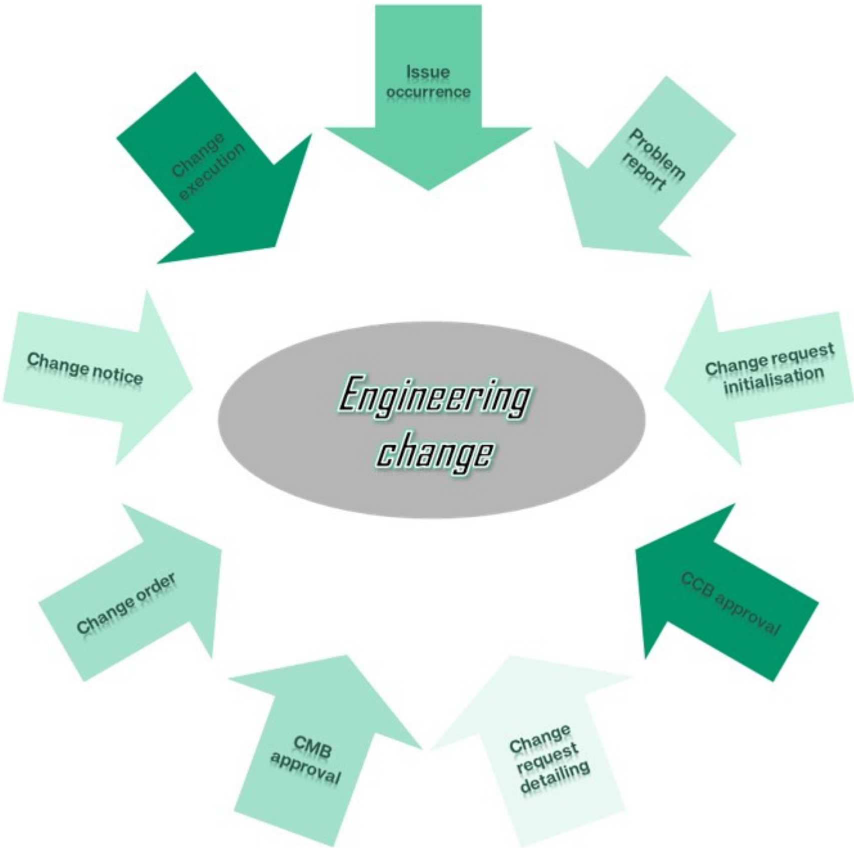

Engineering Change management

A study on how to develop an Engineering Change Management framework at Northvolt AB

Master's thesis in Product development

Raahul Kumar Siva Kumar

DEPARTMENT OF INDUSTRIAL AND MATERIAL SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2022
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RAAHUL KUMAR SIVA KUMAR

Department of Industrial and Material Science
Division of Product development
Chalmers University of Technology
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A study on how to develop an Engineering Change Management framework for the design team
Raahul Kumar Siva Kumar

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Cover: Overview of the process flow developed

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Abstract

Northvolt, an explorer in battery manufacturing, has been developing various types of battery cells for different applications. For this, there is a wide range of activities involved in producing batteries successfully. This includes R&D, sourcing the raw materials, getting components from the suppliers, testing the material- part and assembly level, producing battery cells, battery module making, and finally, delivering the product. In parallel to these developmental activities, changes emerge, and these can be on a whole termed error correction, performance enhancements, and business-related factors. The changes can vary from a clerical change in a drawing to a supplier change that affects the entire process line. And these changes are largely iterative (plan, test and review) in nature and span for weeks. In a fast-growing organization like Northvolt, a proper system to streamline the workflow in managing these changes is essential. The main objective of this thesis is to study the current system in the company, specifically in the cell design division, and form a working framework that focuses on impact analysis. The process flow evolves with the aid of literature and feedback from the stakeholders- The aim is to use the Engineering change management layout on the abstract level and build a customized set-up concurrent to the organization's requirements.

Keywords: Battery manufacturer, Cell design, Change impact analysis, Design Change, Engineering Change Management.

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I would like to recognize the efforts of my friends and well-wishers for their moral support. I would not have pulled it out without their motivation and assistance.

Next, I would like to thank my family for their support, without them I would not have been here. Finally, thank you dad!

Raahul Kumar Siva Kumar, Gothenburg, September 2022

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

ALLEA	ALL European Academics
BOM	Bill Of Materials
BOP	Bill Of Process
BS	Battery Systems
CAD	Computer-Aided Design
CCB	Change Control Board
CM	Configuration Management
CMB	Change Management Board
CO	Change Order
CN	Change Notice
CR	Change Request
EC	Engineering Change
ECM	Engineering Change Management
ECN	Engineering Change Notice
ECO	Engineering Change Order
ECR	Engineering Change Request
ERP	Enterprise Resource Planning
FBS	Function Based System
IATF	International Automotive Task Force
IT	Information Technology
IP	Intellectual Property
OEM	Original Equipment Manufacturer
MDM	Multiple Domain Matrix
NDA	Non Disclosure Agreement
NMC	Nickel Manganese Carbon
NPD	New Product Development
NV	Northvolt
PDM	Product Data Management
PLM	Product Life-cycle Management
PR	Problem Report
QC	Quality Control
QCD	Quality Cost and Delivery
RQ	Research Question
SCM	Supply Chain Management
UK	United Kingdom
UN	United Nations
UNFCC	United Nations Framework Convention on Climate Change

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1 Introduction

This chapter presents the company profile, the problem, its scope and the limitations of the work in detail as sub-sections.

