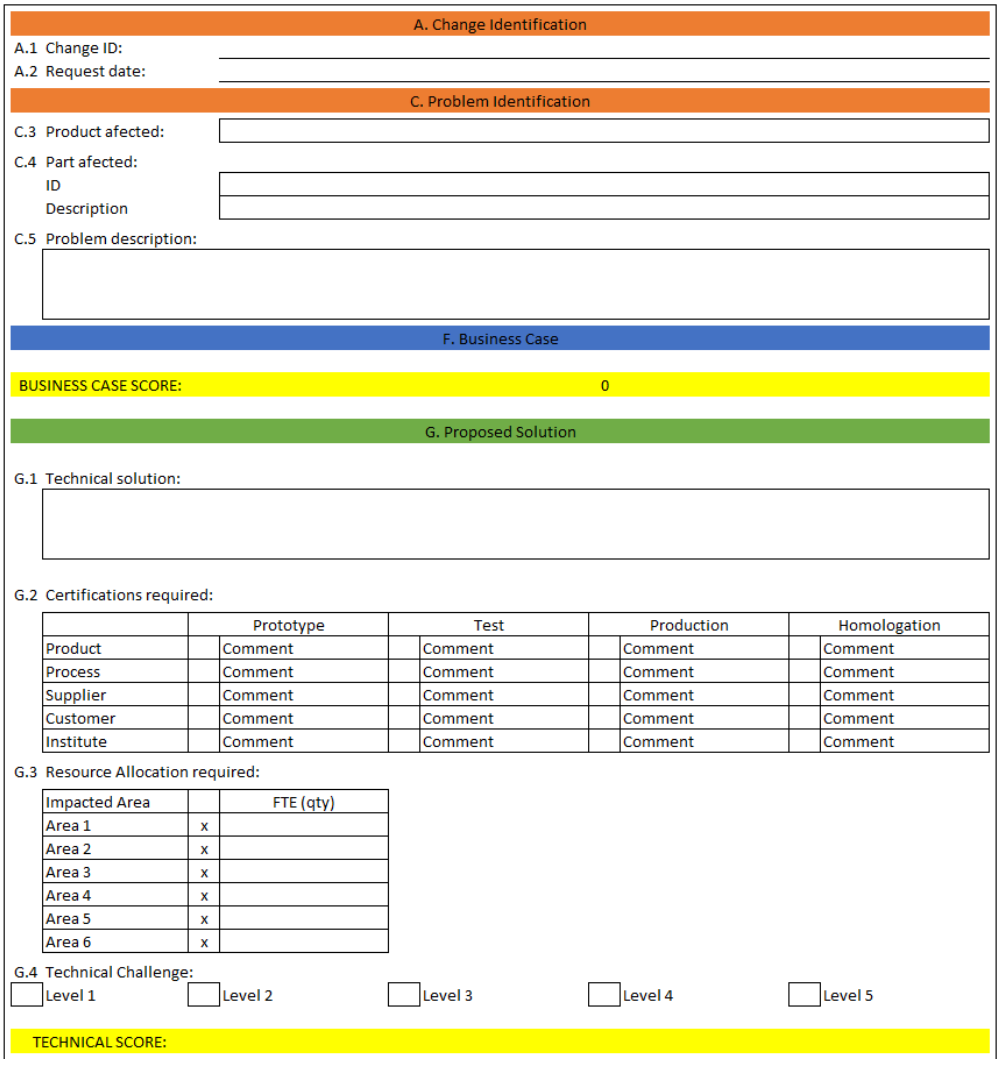
F.6 Payback impact: ☐ High ☐ Medium ☐ Low

BUSINESS CASE SCORE: 0

Source: Author (2019)

For TBC illustrated in Figure 59, two categories “Change Identification” and “Problem Identification” from TPR to support business case identification. Three new categories of “Problem Analysis,” “Cost identification,” and “Business Case” are included with the “Business Case score,” which is a consolidation of the evaluation from the previous categories. The items considered in these categories are based on usual areas for products with multiple parts and sub-system assembly on high volume of similar product produced at a small-time rate and may be customized if the company has a specific scenario to consider. Besides that, the relevance of each item can also be decided by the company. A practical example on how to use the items and the scores is described in Chapter 5.

Figure 60 - Template for Change Request (TCR)



A. Change Identification

A.1 Change ID:

A.2 Request date:

C. Problem Identification

C.3 Product afected:

C.4 Part afected:

ID

Description

C.5 Problem description:

F. Business Case

BUSINESS CASE SCORE: 0

G. Proposed Solution

G.1 Technical solution:

G.2 Certifications required:

	Prototype		Test		Production		Homologation
Product		Comment		Comment		Comment		Comment
Process		Comment		Comment		Comment		Comment
Supplier		Comment		Comment		Comment		Comment
Customer		Comment		Comment		Comment		Comment
Institute		Comment		Comment		Comment		Comment

G.3 Resource Allocation required:

Impacted Area		FTE (qty)
Area 1	x	
Area 2	x	
Area 3	x	
Area 4	x	
Area 5	x	
Area 6	x	

G.4 Technical Challenge:

☐ Level 1 ☐ Level 2 ☐ Level 3 ☐ Level 4 ☐ Level 5

TECHNICAL SCORE:

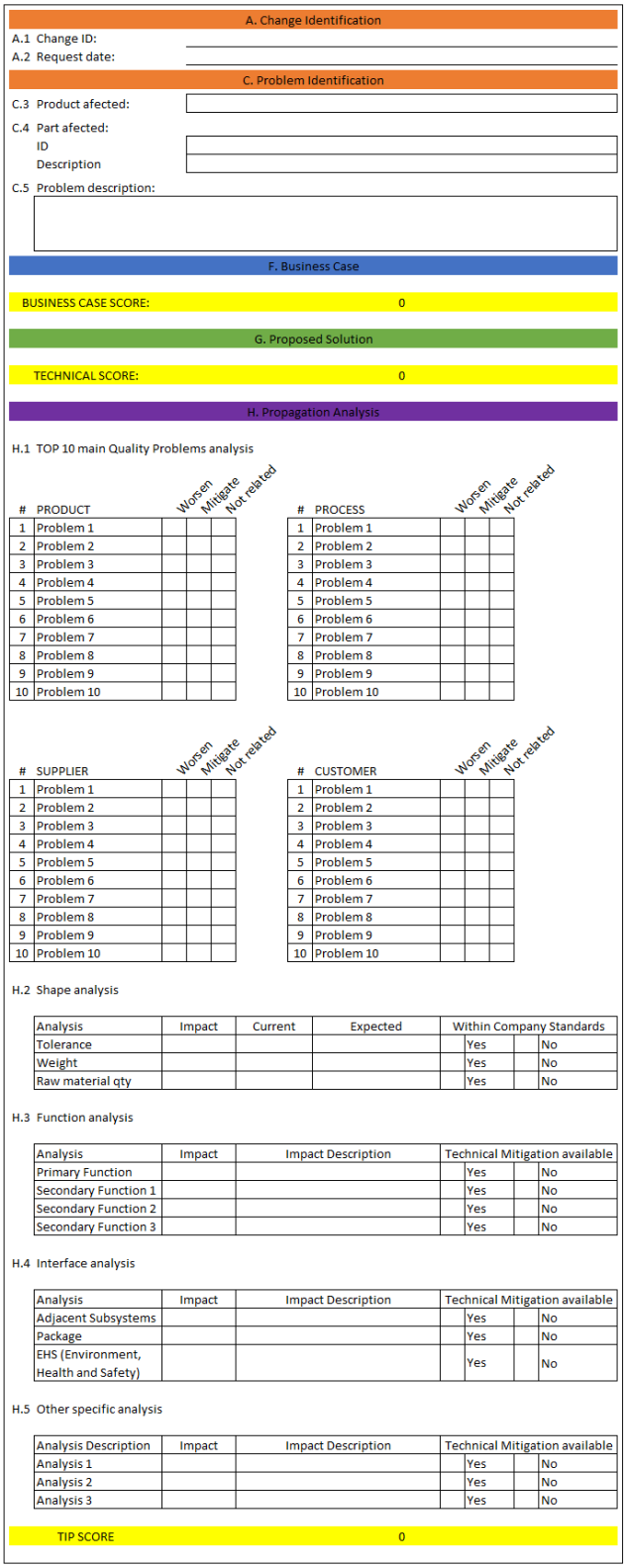
Source: Author (2019)

For TCR illustrated in Figure 60, two categories “Change Identification” and “Problem Identification” from TPR and the “Business Case” with business case score from TBC. The category “Proposed solution” included usual areas for products with multiple parts and sub-system assembly on high volume of similar product produced at a small-time rate and may be customized if the company has a specific scenario to consider. The technical challenge with 5 steps is based on in loco research benchmarking. The technical score priority considers the complexity of certification required together with technical challenge. The relevance of each item can be decided by the company. A practical example on how to use the items and scores is described in Chapter 5.

The TIP illustrated in Figure 61 considers two categories “Change Identification” and “Problem Identification” from TPR, the “Business Case” with business case score from TBC, and “Proposed solution” with technical score from TCR. The “Propagation Analysis” is included based on in loco research benchmarking. The top 10 quality problems are a suggestion, considering a quality analysis on a paretto chart usually comprehends 80% of problems with less than 10 items. The shape, function, interface and other analyses considered general aspects from products with multiple parts and sub-system assembly on high volume of similar product produced at a small-time rate and to be customized by the company in case of need. The TIP score is the consolidation of Business Score, Technical Score and Propagation Analysis. The relevance of each item can be decided by the company. A practical example on how to use the items and scores is described in Chapter 5.

In Figure 62, the TPFast considers the “Change Identification” from TPR and includes the “Prioritization for Fast Track” category, evaluating the Business Case Score from TBC, The Technical Score from TCR, the TIP Score from TIP, and the FTE quantity from TBC. The company standards for the Fast Track classification can be included when the attractiveness level is defined according to company customization as well as the priority result. A practical example on how to use the items and scores is described in Chapter 5.

Figure 61 - Template for Impact Propagation (TIP)



A. Change Identification

A.1 Change ID:

A.2 Request date:

C. Problem Identification

C.3 Product afected:

C.4 Part afected:

ID

Description

C.5 Problem description:

F. Business Case

BUSINESS CASE SCORE: 0

G. Proposed Solution

TECHNICAL SCORE: 0

H. Propagation Analysis

H.1 TOP 10 main Quality Problems analysis

#	PRODUCT	Worsen	Mitigate	Not related
1	Problem 1			
2	Problem 2			
3	Problem 3			
4	Problem 4			
5	Problem 5			
6	Problem 6			
7	Problem 7			
8	Problem 8			
9	Problem 9			
10	Problem 10			

#	PROCESS	Worsen	Mitigate	Not related
1	Problem 1			
2	Problem 2			
3	Problem 3			
4	Problem 4			
5	Problem 5			
6	Problem 6			
7	Problem 7			
8	Problem 8			
9	Problem 9			
10	Problem 10			

#	SUPPLIER	Worsen	Mitigate	Not related
1	Problem 1			
2	Problem 2			
3	Problem 3			
4	Problem 4			
5	Problem 5			
6	Problem 6			
7	Problem 7			
8	Problem 8			
9	Problem 9			
10	Problem 10			

#	CUSTOMER	Worsen	Mitigate	Not related
1	Problem 1			
2	Problem 2			
3	Problem 3			
4	Problem 4			
5	Problem 5			
6	Problem 6			
7	Problem 7			
8	Problem 8			
9	Problem 9			
10	Problem 10			

H.2 Shape analysis

Analysis	Impact	Current	Expected	Within Company Standards			
Tolerance					Yes		No
Weight					Yes		No
Raw material qty					Yes		No

H.3 Function analysis

Analysis	Impact	Impact Description	Technical Mitigation available			
Primary Function				Yes		No
Secondary Function 1				Yes		No
Secondary Function 2				Yes		No
Secondary Function 3				Yes		No

H.4 Interface analysis

Analysis	Impact	Impact Description	Technical Mitigation available			
Adjacent Subsystems				Yes		No
Package				Yes		No
EHS (Environment, Health and Safety)				Yes		No