1.1 Background

In 1992, the UN realized that climate change was a case that the world must handle quickly. Based on this, the UNFCC was formed during the renowned Earth Summit held in Rio de Janeiro. Many summits had convened and had taken momentous decisions in promoting sustainability. The measures largely involved finding alternatives for fossil fuels, dependency on public transport to reduce emissions, etc. Going for a sustainable transport system was seen as one of the solutions to bring down the increasing trajectory of emissions. In 2009, at the Copenhagen Summit, it was agreed that the global temperature rise must not run over 2°C. To control the temperature rise, the evolution of an electromobility system was seen as essential. In the Paris agreement, held in 2015, a quantum leap was achieved -nearly every country in the world agreed to join the task of lowering greenhouse gas emissions. As a part of the European Green deal, 'Fit for 55' was set. The main objective of this arrangement was to set a target of achieving climate neutrality by 2050 [1]. This implies a reduction in greenhouse gas emissions in the next decade. As an intermediate step, a target for 2030 was set to reduce emissions by 55% compared to that of 1990. This package included reducing the emissions from the transport sector [2]. The other aspects of the package are energy efficiency, alternate fuel infrastructure, energy taxation, renewable energy, and CO_2 emission standards for cars and vans. When closely observed, of all the factors transportation accounts for a quarter of total emissions [3]. According to the International Energy Agency, global rail transport had to be electrified and at least 20% of all road transport vehicles globally must be electrical. If these electrifications were operational, the emission and temperature control targets can be achieved by 2030 [2]. And unlike other sectors, emissions tend to be raising in transportation. To contain this raise in transportation, the package proposed building an infrastructure for refuelling or recharging vehicles with alternate fuels. And the major stakeholders for this proposal were member states, OEMs, vehicle manufacturers, and vehicle buyers [4]. To execute this, major automakers turned their compass toward E-vehicles. This resulted in new fuel cell producers and opened new prospects. Optimistic reception towards sustainability from the nations and the investments received motivated automakers on battery fuel production. The industry had lured more than $400 billion over the last decade. Of that roughly $100 billion during 2020-2021(Sept)[5].

1.2 Company

Amongst all the producers of battery cells, Northvolt is the frontrunner in the battery industry across Europe. Founded in 2016, the company has been working towards the production of batteries with the mission of 'Green batteries for a blue planet' [6]. The organization's goal of achieving 150GWh annual cell output by 2030 requires astute planning and an intelligent working strategy. Along with the automotive sector, the company strives in giving resolutions for Grid, Construction, portable equipment, Industries, and E-mobility. The firm with its home base in Stockholm has its manufacturing sites commissioned in Sweden, Poland, and one planned in Germany. Northvolt Ett, built-in Skellefteå - Sweden, is Europe's first homegrown Gigafactory. The factory when in full operation will accomplish a power output 32 GWh per year [7]. The company's product is broadly classified into three types: Battery cells, Battery systems, and Revolt as shown in figure 1.1 below [8].

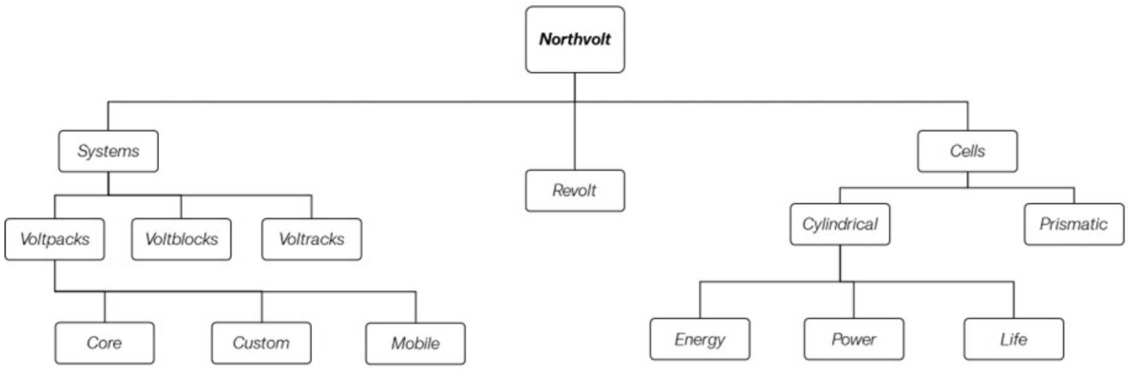


Figure 1.1: Classification of the organization based on the product

Battery cells: Battery cells are high-performance Lithium-ion battery cells. These were based on proprietary Lingonberry NMC chemistry in two commonly used formats- Cylindrical and Prismatic. Cylindrical cells come out in three forms viz Energy, Life, and Power, getting their application in areas of power tools and snowmobiles. Prismatic was customized and built based on the customer requirements [8]. Images of these products are shown in figure 1.2.

Figure 1.2: Battery cells products [8]

Battery systems: Battery systems include modular components where cells are arranged for battery-powered operations. These are further classified into voltpacks, voltblocks and voltracks.

- **Voltpacks**-Energy storage for land, air, or sea.
- **Voltblocks**- For demanding industrial applications.
- **Voltracks**- Next-generation battery modules.

These are shown in figure 1.3.

Figure 1.3: Battery system products [8]

Revolt: Revolt deals with the recycling of old battery cells into raw materials for new ones. The projection is that 50% of the raw materials needed for production will be fulfilled by recycling by 2030 [9].