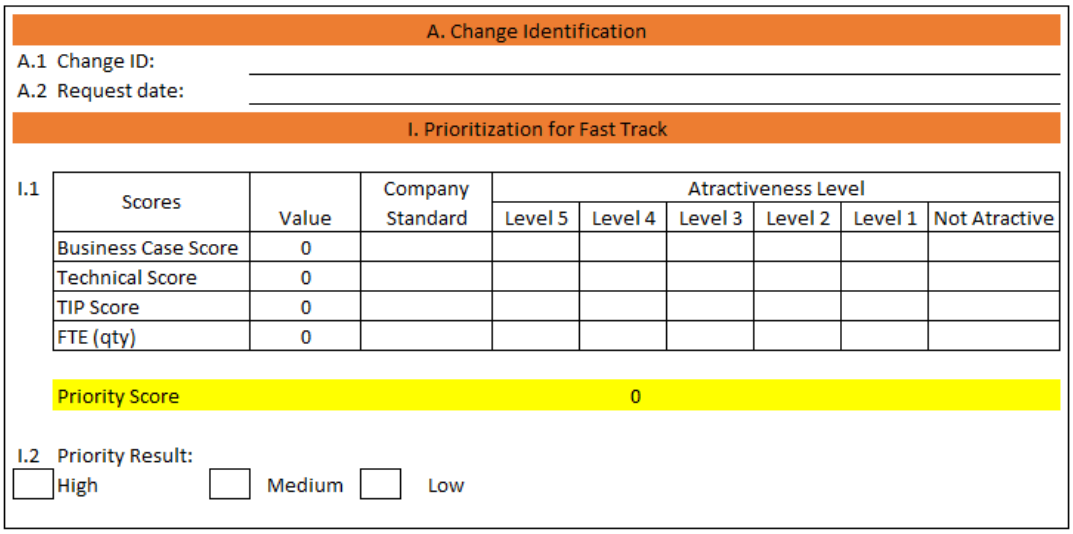
H.5 Other specific analysis

Analysis Description	Impact	Impact Description	Technical Mitigation available			
Analysis 1				Yes		No
Analysis 2				Yes		No
Analysis 3				Yes		No

TIP SCORE 0

Source: Author (2019)

Figure 62 - Template for Fast Track Prioritization (TPFast)



A. Change Identification

A.1 Change ID: _____

A.2 Request date: _____

I. Prioritization for Fast Track

I.1

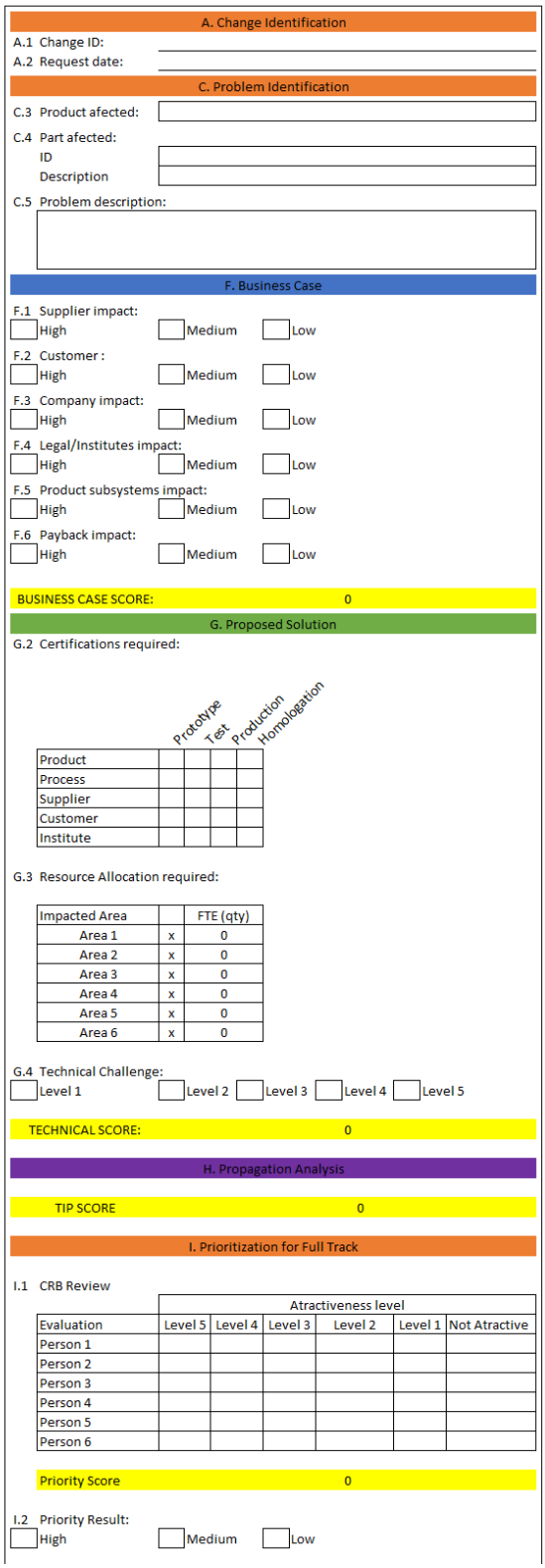
Scores	Value	Company Standard	Atractiveness Level					
			Level 5	Level 4	Level 3	Level 2	Level 1	Not Atractive
Business Case Score	0							
Technical Score	0							
TIP Score	0							
FTE (qty)	0							
Priority Score				0				

I.2 Priority Result:

☐ High ☐ Medium ☐ Low

Source: Author (2019)

Figure 63 - Template for Full Track Prioritization (TPFull)



A. Change Identification

A.1 Change ID:

A.2 Request date:

C. Problem Identification

C.3 Product afected:

C.4 Part afected:

ID

Description

C.5 Problem description:

F. Business Case

F.1 Supplier impact: ☐ High ☐ Medium ☐ Low

F.2 Customer : ☐ High ☐ Medium ☐ Low

F.3 Company impact: ☐ High ☐ Medium ☐ Low

F.4 Legal/Institutes impact: ☐ High ☐ Medium ☐ Low

F.5 Product subsystems impact: ☐ High ☐ Medium ☐ Low

F.6 Payback impact: ☐ High ☐ Medium ☐ Low

BUSINESS CASE SCORE: 0

G. Proposed Solution

G.2 Certifications required:

	Prototype	Test	Production	Homologation
Product				
Process				
Supplier				
Customer				
Institute				

G.3 Resource Allocation required:

Impacted Area		FTE (qty)
Area 1	x	0
Area 2	x	0
Area 3	x	0
Area 4	x	0
Area 5	x	0
Area 6	x	0

G.4 Technical Challenge: ☐ Level 1 ☐ Level 2 ☐ Level 3 ☐ Level 4 ☐ Level 5

TECHNICAL SCORE: 0

H. Propagation Analysis

TIP SCORE 0

I. Prioritization for Full Track

I.1 CRB Review

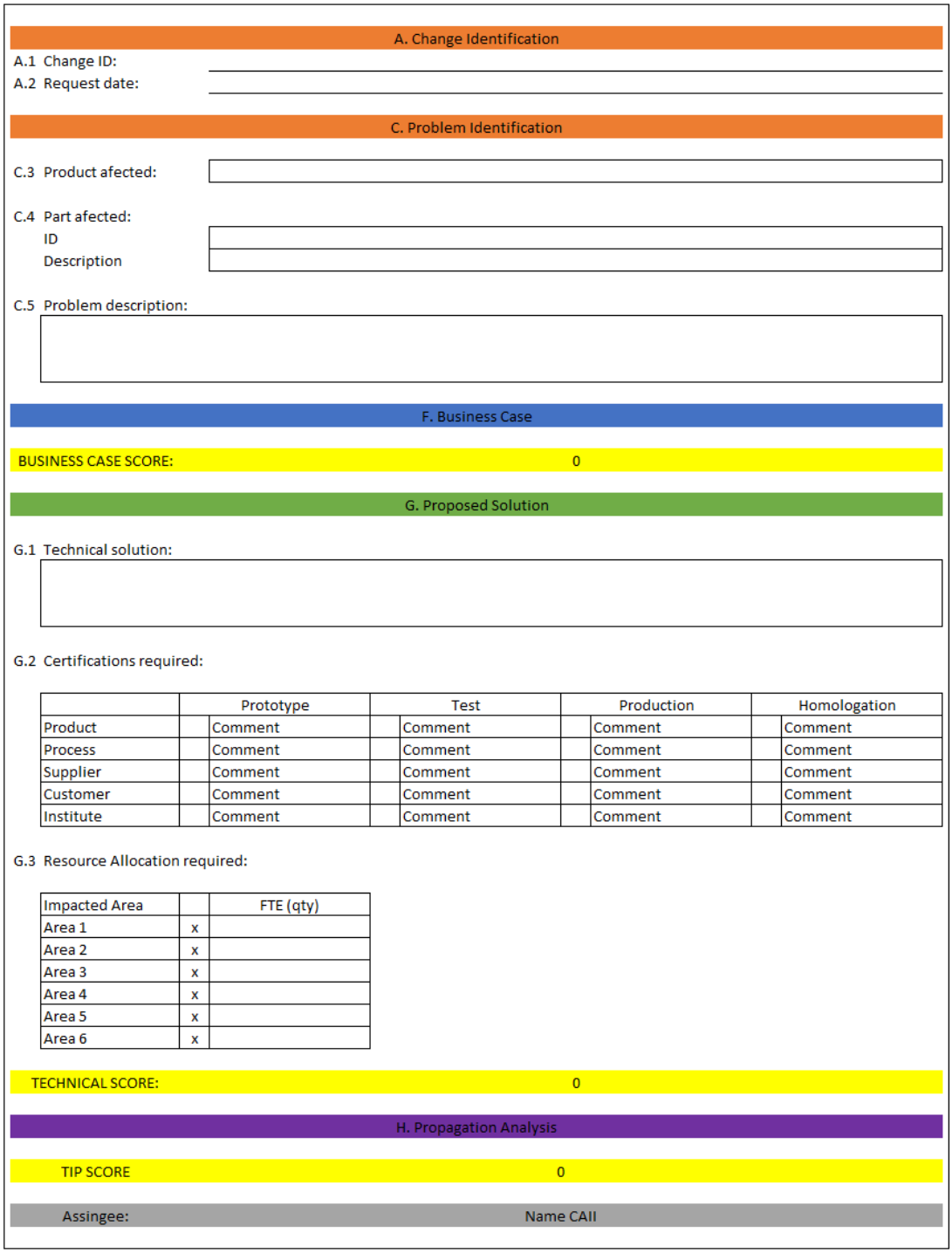
	Atractiveness level					
Evaluation	Level 5	Level 4	Level 3	Level 2	Level 1	Not Atractive
Person 1						
Person 2						
Person 3						
Person 4						
Person 5						
Person 6						

Priority Score 0

I.2 Priority Result: ☐ High ☐ Medium ☐ Low

Source: Author (2019)

Figure 64 - Template for Change Notice (TCN)



A. Change Identification

A.1 Change ID:

A.2 Request date:

C. Problem Identification

C.3 Product afected:

C.4 Part afected:

ID

Description

C.5 Problem description:

F. Business Case

BUSINESS CASE SCORE: 0

G. Proposed Solution

G.1 Technical solution:

G.2 Certifications required:

		Prototype		Test		Production		Homologation
Product		Comment		Comment		Comment		Comment
Process		Comment		Comment		Comment		Comment
Supplier		Comment		Comment		Comment		Comment
Customer		Comment		Comment		Comment		Comment
Institute		Comment		Comment		Comment		Comment

G.3 Resource Allocation required:

Impacted Area		FTE (qty)
Area 1	x	
Area 2	x	
Area 3	x	
Area 4	x	
Area 5	x	
Area 6	x	

TECHNICAL SCORE: 0

H. Propagation Analysis

TIP SCORE 0

Assingee: Name CAII

Source: Author (2019)

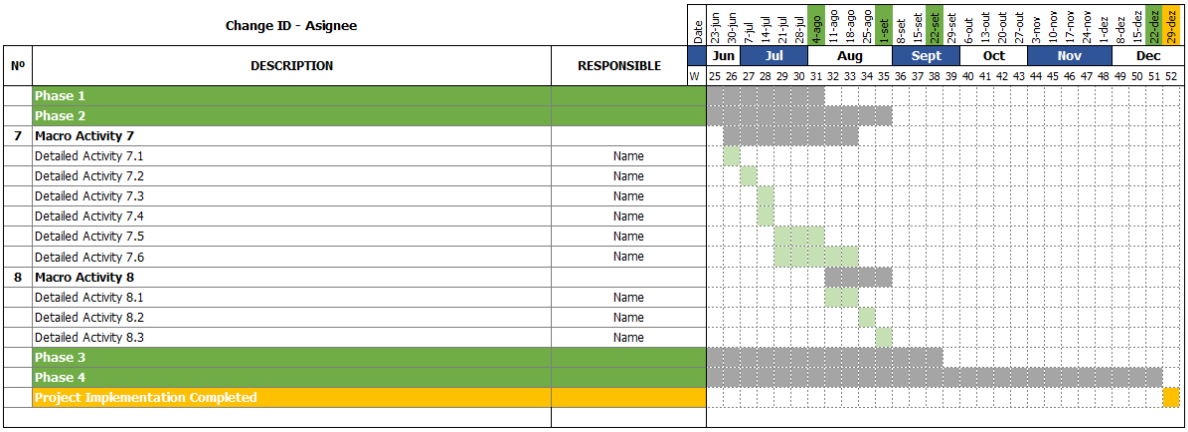
The TPFull in Figure 63 considers two categories “Change Identification” and “Problem Identification” from TPR, the “Business Case” with business case score from TBC, the “Proposed solution” with technical score from TCR, and the “Propagation Analysis” with

TIP score from TIP. The new category, “Prioritization for Full Track” considers the CRB people to evaluate the attractiveness level for the change according to company standards that are customized as well as the priority result. A practical example on how to use the items and scores is described in Chapter 5.