1.3 Aim

There are a lot of product changes and updates happening in the company with the variety of the products, and the iterations done. These changes should be properly streamlined and processed for better traceability and execution. The objective of this work was to study the current Engineering Change process followed by the team and list down the sources. Efforts to study the gaps between the ones mentioned in texts and the system followed at Northvolt were made with the performed analysis and literature aid. Along with that, a foundation for a new framework was laid. This was done by including the stakeholders and decision-making group as the focus group. A high-level abstraction of the process was done with decision-making statements and deliverables at each level. These standardized deliverables were in the form of reports or templates. Reports were from the tests performed; analysis conducted. Templates were questions on estimating the impact of the change that stakeholders answer. The questions probed in the templates made sure that all preliminary information needed for planning and executing the change were addressed. Following this the flow work was tested with practical cases, observed, and updated. Finally, the focus was given towards improvement areas that would develop the basic version into a sophisticated system.

1.4 Scope

The work was conducted in correlation with the battery industry. Usually, the development of the process and its customization were based on the product the company deals. Initially, it was decided that this framework starts by reporting a problem. The trigger for the issue and its history were not taken into consideration. The primary focus was to form a process flow that guides the design review and execution of the change. The gap evaluation and study of known tools were meant to highlight the possible ventures for future scope. The major stakeholders considered include the change team, the Cell design, the Simulation team, the Mechanical design, Testing & Validation team, the Manufacturing team, Quality, Customer Management, Purchasing, and Logistics. Interaction with the stakeholders, along with field observation and literature study, helped in framing the requirements for the new process flow. These requirements acted as a compass while framing the outline of the process flow.

1.5 Limitations

This work focused on the process flow, needs set up, and steps for implementation. Implementing and launching the process using a tool is not in scope. Only recommendation of how the tool can be picked and how it can be implemented is done. The entire study is performed for the design team that works on a particular type of cells. This may not be suitable across the entire organization for now. Prioritizing the CR was not taken into scope. The reason for this was it involved discussions at the management level, and it will vary with team requirements and time availability.

So, the focus was on the execution of the change and not picking them. But this can be included in the future study- on how organizations can prioritize the change with capacity and demand in mind. The customer aspect was not focused by the system, as this team does not deal directly with any external customers now. A few exceptions like urgent requests that bypass the process were not dealt with, but only mentioned. Configuration of the changes, numbering them was not taken into the scope.

1.6 Specification of the issue under investigation

From the grounds of aim, a new process flow is expected to improve the existing method. The idea was to use the Engineering Change Management layout on the abstract level and build a customized set-up concurrent to the organization's requirements. To fulfil this a customized process flow was explored during the thesis. The major areas under investigation whilst creating this process flow were: Can an existing workflow from theory be customized as per the organization setup? What could be the challenges and possible trade-offs? How open the process flow was to the forthcoming updates on it. After the completion of the work, these questions are examined and recalled.

1.7 Gantt Schedule

The duration of the thesis was 20 weeks, as per the timeline mentioned by the university. The details of the plan are shown as a Gantt chart attached in Appendix A. Days marked in red were national holidays. The thesis milestones, as tasks are mentioned as rows in the schedule.

2

Theory

This chapter ponders on theory and supporting literature relevant to the scope. It includes the definition of ECM, steps followed in different industries, standards in ECM, the importance of ECM and change propagation in detail. The content is segregated into broader sub-topics for better readability.

2.1 ECM and steps in ECM

In this section, an overview of ECM and the steps involved are described. The automotive manufacturing industry including trucks, commercial, and passenger vehicles, was predicted to cross $1.7 trillion by 2015 of which about 61.5% was cars [10]. Amongst these car makers, about 40% of the challenges reason out to frequent engineering changes resulting in the allocation of resources and time. A change usually lies at the core of a design process. Of all these changes, about 56% occurred after the initial design phase and nearly 39% of these were termed inevitable [11]. So how the design process spreads itself out was the subsequent thing to be looked at. The process of designing could be classified into two broad types: creative design and innovative design. Creative design deals with designing from scratch [12] and hence takes more time and effort. On the other hand, innovative design was more of a modification type. More changes occur in the innovative design type, as they deal with modifying or uplifting an existing design. Having said that, from the literature it was seen that both these types of changes were involved in the creation of EC, as an NPD process is a continuous improvement process.
Next, *what is an Engineering change then?* At a basic level, Engineering Change is defined as the process of implementing a change to a component or a process [13]. As per Siemens, one of the leaders in PLM, a simple change process was as in figure 2.1

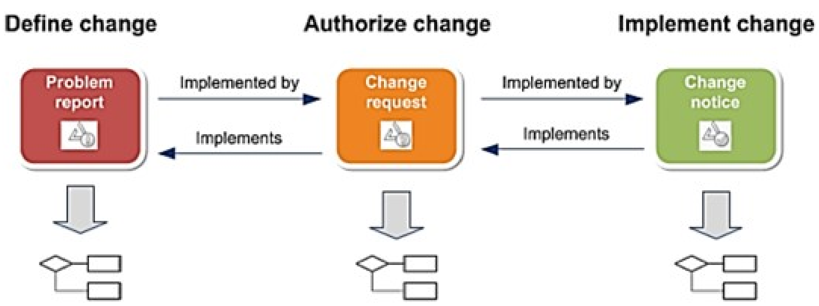


Figure 2.1: Overview of Change process[14]

In generic terms, a change process has a problem report, a change request and a change notice phase. These steps get detailed in different forms and sub-processes, but this overall process outline was true in most ECM. Next, *what causes these changes?* The requirement for a change arises from factors such as an error in the product, performance improvement of the product, business reasons, etc. And a change could be triggered at any step in a product lifecycle [15] as shown in figure 2.2. More details on these triggers are dealt with in the following sections.

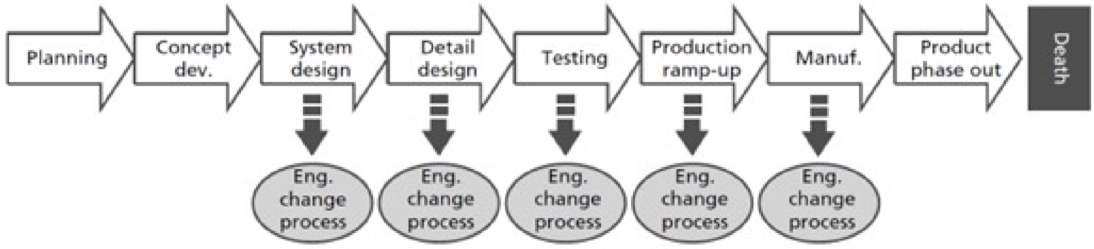


Figure 2.2: Product lifecycle and engineering change process [16]

So, when there was a need for a design change, *how the process was executed?* Different techniques to process the ECs were available throughout the literature. As per some of these studies, EC was a two steps procedure: the first step was where the decisions were taken, and the second involved rapid implementation [17]. Another method described was dividing the process into four stages- identifying, evaluating, implementing, and auditing ECs [18]. And from the PLM architect's view, change management was no different. Some study works signify the need for a stage-gate approach and filter mechanism to remove the impractical ones in the initial phase of the process. Backed by the data from a German manufacturing firm, only 40-60% of the changes were technically necessary [15]. Succeeding, when looking at changes and production, it was no different. Engineering change in production was intricate to handle [19]. These production changes were handled by adaptable systems that minimize complexity. Two important aspects considered for changes in production were effectivity and variants (versions). Along with that, technical analysis of ECR was important as it assists in gaining a comprehensive view of the ECR [20]. This technical analysis aimed at checking the impact of the change on activities like prototype creation, certification, logistics, and quality assurance.
Ideally, four principles for an ideal ECM as per [21] are:

- Avoid unnecessary changes.
- Decision making should avoid the negative impacts of the EC.
- Decision-makers should detect EC early.
- Decision-makers should speed up the EC.

It is often seen that these steps at an abstract level could yield better results. But equipping details in these steps according to the organization is vital.

2.2 Change triggers

The primary principle for a functioning ECM was to avoid unnecessary changes. And to avoid unnecessary changes, the reasons for the changes had to be investigated. As mentioned in the previous section, the triggers for the changes were under these broad paths- to correct mistakes and to enhance the product. This goes in line with the theory too [22]. According to the literature two main drivers for changes were -product improvement changes and error corrections which reiterates the above-mentioned views [23]. To understand the practicalities of these theories, some experimental analyses were looked at to grasp these change triggers. An expert team had studied the car manufacturers for change triggers. As per the study, experts believed that only 5% of the ECs are related to engineering design. The rest were all triggered by customers. And among all the ECs generated in a company, suppliers, process optimization and document synchronization were the major [21]. So, though seen in various forms, the triggers for changes were an important aspect to consider. So, to control these triggers and hence the change, a design freeze was an important factor. This is because a design freeze reduced the scope for engineering change [24].

2.3 Standards for ECM

When scouting for standards, there wasn't anything specific for ECM. Using the key principles and the conceptual level of the process, a reference process was framed [25] [20]. This was drafted by Strategic Automotive product data Standards Industry Group- SASIG. The approach gives an overview of the different stages and scenarios in the process flow. One important aspect was the urgency-based decision-making that was illustrated. With normal and fast-track options, time-constrained scenarios could be handled effortlessly. Another aspect is rollback and revision. In rollback, the activities are performed in repetition and revision, the releases are dealt with.

2.4 Importance of ECM

Change is inescapable in design, manufacturing, packaging, and quality assurance. In recent years the focus on ECM had gained popularity due to concepts like concurrent engineering, platform design, and configuration management [22]. Most authors refer to the 'rule of tens' or similar studies to stress the significance of EC in stages of manufacturing and post-manufacturing [12]. Ideally, a good ECM system avoids or reduces the number of ECs even before they occur. They also aid in selecting, and executing the process efficiently, and learning from the implementation. So, the efficiency of managing change determines how the firm gets the cost under control. And how the changes were planned and prioritized depends on the impact they exert on the product and the product architecture. Prioritizing this way had led to a reduction in lead time in making decisions [26]. The worst-case scenario of bad change management was a production halt or recalling of delivered products. From publications, it was seen that about 50% of change requests made during the development, manufacture, and testing phase were unplanned [27]. This shows that EC processes with a flexible workflow were more practical. Being flexible ensures that all the participants receive the document that they need to manage the change. Adding to that, the inclusion of an external supplier in data sharing was also crucial as it enables the flow of information and improves decision-making irrespective of the location [17]. And when automotive OEMs were investigated, the role of suppliers had grown which restates the need for sound ECM [21]. Web-based ECM frameworks had been developed in the supplier-dominant era [28]. Using these approaches, suppliers from different time zones and geographical locations were incorporated under one roof. Adding to that, these web-based methods possess the following advantages-less paperwork, faster throughput time and effective data sharing. The effect of these web-based ECM was addressed through CAD, PDM and ERP. In one of the research projects, an examination to understand why changes were done to the specification of the product was done [23]. This is a vital element to look at, as EC consume about 70% of the production capacity and about 20-50% of the tool cost.

Even after acknowledging all the benefits, usually, ECM receives very little attention in industries when compared with its significance. Late ECs are costly resulting in consuming $\frac{1}{3}$to $\frac{1}{2}$ of total engineering capacity and about 20-40% of total cost [17]. Factors for a longer lead time were a complicated approval process, scarce capacity, organization issues, and snowballing changes. Consumption of resources for the changes also involves funds increasing development costs [29]. This was logical, as in the early stages there were fewer stakeholders involved and less cost of change and labour cost. ECs were inevitable in an active environment where product quality, time, and cost are the major factors for the manufacturer [30]. For instance, when the priority was on efficiency, the EC process must be as minimal as possible whereas it should be extensive if effectiveness was the purpose. And a major problem with EC was ensuring the documentation [31]. And finally, ECM was ought to be a vital part of the production process that gets inadequate attention. This is because ECM was one of the hidden costs that levy the OEMs enormously [10].