The TCN illustrated in Figure 64 considers two categories “Change Identification” and “Problem Identification” from TPR, the “Business Case” with business case score from TBC, the “Proposed solution” with technical score from TCR, and the “Propagation Analysis” with TIP score from TIP. The new category included is only the Asignee to record who will be responsible as CAII.

The TCP illustrated in Figure 65 is a project plan chart similar to commercially available tools for project management that consider phases, macro activities, and detailed activities for the project implementation. On the template, the major deadlines are highlighted to support project execution.

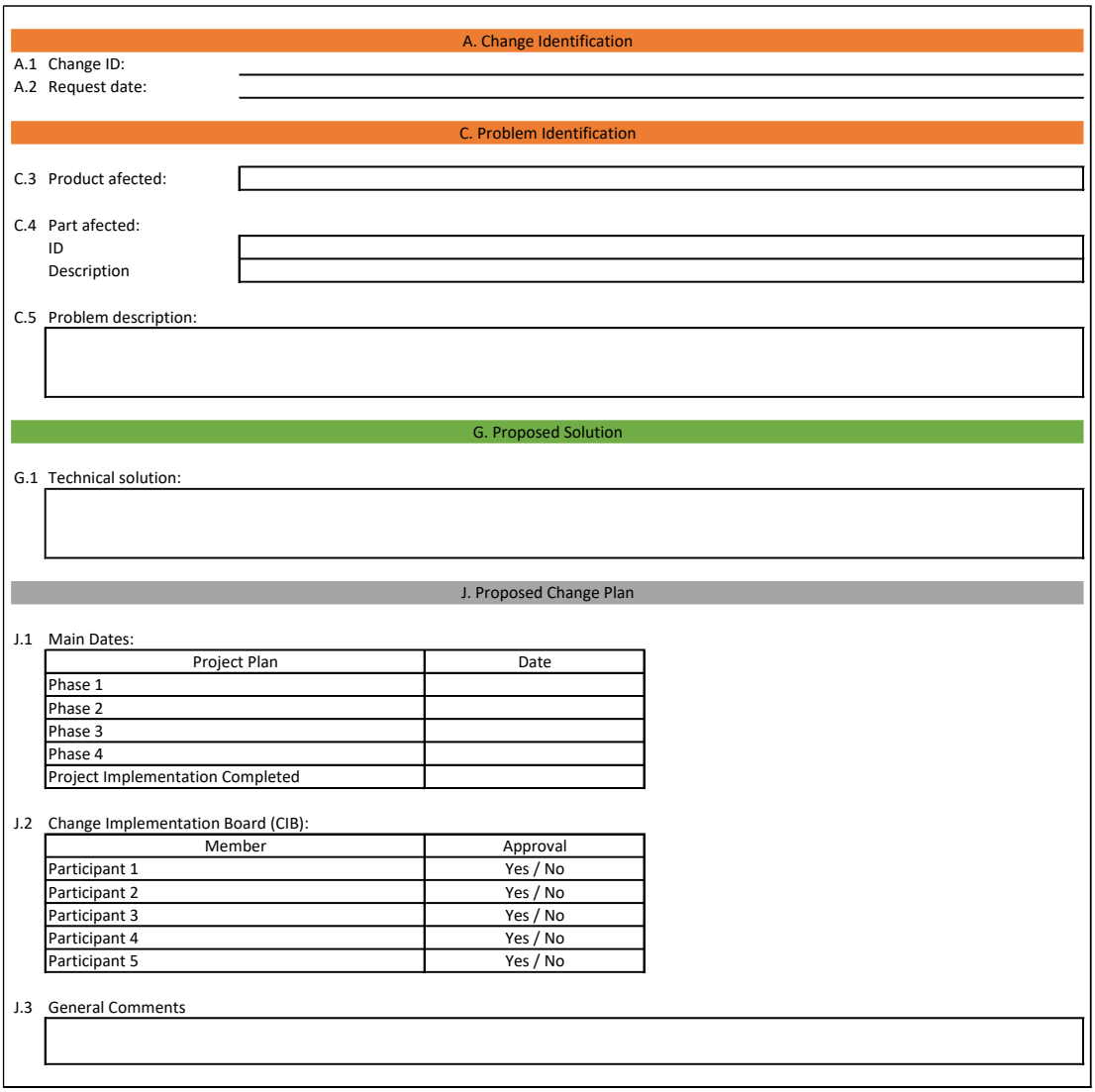
Figure 65 - Template for Change Plan (TCP)



Source: Author (2019)

The TCPA illustrated in Figure 66 considers two categories “Change Identification” and “Problem identification” from TPR, and “Proposed solution” from TCR. The category included “Proposed Change Plan” and organizes the data of the main dates from TCP, and the approval and comments from CIB members to formalize the approval of the change plan into a table.

Figure 66 - Template for Change Plan Approval (TCPA)



A. Change Identification

A.1 Change ID:

A.2 Request date:

C. Problem Identification

C.3 Product afected:

C.4 Part afected:

ID

Description

C.5 Problem description:

G. Proposed Solution

G.1 Technical solution:

J. Proposed Change Plan

J.1 Main Dates:

Project Plan	Date
Phase 1	
Phase 2	
Phase 3	
Phase 4	
Project Implementation Completed	

J.2 Change Implementation Board (CIB):

Member	Approval
Participant 1	Yes / No
Participant 2	Yes / No
Participant 3	Yes / No
Participant 4	Yes / No
Participant 5	Yes / No

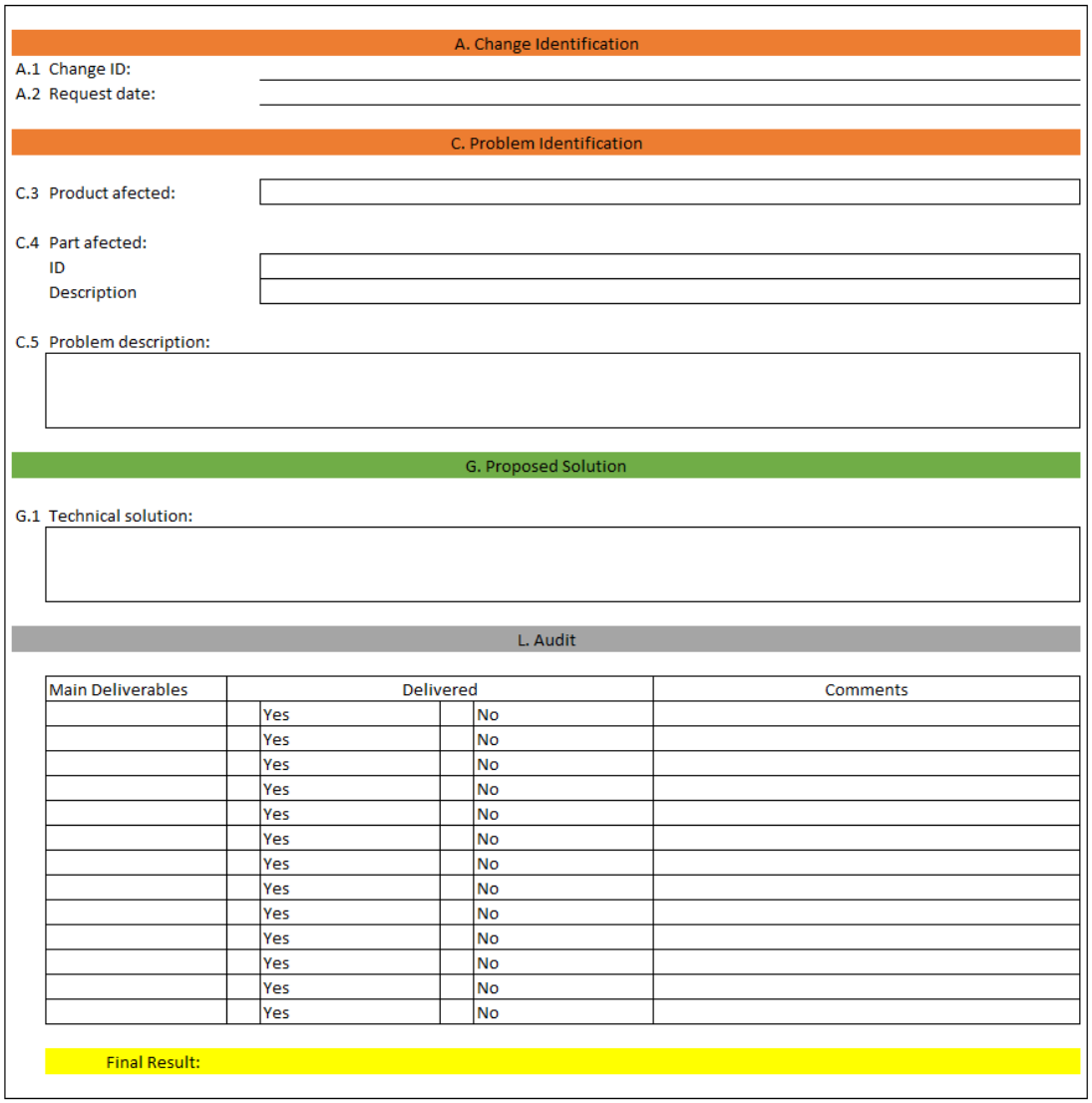
J.3 General Comments

Source: Author (2019)

The TCA illustrated in Figure 67 considers two categories “Change Identification” and “Problem identification” from TPR, and “Proposed solution” from TCR. The new category “Audit” consolidates the main deliverables from TCP and the evaluation from CAIII regarding the deliverables quality. The purpose is to consider the change of “Approved” or “Not Approved’ as the final decision.

The TH illustrated in Figure 68 is similar to TCP. This is because it is a project plan chart similar to commercially available tools for project management. The tools consider phases, macro activities and detailed activities for the evaluation of impacts of changes. They are then implemented together with a final decision regarding not relevant impact. The practical application for these templates are in Chapter 5.