2.5 Implementations of ECM

For change implementation, there were two types- individual implementation and batch implementation. It's seen that batch implementation was far excellent. In ECM, ECO was an important record which reflects the implementation of the change request. An ECO is defined as a document that deals with changes in parts, design, software, or drawings to a product that was released already. ECO was the result of the implementation of the agreed action course of the change turning the product error-free and more mature [29]. The action could be correcting mistakes, integration of components, or fine-tuning. And as per the literature, principles were laid and followed religiously while execution. These include- avoiding unnecessary changes, reducing the negative impacts, and detecting the changes earlier.

In some publications, scientific research had been carried out to analyze the ECR process and its implementation [32]. Some important areas where decision-making was vital were the change prediction and the risk analysis [22]. Some aiding techniques were suggested in the literature for effective decision-making. Design Structure Matrices were created that offer aid to both qualitative and quantitative analysis of the process. Markov chain models were created for modelling and analysis of the process. And from these models' improvement points and conclusions were inferred. Focus on model-based techniques was evident. These are techniques that combine engineering methods into a computer language. The change models thus created suggest linking change orders, then orders to change requests, impact analysis results and production plans [19]. A suggestion for creating a maturity grid was also seen in literature [33]. Usage of these maturity models had been turning the ECM process more efficient. A major liability of using these methods, and models were the professional expertise required to plan, perform, analyse, and interpret the results as per literature [32]. One such important decision-making aspect was change propagation, which is dealt with in detail in the following section.

2.6 Change propagation

Change propagation in simple terms represents changes affecting other parts in the chain [15]. And this propagation goes along the chain up to a certain level until the change impact becomes negligible. In some cases, the change orders determine the change propagation. From the literature, three different types of change propagation were identified, which were:

- Between components and manufacturing
- Between components within the same sub-system
- Between components in different sub-systems.

These were the three key coupling areas that were supposed to lead to propagation. Adding to this many scientific methods had been mentioned to find the extent of propagation. FBS was one, that helps in finding the level of propagation [27]. The focus of these models varied from being suitable for adaptive design to a variant design or implementation at the initial stages to the later stages. The importance of assessing the change propagation and how the product attributes get affected by EC was shown in literature [34]. In this method, a framework for modelling the change had been proposed using an MDM. A simple MDM matrix is shown in figure 2.3.

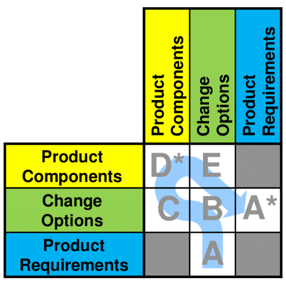


Figure 2.3: Change propagation[16]

Here the propagation takes place in sub-steps from A to E with a scope for a feedback loop between E and A. Though built-in order, it need not be the same. For instance, a change can proceed from D. Field A deals with the change options, B with the interaction of the change options with one another. Field C involved the relevance of these changes with the product component. Field D worked on mapping the change-instigating component of change propagation. In E the product component and the change options are mapped for a decision. A sample case of the matrix is shown in figure 2.4 [34].

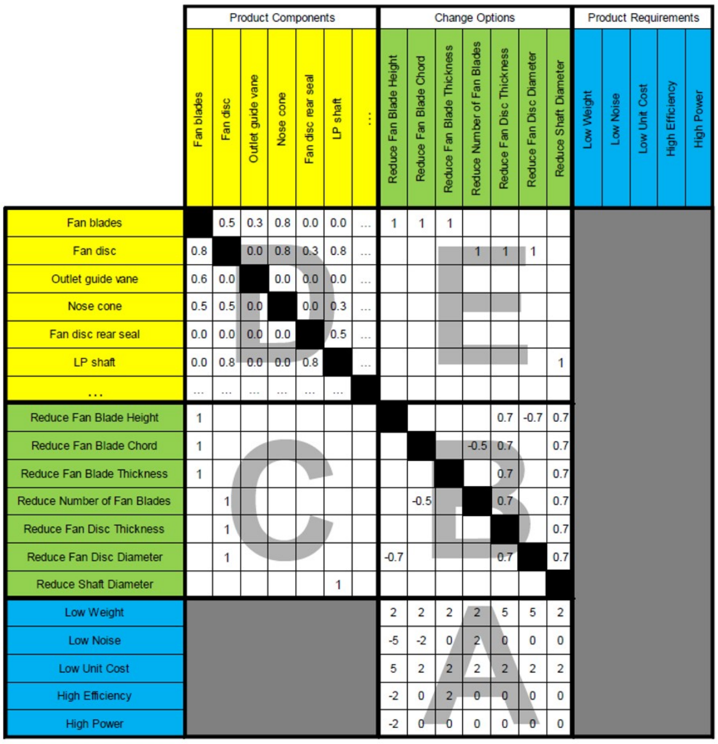


Figure 2.4: Change propagation case study[16]

A multi-layer network model was another method that was mentioned in the literature for predicting change propagation [35]. The model proposed a multi-level organization where the influence of three layers viz-product, change and social were considered. These support in preventing and predicting change propagation. These models were characterised by case studies involving CR. For analysing and predicting the changes, data-driven models were suggested by researchers [36]. This data-driven approach helps in redesigning and planning the propagation mechanism. An interesting read in finding the dependency of parts was using pictorial replica as mentioned in literature [37]. This was by using a pre-defined database that aids in finding the part dependency by linking the attributes. Minimizing human intervention was thus achieved, decreasing the possibility of manual errors. While deciding on propagation, different users use different approaches in picking the chain and the affected products. In safety-critical products, for instance, changes were avoided owing to the criticality and the extensive validation required [11]. The work also suggested a three-stage method: Product linkage model, combined dependency model, and risk prediction for change propagation management.

2.7 ECM In Industries

The ECM systems practised varied in companies from being formal to ad-havoc [17]. From the literature on assessing the change process in many industries, it was inferred that every company had its method of handling the changes and baseline of the components in PLM [26]. In industries that share data with external parties or suppliers, the change process and its execution were different. It was right to conclude that based on industry and the product, the extent of data shared varies. For instance, in aerospace and defence-related products, the final specs and documents were closely scrutinized by the customer. In a few cases, updates on the documents and products were automatically retrieved by the supplier or other stakeholders. This ensures that complete transparency was maintained [26]. In general, the research among the IT industries concluded that three major factors must be considered during the successful integration of two systems: tool & technology, process, and the culture of the people [38]. This in turn led to a new approach to design called Service-Oriented Approach (SOA). This approach helps in merging heterogeneous systems like PDM and SCM in PLM. Works performed surveys in four manufacturing companies in Hong Kong in 1999 and the survey results were engaging [30]. It concluded that in managing ECs many disciplines were involved and it required a broader view to examine these ECs. When looking into the current practices in the UK-based industry, it was seen that the ECs were approached in two ways- formal and ad hoc. But it was agreed that deriving a generic pattern for implementing EC was difficult as these activities were specific to the company that performed the activities [18]. Another key factor was the organization's reaction to these changes [22]. Organizational attitude includes company structure and culture, and attitude towards the engineering change. Applying the lean principles was also seen as an option for developing a model for ECM [21]. In this study work, a model was created, tested, and assessed amongst the automotive suppliers. The assessment was based on the criteria such as process flow, exploration of the design with a set-based approach, customer-defined values, knowledge management, and continuous improvement of culture. ECM-based models had gained attraction in recent days. Models that integrate CMII and ECM were tried in motorcycle manufacturers in Taiwan [39]. For example, PLM and ERP integration had reaped the following benefits: consistent use of product/plant-related information, reducing the time and lowering the cost to bring new and better products to market and ensuring the use of common product-related terminology. The CMII-based framework developed had five phases: Identifying the issue, conducting the analysis, planning the change, releasing the change, and changing the product configuration. These were essential aspects that on a higher level apply to any change process.

With this overview of the theory for ECM, the methodology was framed which is detailed in the following chapter.

3
Methodology

This chapter gives an overview of the methodology that has been used throughout this work. That includes data collection methods, ethics, interviews, and the research questions framed.

3.1 Data collection

This work wholly aligns with the qualitative methodology. A qualitative approach is associated with a holistic perspective view and this approach tends to be associated with data analysis during data collection [40]. In the qualitative research approach, usually, the problem definition is an action research strategy type. The goal of such research was to study and lay out the guidelines for best practices. The data collection method used were one-to-one longer interviews, systematic observation, and participant observation. This was framed as per the guidelines of a qualitative approach [40]. The steps followed for the qualitative analysis were:

1. Data preparation
2. Initial exploration of data
3. Analysis of the data
4. Presentation of the data
5. Validation of the data

The preliminary source of data collection was the interview with the focus group and participant observation. The observation was through attending change meetings that happened on weekly basis and getting involved in the change documentation activities. Adding to this, current working documents were a source of data collection. Using this information and observations, a flow chart was created that illustrates the functioning of the team. This constituted the initial exploration of the data. The flow chart helped in visualizing the process in a better way. This was then presented with the focus group as a part of the presentation of the collected data for confirmation and feedback. One-on-one discussions were held with the stakeholders to get their opinion on the current work and what they would desire in the new process. These expectations from the stakeholders helped in drafting the requirements list. Then a new framework was formed, using the collected data and its analysis. The creation of the process flow was a two-level approach. First, a higher-level abstraction in line with books was created. Then details were added to it as per the team working style. The formed framework is tested and validated with stakeholders and a real-life case. This gave an insight into how reasonable the data collected, and the performed analysis was.

3.2 Ethics

Ethical rules set were set up front and followed religiously throughout the work. The topic under research and the type of information needed from them was clearly explained to the participants. Volunteers' consent was asked for before the interview. For digital meetings, their consent was asked before recording. Nowhere in the public, their names were revealed nor the exact content of the interview. Only a summarized transcript was attached to this report. All the collected data were not taken out from the company server as per the signed NDA. The collected data was handled discreetly, allowing only people with credentials to use them. All stored information was carefully stored under the company's supervision and was not used for any personal benefit. Also, the entire research approach dealt with scientific integrity, abiding by the laws of the land. The information referred to in the work was cited in the bibliography section. All of these guided this work to produce quality work bound by professional ethics and morals. To an extent, the specifics were avoided throughout the report, without falling from the overall essence of the subject. This means, that at a higher level the process and flow are accurate, but the precise details are nowhere cited. This was to convey the overall concepts without disclosing the business details of the organization. During the internet search, ethics were maintained taking into mind IP, and copyright issues. Throughout the process, the moral code was in line with the professional integrity mentioned by the ALLEA in *The European Code of Conduct for Research Integrity* [41]. The main motive of this organization was to guide researchers with the objectives below:

- Reliability in safeguarding the quality of the research.
- Honesty in informing others.
- Respect for colleagues.
- Accountability for the research.