Figure 67 - Template for Change Audit (TCA)



A. Change Identification

A.1 Change ID:

A.2 Request date:

C. Problem Identification

C.3 Product afected:

C.4 Part afected:

ID

Description

C.5 Problem description:

G. Proposed Solution

G.1 Technical solution:

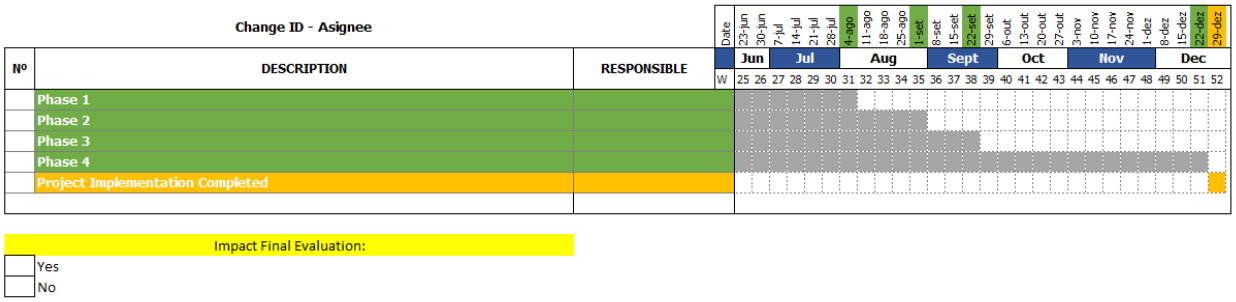
L. Audit

Main Deliverables	Delivered				Comments
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	
		Yes		No	

Final Result:

Source: Author (2019)

Figure 68 - Template for Homologation (TH)



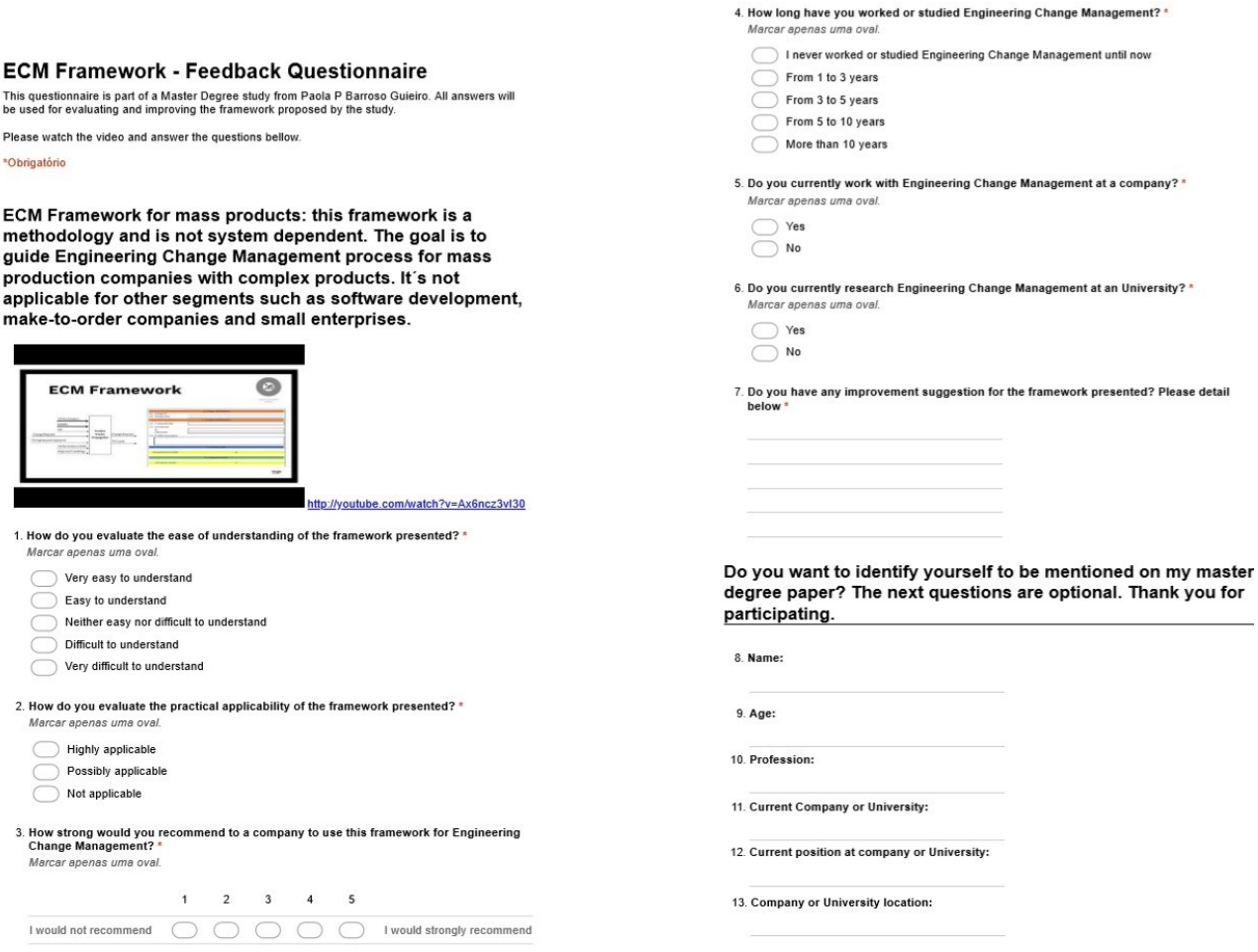
Source: Author (2019)

APPENDIX C – ECM Framework Feedback Questionnaire

C.1 ORIGINAL ECM FRAMEWORK FEEDBACK QUESTIONNAIRE

The ECM questionnaire was distributed with a free sharing file platform, Google Drive, through its form tool, Google Forms, as shown in Figure 69.

Figure 69 – ECM Framework feedback questionnaire



ECM Framework - Feedback Questionnaire

This questionnaire is part of a Master Degree study from Paola P Barroso Guieiro. All answers will be used for evaluating and improving the framework proposed by the study.

Please watch the video and answer the questions bellow.

*Obrigatório

ECM Framework for mass products: this framework is a methodology and is not system dependent. The goal is to guide Engineering Change Management process for mass production companies with complex products. It´s not applicable for other segments such as software development, make-to-order companies and small enterprises.

ECM Framework

http://youtube.com/watch?v=Ax6ncz3vl30

1. **How do you evaluate the ease of understanding of the framework presented?** *
Marcar apenas uma oval.
- Very easy to understand
- Easy to understand
- Neither easy nor difficult to understand
- Difficult to understand
- Very difficult to understand

2. **How do you evaluate the practical applicability of the framework presented?** *
Marcar apenas uma oval.
- Highly applicable
- Possibly applicable
- Not applicable

3. **How strong would you recommend to a company to use this framework for Engineering Change Management?** *
Marcar apenas uma oval.

	1	2	3	4	5	
I would not recommend	◯	◯	◯	◯	◯	I would strongly recommend

4. **How long have you worked or studied Engineering Change Management?** *
Marcar apenas uma oval.
- I never worked or studied Engineering Change Management until now
- From 1 to 3 years
- From 3 to 5 years
- From 5 to 10 years
- More than 10 years

5. **Do you currently work with Engineering Change Management at a company?** *
Marcar apenas uma oval.
- Yes
- No

6. **Do you currently research Engineering Change Management at an University?** *
Marcar apenas uma oval.
- Yes
- No

7. **Do you have any improvement suggestion for the framework presented? Please detail below** *

Do you want to identify yourself to be mentioned on my master degree paper? The next questions are optional. Thank you for participating.

8. **Name:**

9. **Age:**

10. **Profession:**

11. **Current Company or University:**

12. **Current position at company or University:**

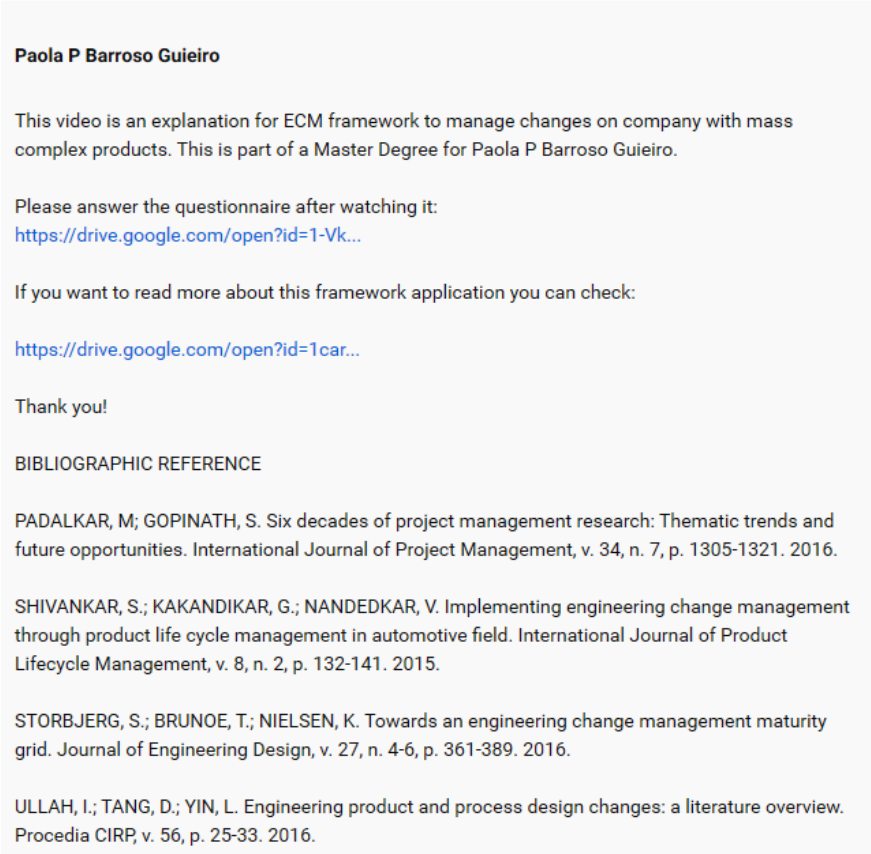
13. **Company or University location:**

Source: Author (2019)

The link used was https://forms.gle/51vMza2Vjk23JWZX9. This link was accessible from any internet browser anywhere in the world during the feedback collection period. The link was disabled following the feedback collection period.

The video described was available through a free sharing video stream with the link https://www.youtube.com/watch?v=Ax6ncz3vI30 together with the description from Figure 70

Figure 70 – Video description at free sharing video stream



Paola P Barroso Guieiro

This video is an explanation for ECM framework to manage changes on company with mass complex products. This is part of a Master Degree for Paola P Barroso Guieiro.

Please answer the questionnaire after watching it:
https://drive.google.com/open?id=1-Vk...

If you want to read more about this framework application you can check:

https://drive.google.com/open?id=1car...

Thank you!

BIBLIOGRAPHIC REFERENCE

PADALKAR, M; GOPINATH, S. Six decades of project management research: Thematic trends and future opportunities. International Journal of Project Management, v. 34, n. 7, p. 1305-1321. 2016.

SHIVANKAR, S.; KAKANDIKAR, G.; NANDEDKAR, V. Implementing engineering change management through product life cycle management in automotive field. International Journal of Product Lifecycle Management, v. 8, n. 2, p. 132-141. 2015.

STORBJERG, S.; BRUNOE, T.; NIELSEN, K. Towards an engineering change management maturity grid. Journal of Engineering Design, v. 27, n. 4-6, p. 361-389. 2016.

ULLAH, I.; TANG, D.; YIN, L. Engineering product and process design changes: a literature overview. Procedia CIRP, v. 56, p. 25-33. 2016.

Source: Author (2019)

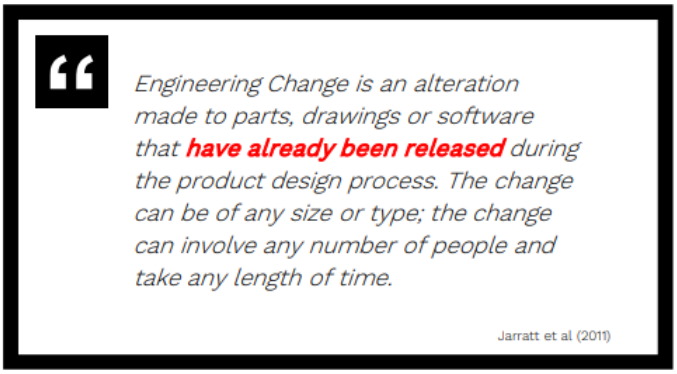
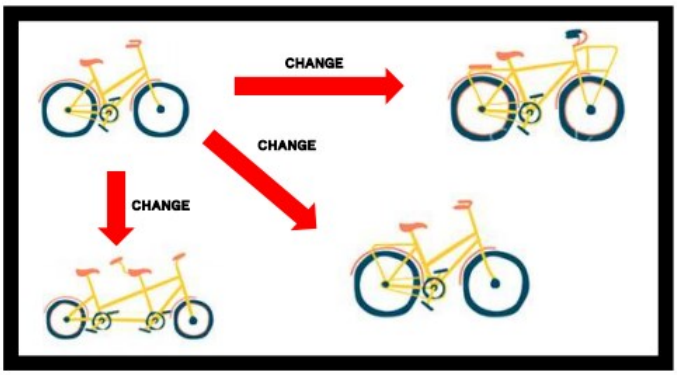
The support material shared in a free sharing file platform (Google Drive) was available with the link, https://drive.google.com/file/d/1car9uEE6VnT7R5_b6Z4B-s-fQiBGIkjc/view during the feedback collection period. The link was disabled following the feedback collection period.