And to the maximum extent, these moral guidelines and ethics codes were followed with professional integrity.

3.3 Research question

Based on the aim and scope of the thesis work, the research questions were framed. The motive of the research questions was to assess the outcome and the findings. The idea was to form the process flow that works for the organization. Literature works repeatedly mention that frameworks can be customized as per the working configuration of the organization [26]. So, the formed framework should fulfil the requirements laid down. The requirements were from the stakeholders and the literature study performed. Based on the requirements and working structure a framework was formed, compared with the requirements, and then concluded in results. For this, the following research questions were framed.

RQ 1: **What are the obstacles the company has while they execute a new process flow?**
With the advantages and the need for a process flow already mentioned in the previous sections, the first research question concentrates on the barriers that exist to the implementation of the process. For answering this question, a study of the organization structure, the current process and the methods used were analyzed. This RQ helps in answering whether the formed framework fit the existing change management needs of the organization and how to manage them. This was the motivation for this question.

RQ 2: **How can the formed process flow address the issue that exists?**
This research question focuses on the outcome and its impact on the organization. To analyze that, sub-questions were framed which were: Were the stakeholder's requirements met by the outcome of this work? Is the framework adaptable enough to accommodate a new requirement hereafter? Can the framework be used for other teams in the organization with minimal modifications? The motive of this research question is to find out the answers to these questions.

The stakeholders were the immediate users, hence a requirements specification was developed based on discussions with them. The objective of the framed process flow was to satisfy the requirements set forth. As the company is in a growing phase, with new developments popping up, the process should be loose enough for updates and mutations. This work should act as a base for further developments if needed. This work focuses on the design team of a certain product. So, the customization depends on the configuration of the team. Consequently, an objective was set to see whether the workflow can be altered with the tiniest measure and be used in other teams in the organization. These in the extended-run benefit in creating a standard interface throughout the organization with faint changes if needed.

3.4 Interviews

Six one-to-one discussions were conducted for data collection. These were one to one and a half hours long, where the questions aimed at getting the way to handle the changes. The guidelines for these interviews were, by the book, as mentioned below [42]:

- Asking a good question
- Being a good listener
- Being adaptive and flexible
- Firm gasps of the issue under study
- Unbiased approach

The focus group was people who handled the change in the organization, and PLM architect working on change management as mentioned in the below table 3.1.

Table 3.1: Interviewee details

Interviewee	Domain
1	Change expert
2	PLM architect
3	Approach A representative
4	Approach C representative
5	Manufacturing meeting representative
6	Manufacturing meeting representative

The questionnaire was a semi-structured one with questions being more of a descriptive type. This permitted people to describe how they operate the changes in the team. From there on follow-up questions were introduced. The motive of these interviews was to find out how they operate the change activities, what could be improved, technical expertise that they are exposed. This helped in understanding the depth of how the different tools were used and to what extent. An overview of the transcribed meetings is attached in the appendix B. Along with these, feedback sessions on the impact template were also conducted with stakeholders.

At the end of the work, the formed research questions are reexamined and diagnosed. The evaluation of the objectives and the outcomes received helps in understanding more details and would open the scope for forthcoming studies.

4 Current Process Study

This chapter deals with the study of the change process employed in the organization, their working, existing process under examination, and exploring the gaps by comparing with the theory.

4.1 Existing systems

In its growing stage, the organization go through many change-related activities. Each team had its way of handling these changes. Beginning from using issue trackers like JIRA, or PLM systems like Teamcenter or Kanban board feature in Microsoft teams' a variety of methods and tools were used. In this section, some of those methods employed by different teams are enlisted with details. For confidentiality, the teams are being renamed and only a conceptual level explanation is mentioned.

Broadly, the setup of performing Change management can be classified into three major types:

- Approach A
- Approach B
- Approach C

The working style and structure of each approach are described in detail in the following sections.

4.1.1 Approach A

An abstract process flow of approach A is shown in figure 4.1. The CR creation phase includes the solution proposal and other relevant information collection phases. The evaluation of the information gathered was accomplished in the following step. One key feature was the focus on customer acceptance in the process flow. Changes based on their impact were termed as serious and not serious. For minor changes, customer approval was not needed. Whereas for serious changes, customer approval was mandatory for the change to get approved. In simple terms, the approval depends on the customer's consent. This meant customer standards and templates should be enclosed in the process. For instance, when involving an automotive client, IATF standards had to be followed. So, a common understanding was reached while developing this process. This was genuinely noticed in the literature too. After the approval by the customer, it was taken for internal approval. Thereafter, implementation actions were carried out.