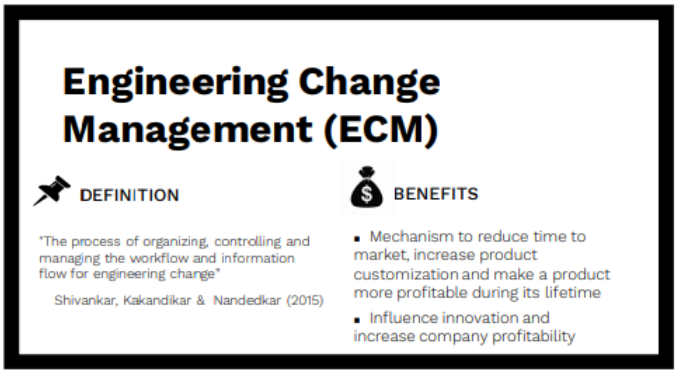
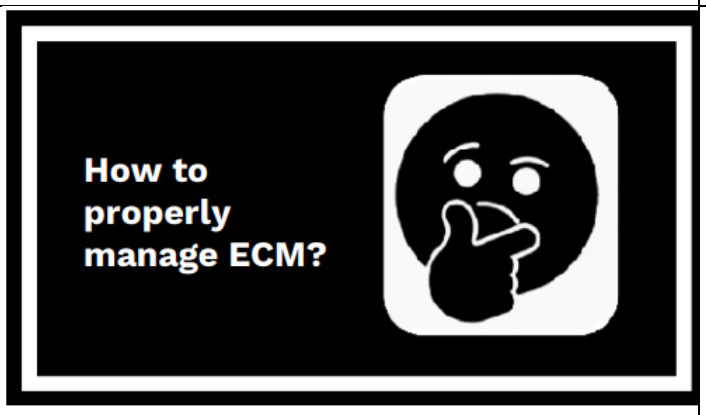
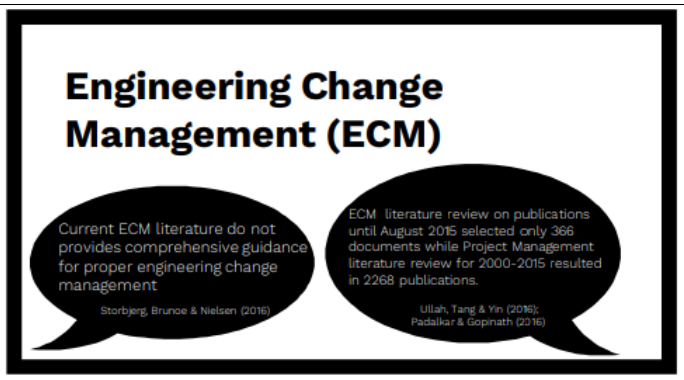
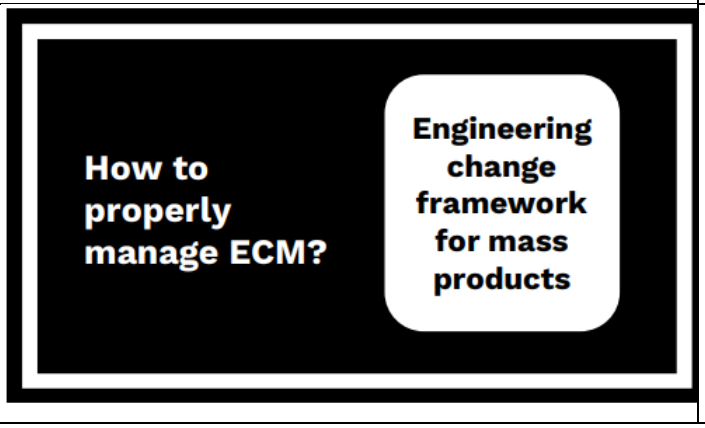
The details for the video content are described in item C.2. The video was available during the feedback collection period. The link was disabled following the feedback collection period.

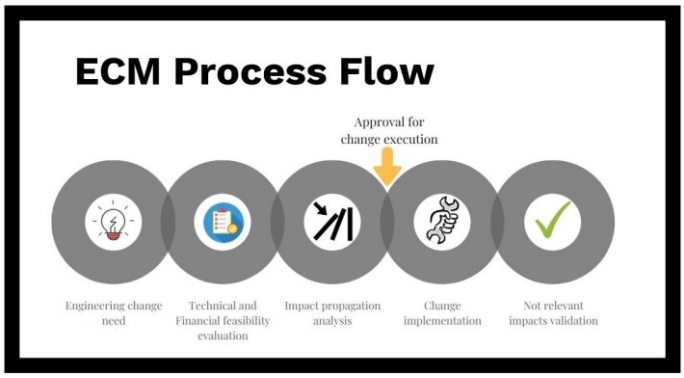
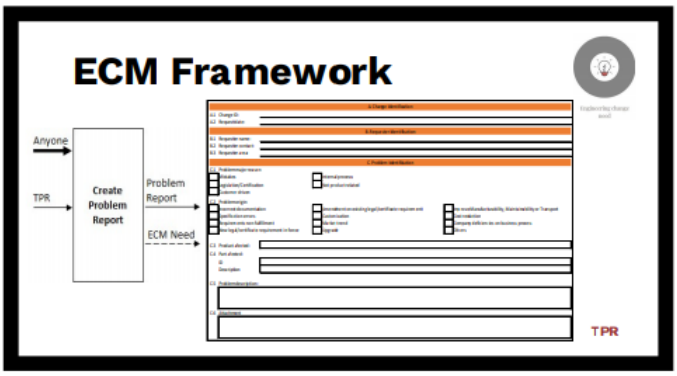
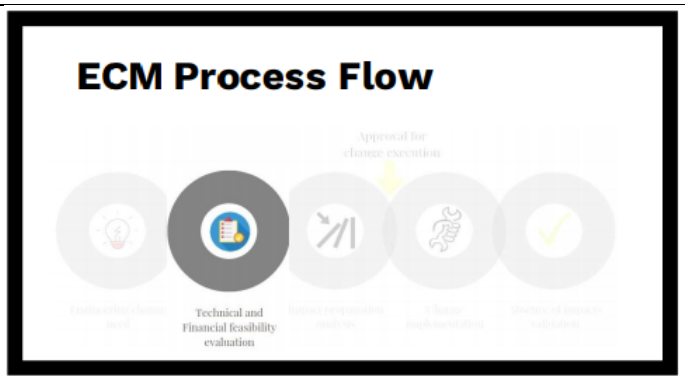
C.2 VIDEO IMAGES AND AUDIO DETAILS

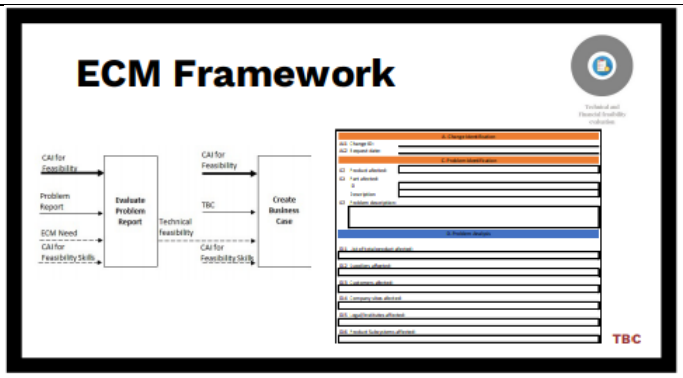
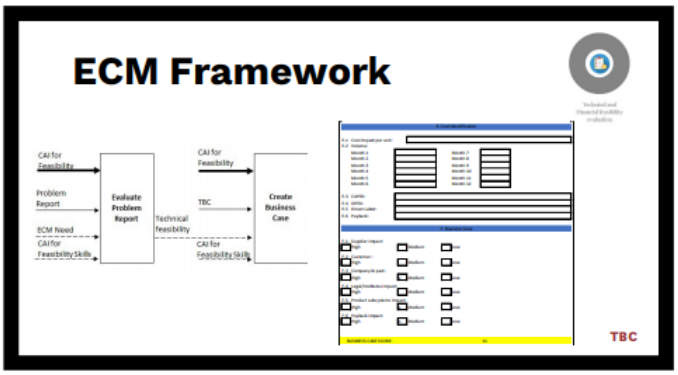
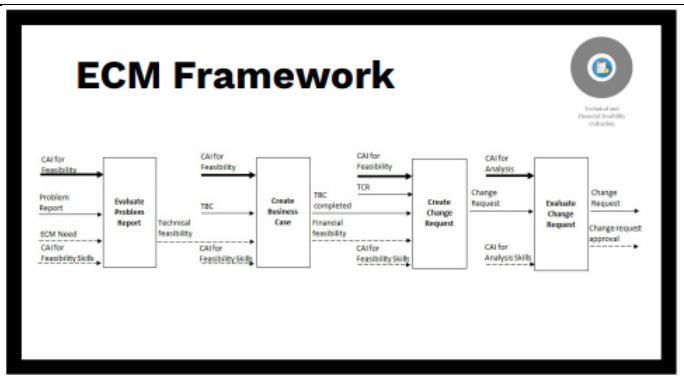
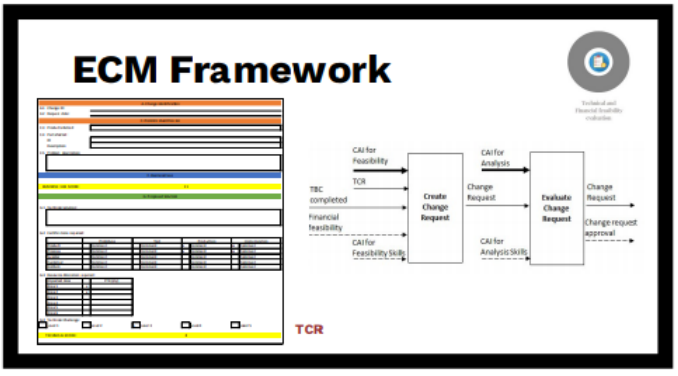
The video for the ECM framework feedback questionnaire had 11 minutes and 29 seconds with the content as illustrated in Board 35.

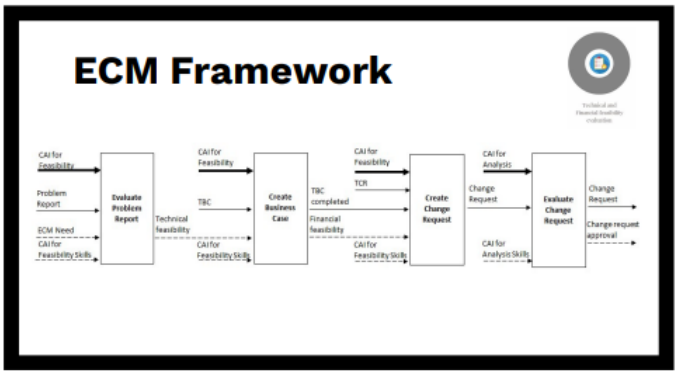
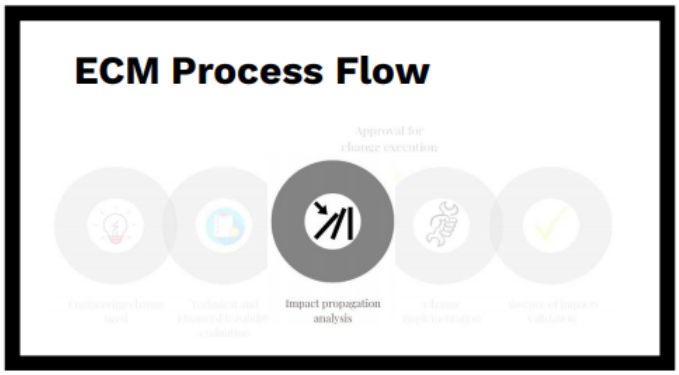
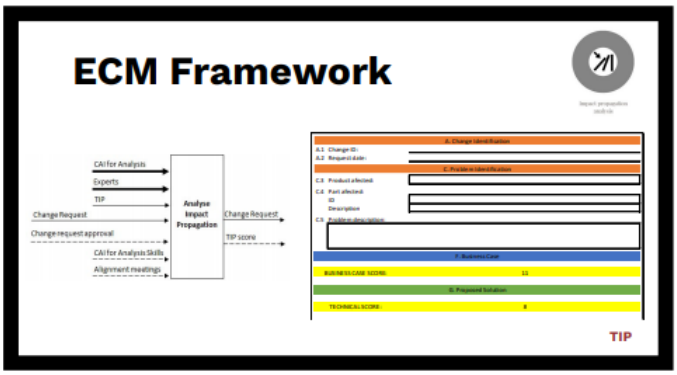
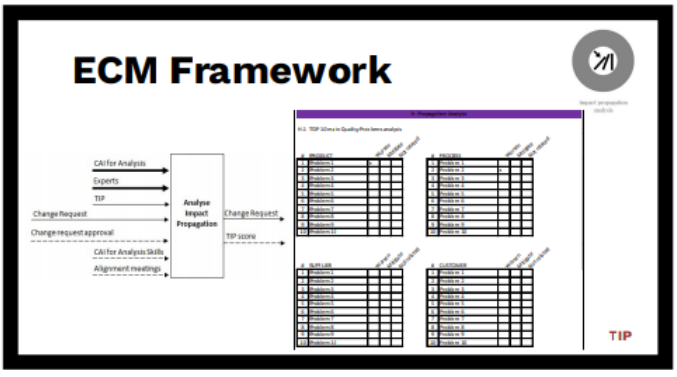
Board 35 – Video Content for ECM framework feedback questionnaire

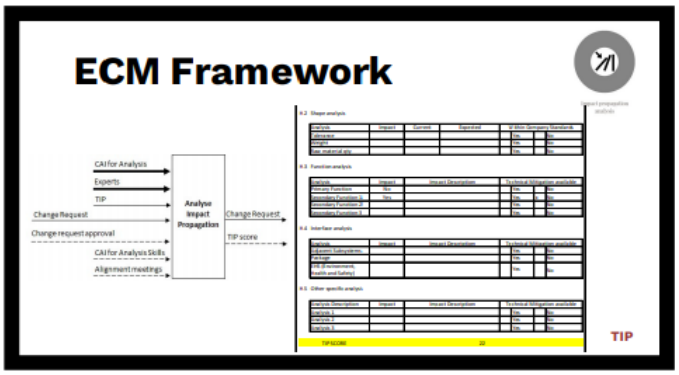
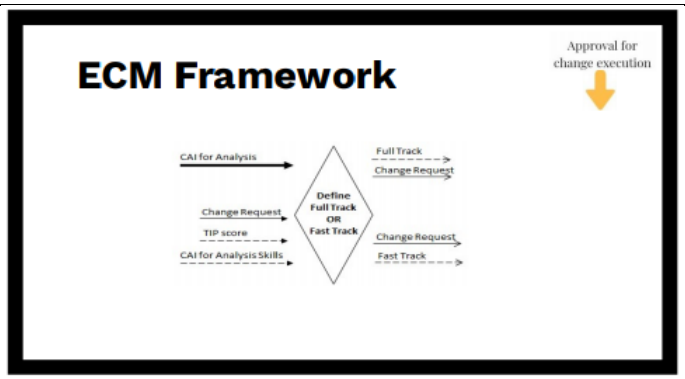
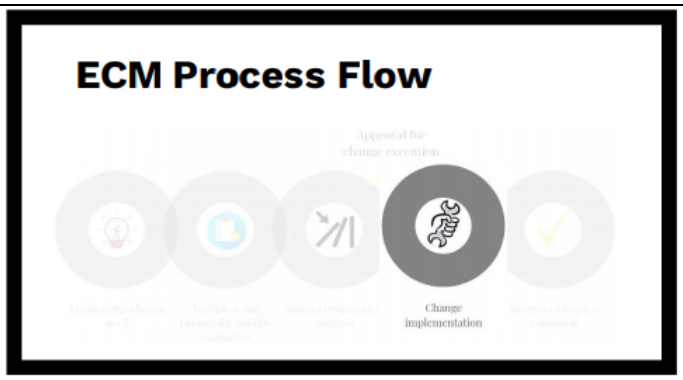
Video Image	**Audio details**
	
	Do you know what engineering change is? Engineering Change is an alteration made to parts, drawings or software that have already been released during the product design process. The change can be of any size or type; the change can involve any number of people and take any length of time.
	In practical terms, this means that any change to the product to increase a feature or adapt to a new market is an engineering change.

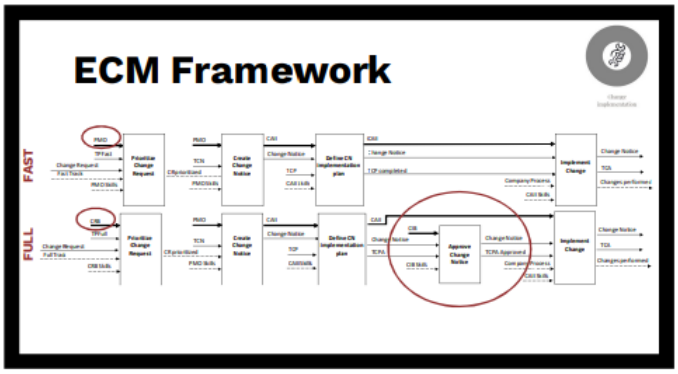
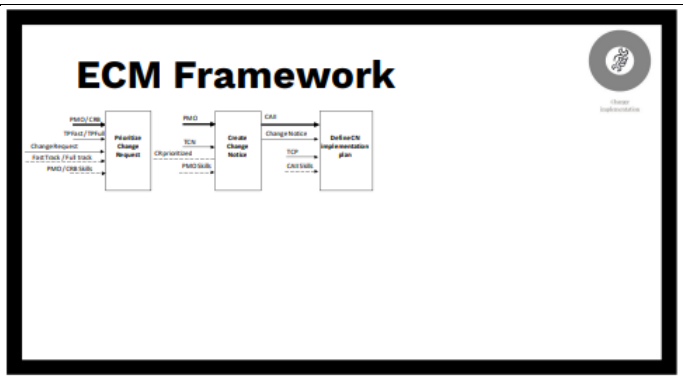
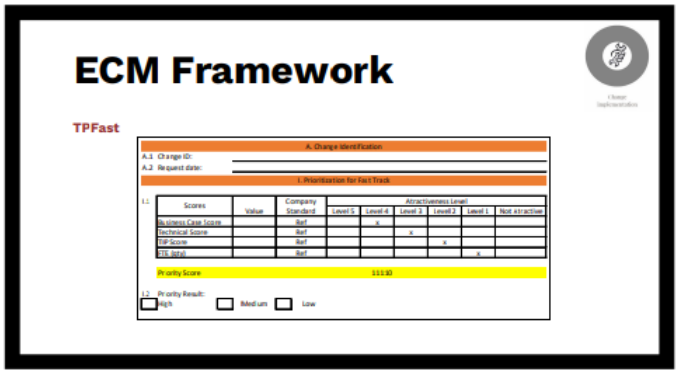
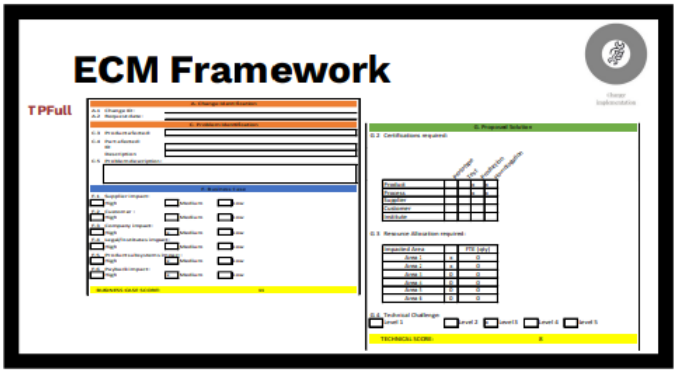
	Properly manage and control the engineering change is called Engineering change Management And it has a potential to reduce time to market on improved products, increase customization and make a product more profitable during its lifetime, after all, everyone likes a new gadget or an upgrade right? Besides that, correct exploring ECM influences innovation and increases company profitability.
	And now you might be asking yourself... How to properly manage ECM?
	Answer this question is the problem. The lack of structured studies on this subject is notable. And the existing literature is not a good guidance for practical implementation. A literature review on publications until August 2015 selected only 366 documents on engineering change management. This is six times less than project management for example.
	For this reason my research proposes an engineering change framework to be applied on engineering change management for high volume of similar product produced at a small-time rate.

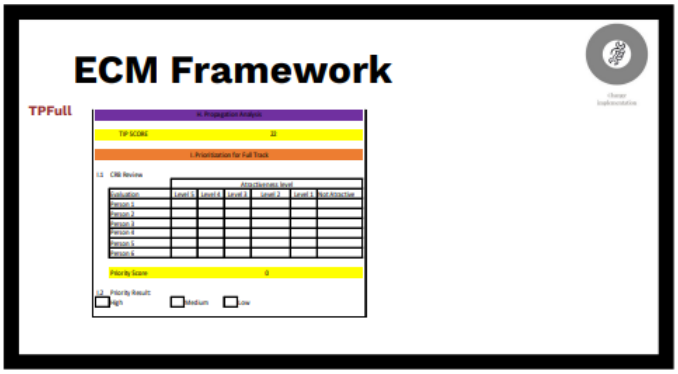
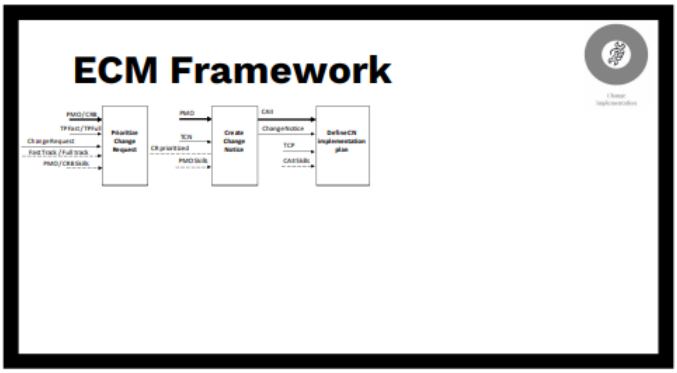
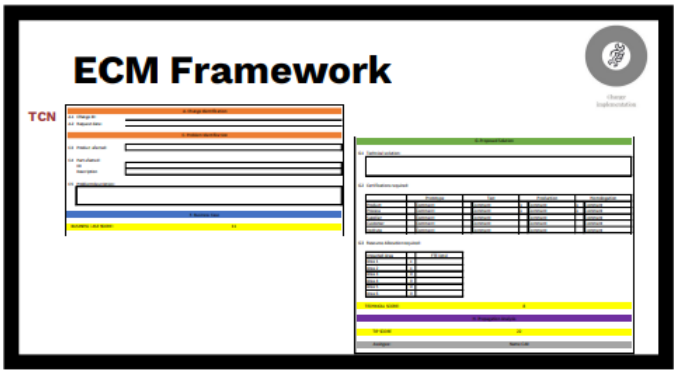
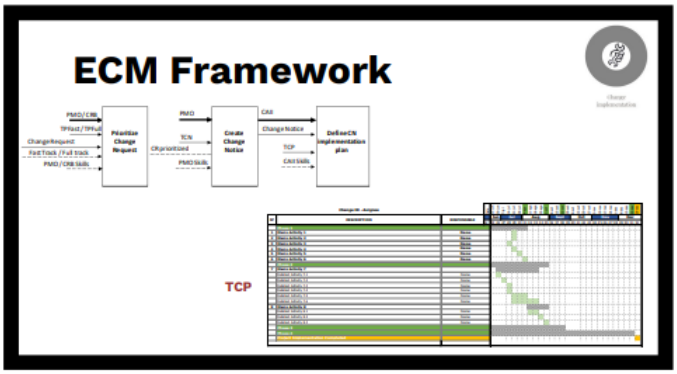
	Everything starts with the ECM Process flow that defines the steps the change has to go from an idea to implementation completed. Five steps are defined
	Engineering Change need to properly identify the request and its characteristics
	At this step, anyone in the company can create a demand to request a change and the template for problem report, TPR support the request The template ensures the change, the requester and the problem are properly identified
	The next step is Technical and Financial feasibility evaluation to ensure the change is financially attractive and technically possible to be executed. The goal is to select ideas that will bring real benefit to the company

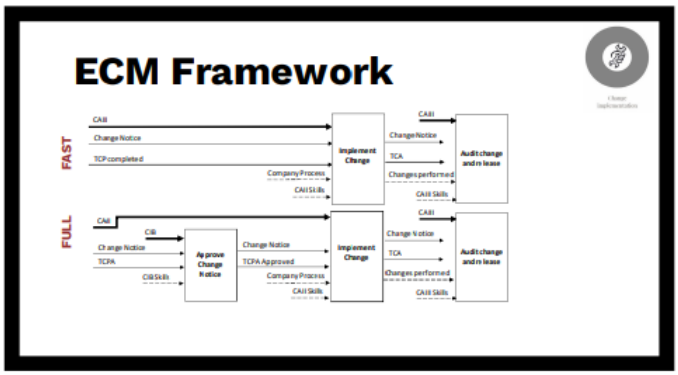
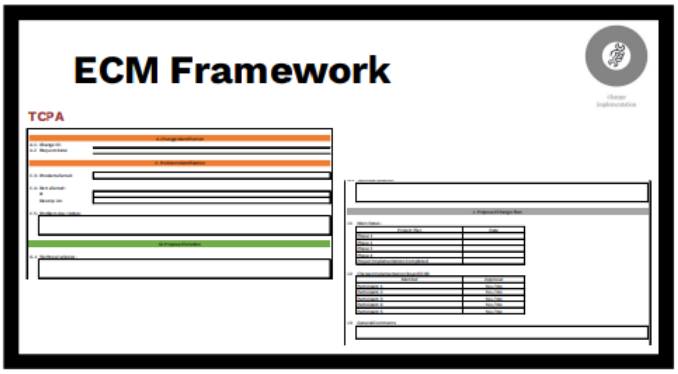
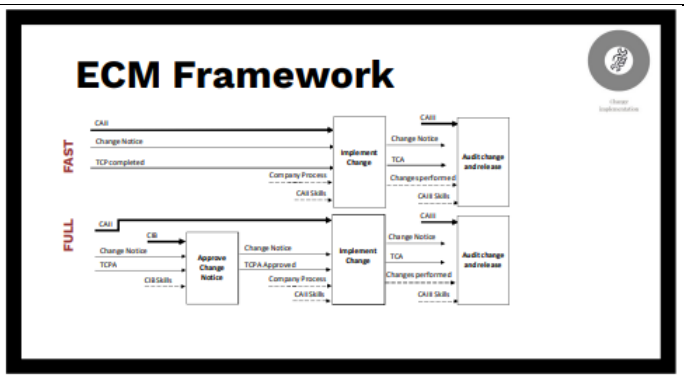
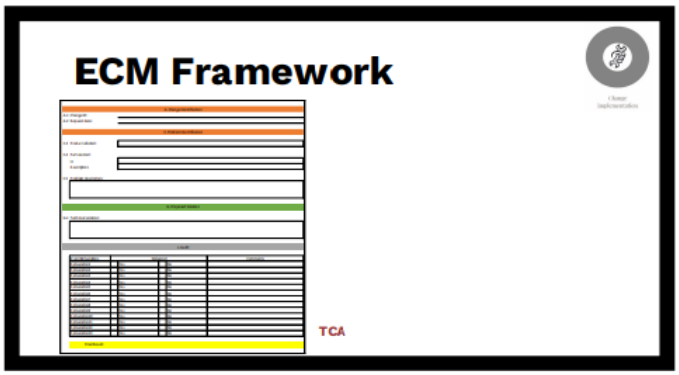
	It´s necessary to evaluate the problem report to ensure its completeness and clearance of the change need and to create a business case that identifies financial feasibility. Feasibility skills are required for the person responsible for these activities that we call Change Admin one or CAI. The template for business case, TBC, ensures problem analysis considering affected products, suppliers, customer, company sites, institutes and subsystems
	Also provides a template for cost identification and impact analysis that is summarized on a business case score
	After the business case, is time to create a change request
	The change request formally defines the proposed solution for the change using the Template for Change request, TCR, to ensure Technical solution, Certifications, Resource Allocation and Technical Challenge are identified and can generate a Technical Score

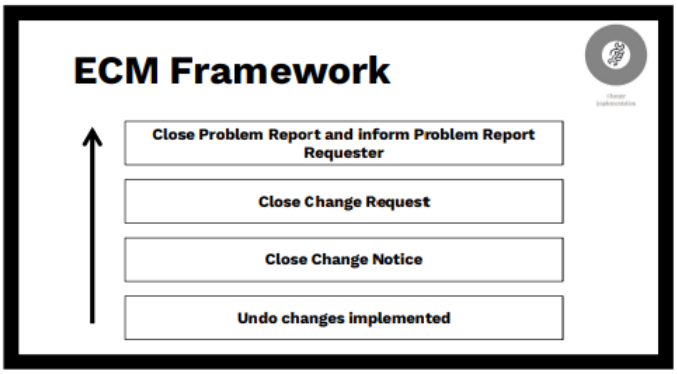
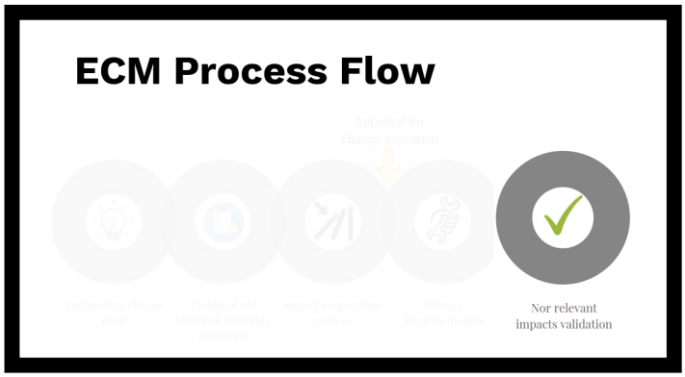
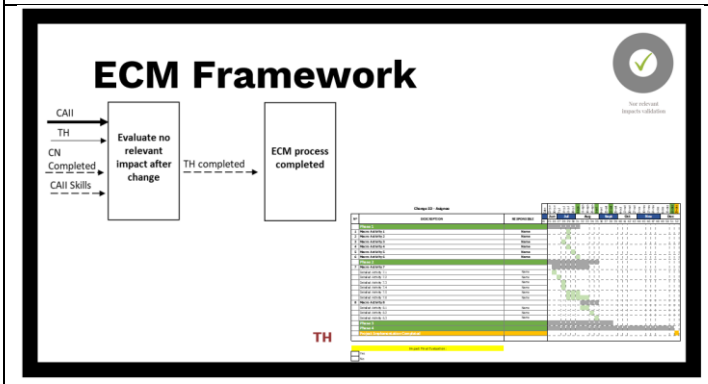
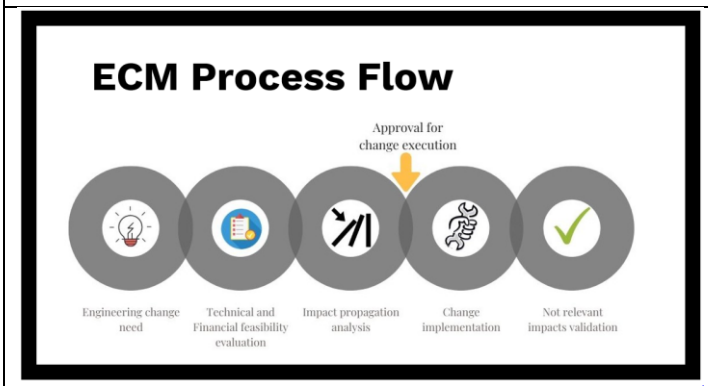
	The change request is then submitted to be evaluated by a Change Admin One with Analysis Skills to approve it. And this completes the Technical and Financial feasibility Evaluation
	The next step is Impact propagation analysis to evaluate the propagation of the change impact and map possible mitigations
	At this activity, the CAI with Analysis skills will involve company experts and promote alignment meetings to identify impact propagation for the proposed change. The template for impact propagation , TIP, will guide these alignments by consolidating the business case score and technical score while
	Iindicating main quality problems related to the product that requires impact evaluation

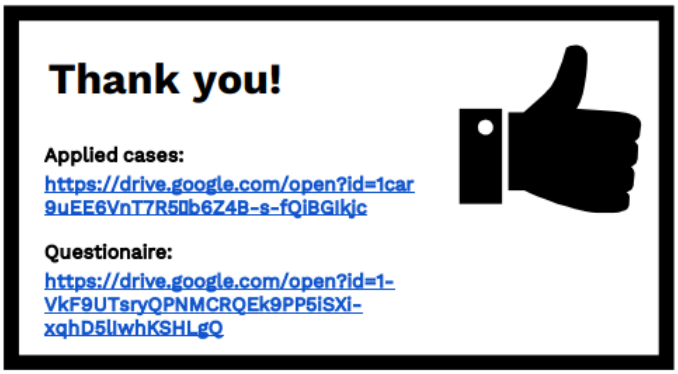
	As well as shape, functional, interface and other specific analysis that may not be forgotten to create a TIP Score related to impact propagation. The bigger the TIP, the higher impact is expected.
	With all this information, an approval for change execution is required as an important milestone to officialize executing changes
	To reduce unnecessary bureaucracy, two paths may be chosen for the change: Fast Track or Full track based on TIP Score. The Fast track for less complex changes and Full track for more complex changes. Each company can creates specific criteria to define if a change will go Fast Track or Full Track.
	And after that, it´s time to start change implementation and the goal at this step is to plan the change schedule and execute the changes required

	According decision taken during approval for change execution, the change can go Fast Track or Full Track The Fast Track is for less complex changes and has reduced number of steps. The change prioritization is made directly by the PMO while for Full track a Change review board with multidisciplinary evaluation is recommended. Besides that, the Full track has an extra activity for approving change notice on change implementation board, in order to ensure plan is adequate and covers all change aspects. Apart from that, change implementation is similar on both Fast and Full Track.
	Considering the first activities, to prioritize the change request is required PMO or CRB skill and a template to support.
	The TPFast support for fast track and consider the Business Score, Technical Score, TIP Score and FTE quantity compared to company standard for the PMO to define the attractiveness level that will generate a Priority Score. According company standard, the score is defined as High, Medium or Low priority for execution
	The TPFull support full track and is more complete. It brings from previous templates the Business Case information, The proposed solution with Technical Score

	And the TIP score from propagation analysis. With this, the Change Review Board, CRB, evaluates the change attractiveness and this generates a priority score that is compared to company standard and defined as High, Medium or Low priority for execution
	With change request prioritized using TPFast or TPFull, the PMO creates the change notice using the Template for Change Notice , TCN
	That consolidates Business Case Score, Technical Score and TIP Score to be shared with the Change Admin Two, or CAII that will be responsible for change plan and implementation. The PMO defines the CAII and the Change Notice is created.
	The next step is to define change implementation plan. At this moment, the CAII skills are very important and the TCP, Template for Change plan standardize the planning

	For Fast track, the CAII will follow the company process and implement the change according planned. For Full Track before going ahead a Change Implementation Board CIB need to approve the plan. The Template for Change Plan Approval, TCPA, formalizes this approval
	By registering the change proposed solution and main deliverables from plan, together with the list of participants on CIB and their comments regarding the change plan.
	For full track, if TCPA is approved then CAII implement the changes planned. After implementation, on both fast track and full track, a change admin three CAIII audit the changes to confirm deliverables and release the changes made as new specifications.
	The audit is supported by the TCA, template for change audit that consolidates main deliverables from change plan and comments from CAIII if they were delivered or not according expected. The final decision is Approved or Not Approved.

	In case of "Not Approved", the CAII need to undo changes implemented, close change notice, change request, problem report and inform the requester that change will not be released. In case of "Approved", then the changes are implemented
	In the end, the Not relevant impacts validation step is to ensure no unpredicted effect is perceived by the product after change implementation
	The template for homologation, TH, supports evaluation and if no impact is identified, than the ECM process is completed. In case of impact a new problem report to correct it need to be opened before the process can be considered completed.
	Finally the flow is completed, the changes are implemented according a framework and properly managed.

	Thank you for watching the video and understand a bit about my ECM Framework proposal. If you want to check cases with this framework applied, check the PDF available on the link. Please, don´t forget to answer the questions to give me your feedback about this framework. It´s very important for my master degree. Bye Bye!

Source: Author (2019)

The links from the last slide are the same mentioned before on this Appendix.

APPENDIX D – "Curriculo Lattes" results and distribution list

Considering the results for the search conducted with the "Currículo Lattes" database using the words "ECM engineering" in both English and Portuguese in September 2019, the list with 117 researchers related to engineering change management is detailed in Board 36.

The e-mail address used to contact them was obtained using Google Academics on paper published by those researchers as described in item 5.4.

Board 36 – Researchers from "Curriculo Lattes" related to ECM

Researchers	Adalberto Luiz Rosa	Flávio Eduardo Aoki Horita
	Adbeel Goes Filho	Francisco Carlos Paletta
	Adjaci Uchôa Fernandes	Gabriel Molina de Olyveira
	Adriana Regina Martin	Geraldo Lucio Marques de Oliveira
	Alexander Thorsten Nitsche	Gladston Junio Aparecido
	Alexandre de Souza	Gledson Pereira Maia
	Alvaro Boson de Castro Faria	Guilherme Luís Roehe Vaccaro
	Alvaro de Lima Veiga Filho	Guilherme Sachs
	Ana Celeste Ximenes Oliveira	Gustavo Ribeiro Cercal
	Ana Lucia Tabet Oller do Nascimento	Henrique Benedetto Neto
	Ana Maria Bolognese	Jairo Pinto de Oliveira
	Ana Maria Moura da Silva	Joacir Giaretta
	Andre Henrique de Siqueira	Joao Souza Neto
	Andre Ricardo Massensini	Jose Mauro Granjeiro
	Anna Gabriela Miranda de Oliveira	José Paulo de Souza
	Anselmo Chaves Neto	Keila Beltrame Fonseca
	Breno Salgado Barra	Lazaro Aparecido da Silva Pinto
	Breno Valentim Nogueira	Leonardo Loureiro de Carvalho
	Bruno José Verçosa	Ligia Maria Manzine Costa
	Carla Maria Figueiredo de Carvalho Miranda	Lirio Nesi Filho
	Carlos Massami Kaneko	Livia Marangon Duffles Teixeira
	Cassius Olivio Figueiredo Terra Ruchert	Luciana Maria Caetano
	Ciro Jose Almeida Macedo	Luciano César Pereira Campos Leonel
	Claudia dos Santos Flores	Luís Gonzaga Trabasso
	Daniel Cardoso Moraes de Oliveira	Luiz Henrique Catalani
	Egon Walter Wildauer	Manoel Veras de Sousa Neto
	Eleonora Carletti	Marcello Peixoto Bax
	Elizete Pereira Sá	Marcelo dos Santos Moreira
	Fabiano Baldo	Marcelo Gitirana Gomes Ferreira
	Fernanda Freitas Lins	Marcia Martins Marques
	Fernanda Maria Policarpo Tonelli	Márcio Mateus Beloti
	Fernando Hadad Zaidan	Marco Aurélio Pinhel Peixoto

Board 36 – Researchers from “Curriculo Lattes” related to ECM (cont.)

Researchers	Mari Cleide Sogayar	Rogerio Atem de Carvalho
	Maria das Graças da Silva Valenzuela	Rogério de Almeida Vieira
	Maria de Fátima Dias Costa	Roquemar de Lima Baldam
	Maria José Soares Mendes Giannini	Roseli Rodrigues de Almeida
	Maria Virgínia Alves Martins	Rumio Taga
	Marilda Martins Coelho	Sanderson Cesar Macedo Barbalho
	Marly Guimarães Fernandes Costa	Sandra Mara de Alencar Schiavi
	Mauricio Sebastiao de Barros	Sebastiao Roberto Taboga
	Maurílio José Inácio	Sergio Ranto Dalmau Arroyo
	Mercedes Matte da Silva	Sheila Maria Brochado Winnischofer
	Miriam Marcela Blanco	Silvya Stuchi Maria-Engler
	Nelson Padrón Sánchez	Sonja Ellen Lobo
	Nilton Ferreira dos Santos	Sueli Patricia Harumi Miyagi de Cara
	Paulo Sérgio de Arruda Ignácio	Symara Helena Penow Campos
	Paulo Tambasco de Oliveira	Tadeu José Costa Santos Cruz
	Pedro Armando Lima Couceiro	Valinda Maria Pantoja Maia
	Pedro Duarte Filho	Vanessa de Oliveira Collere
	Peter Jandl Junior	Veturia Lopes de Oliveira
	Renato Dourado Maia	Victor Eliseo Leiva Sanchez
	Renato Machado Costa	Victor Túlio Ribeiro de Resende
	Ricardo Renzo Brentani	Vinicius Miana Bezerra
	Rita de Cássia Marqueti Durigan	Walmir Matos Caminhas
	Robert Wayne Samohyl	Willian Fernando Zambuzzi
	Roderlei Camargo	Willians Cesar Rocha Gaspar
	Rodrigo Cardoso de Oliveira	Wilson Silva Pinto
	Roger Chammas	Yara Maria Corrêa da Silva Michelacci

Source: Author (2019)

APPENDIX E – ECM framework feedback questionnaire response list

The questionnaire for ECM framework feedback received 28 responses listed in Board 37, Board 38, Board 39 and Board 40. The ID is used to identify the response in those tables.

Board 37 – ECM framework feedback questionnaire responses for mandatory questions – Part 1 of 3

ID	How do you evaluate the ease of understanding of the framework presented?	How do you evaluate the practical applicability of the framework presented?	How strong would you recommend to a company to use this framework for Engineering Change Management?
1	Neither easy nor difficult to understand	Possibly applicable	3
2	Easy to understand	Possibly applicable	3
3	Easy to understand	Highly applicable	5
4	Very easy to understand	Highly applicable	5
5	Easy to understand	Highly applicable	4
6	Easy to understand	Highly applicable	4
7	Neither easy nor difficult to understand	Possibly applicable	3
8	Neither easy nor difficult to understand	Possibly applicable	3
9	Very easy to understand	Highly applicable	4
10	Easy to understand	Highly applicable	4
11	Easy to understand	Highly applicable	3
12	Easy to understand	Highly applicable	4
13	Easy to understand	Possibly applicable	4
14	Easy to understand	Highly applicable	4
15	Very easy to understand	Possibly applicable	4
16	Difficult to understand	Not applicable	1
17	Easy to understand	Highly applicable	4
18	Easy to understand	Highly applicable	5
19	Easy to understand	Highly applicable	4
20	Neither easy nor difficult to understand	Highly applicable	3
21	Neither easy nor difficult to understand	Possibly applicable	4
22	Easy to understand	Highly applicable	4
23	Neither easy nor difficult to understand	Possibly applicable	3
24	Very easy to understand	Highly applicable	4
25	Neither easy nor difficult to understand	Possibly applicable	4
26	Easy to understand	Possibly applicable	3
27	Easy to understand	Highly applicable	4
28	Easy to understand	Highly applicable	4

Source: Author (2019)

Board 38 – ECM framework feedback questionnaire responses for mandatory questions – Part 2 of 3

ID	How long have you worked or studied Engineering Change Management?	Do you currently work with Engineering Change Management at a company?	Do you currently research Engineering Change Management at an University?
1	From 3 to 5 years	No	No
2	From 5 to 10 years	Yes	No
3	From 5 to 10 years	Yes	No
4	From 3 to 5 years	No	Yes
5	From 3 to 5 years	No	Yes
6	From 5 to 10 years	Yes	No
7	From 5 to 10 years	Yes	No
8	I never worked or studied Engineering Change Management until now	No	No
9	From 5 to 10 years	Yes	Yes
10	From 3 to 5 years	No	No
11	More than 10 years	No	No
12	From 1 to 3 years	No	Yes
13	From 3 to 5 years	Yes	No
14	From 1 to 3 years	Yes	Yes
15	From 5 to 10 years	No	No
16	I never worked or studied Engineering Change Management until now	No	No
17	More than 10 years	No	Yes
18	From 5 to 10 years	Yes	Yes
19	From 5 to 10 years	Yes	No
20	From 1 to 3 years	Yes	Yes
21	From 1 to 3 years	No	No
22	From 3 to 5 years	No	No
23	From 3 to 5 years	No	Yes
24	More than 10 years	Yes	No
25	From 3 to 5 years	No	Yes
26	From 3 to 5 years	No	Yes
27	From 3 to 5 years	No	No
28	More than 10 years	Yes	No

Source: Author (2019)

Board 39 – ECM framework feedback questionnaire responses for mandatory questions – Part 3 of 3

ID	Do you have any improvement suggestion for the framework presented? Please detail below
1	No.
2	Too many templates, it would be good to have a consolidated view similar to Canvas methodology
3	Compare to ITIL
4	Good approach
5	No
6	Implement Agile Approch for engineering change (treat as agile project management) with teams to fast approval scenario
7	Usar software para facilitar a gestão dos templates
8	It seems to me that you have just developed a customization of the good and old ptoject management discipline. I can do everything you detailed in your video with PMBoK 6 guidance. I don't need another framework for that.
9	no
10	Include Learned Lessons session
11	no
12	No
13	NA
14	Develop specific templates for company segment
15	Keep testing and refining
16	Proposal is too complex to understand
17	Good
18	Proposal is clear
19	n/a
20	.
21	Too much information to understand
22	no
23	.
24	Hi Paola. First of all congrats for your master and thanks for sharing this useful framework with us. 2 small sugestions from my side: 1. Try to combine many templates in 1 template that flows throught the stages. 2. The decision making in the end should include also a Rework process not only approve or reject. Sometimes small improviment can change the status from rejected to approved. Thats all. Well done.
25	No
26	.
27	Incluir uma etapa final após o template de homologação para fazer auditoria da homologação antes de concluir o processo de ECM
28	Consider adopt UAT - User Acceptance Testing

Source: Author (2019)

Board 40 – ECM framework feedback questionnaire responses for optional questions

ID	Name:	Age:	Profession:	Current Company or University:	Current position at company or University:	Company or University location:
1	Christiane Bublitz	30	R&D Engineer	Embraco	Thermal Science Specialist	Slovakia
2	Sergio Perin	31	Product Engineer	Embraco	Coorporate Product Specialist	Brazil
3	Raphael Bedran	35	ITIL Manager	Ab-Inbev	Service Continuity Manager	Campinas, SP
4	Claudia Santos					
5				Pitagoras		
6	Gustavo Cercal	27	Chemical Engineer	Robert Bosch	Project Manager	Curitiba - Brazil
7	Luis	42	Engenheiro	Embraco	Engenheiro	Joinville
8	Joao Souza Neto	61	Professor	Universidade Católica de Brasília	Professor	Brasílialia
9	Pedro					
10	Adriano Santos	32	Product Manager	Philip Morris International	Program Manager	Switzerland
11						
12	Alexandre					
13	Willians Cesar Rocha Gaspar	46	Engenheiro	Companhia Caminho Aéreo Pão de Açúcar	Companhia Caminho Aéreo Pão de Açúcar	Companhia Caminho Aéreo Pão de Açúcar
14	Anna Oliveira			Unihorizontes		
15	Dave Christy	41	Senior IT Leader	Guru BTG	CTO	Philadelphia, PA US
16	Anna Soares	21	Production Engineer	Unilever	Intern	São Paulo
17	Rogerio			Cefet		
18	Guilherme	43		Unisinos		
19	João Carlos Canellas	32	Product Engineer	Embraco	Product Engineer	Joinville-SC, Brazil
20						
21	Marco Aurélio	26				
22						
23			Researcher	Unifor		
24	Edson	45	Engineer	Vinfast	Leader Process Engineer	Vietnam
25						

26	Maria Martins		Master Degree Student			
27	Marcele Pauli		Engenheira de Vendas	Embraco	Engenheira de Vendas	Eslováquia
28	Stella Andrade	42	Change Manager	ABI	Change Approval Board Manager	Leuven, Belgium

Source: Author (2019)

Some answers are in Portuguese due to the original response and were not translated to maintain accuracy of data. In analysis from item 5.4, they were translated for comparison purpose.