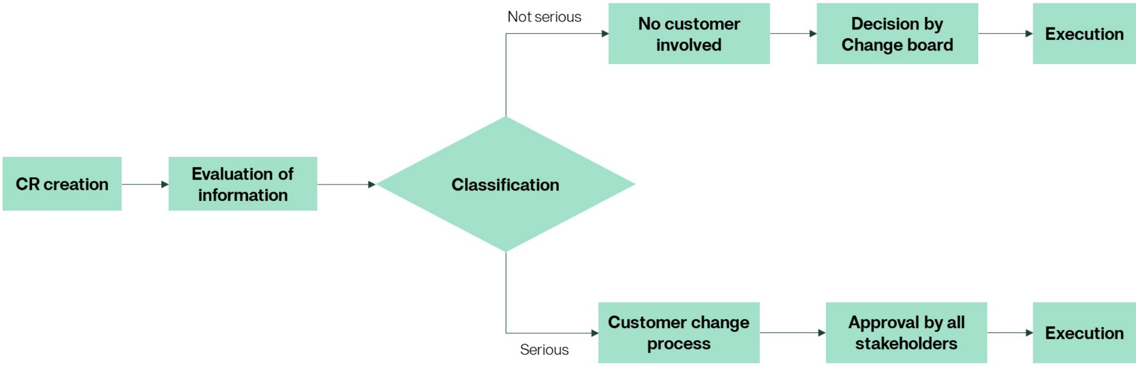


Figure 4.1: Sample workflow for Approach A

4.1.2 Approach B

This system was more of a hybrid one that uses Teamcenter, and JIRA for the execution of engineering change activities. In this, the PR was recorded in JIRA by raising tickets. Once the problem report was approved the change request was created in the Teamcenter network. The following activities of the change order and manufacturing orders were carried out in the Teamcenter setup built. An outline of the process is shown in figure 4.2. The advantage was using the PLM system where it was easier for tracing the related items. This aided in estimating the impact of the change on the overall product. But a drawback was the usage of two systems. Unless there is right synchronisation, the chances of losing the linkage are high.

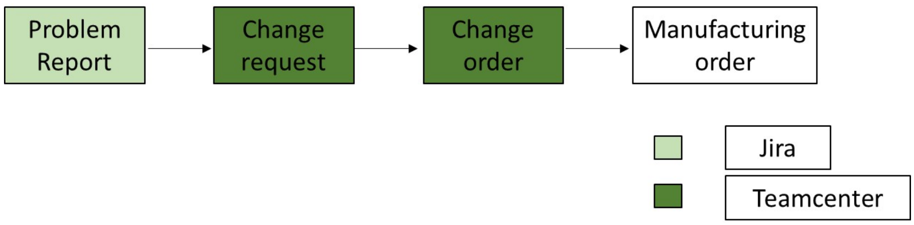
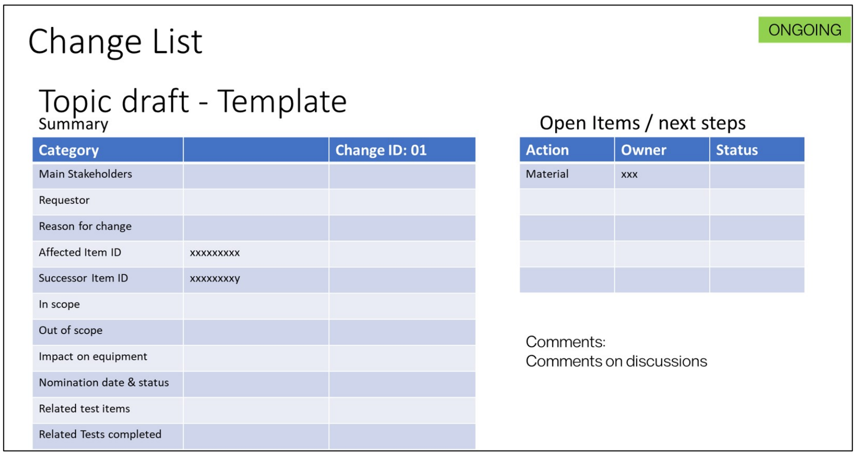


Figure 4.2: Top level abstraction of Approach B

In the Change request phase, activities like solution proposal, feedback from stakeholders, review and decision on the change were accomplished. Once the solution was approved, it was taken to the Change order phase. The change order phase activities include drawing updates, BOM creation, and technical review. These were again sent for approval to the board with stakeholders in planning and other related departments. Once approved, then the process was taken for implementation in the Manufacturing order phase.

4.1.3 Approach C

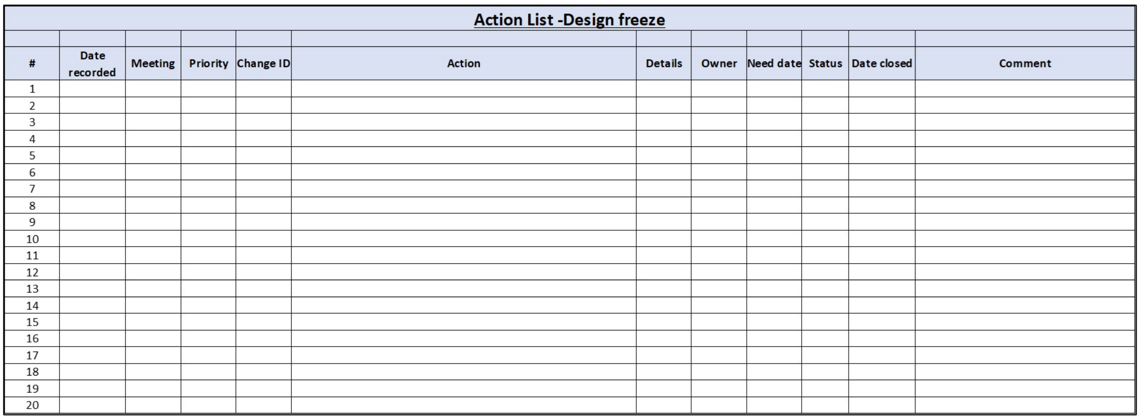
This approach was used by the design team which was under investigation. In this MS Excel and PowerPoint were used as tools. The PowerPoint setup had a track of changes and excel had the actions for each change. Every change had multiple actions that were filled in the excel and tracked. And the actions were discussed based on the due date in the change meetings. A sample image is shown in figures figures 4.3 and 4.4. Additionally, details of how these were accomplished are dealt with in detail in section 4.3.



Category		Change ID: 01
Main Stakeholders		
Requestor		
Reason for change		
Affected Item ID	xxxxxxxxx	
Successor Item ID	xxxxxxxxy	
In scope		
Out of scope		
Impact on equipment		
Nomination date & status		
Related test items		
Related Tests completed		

Action	Owner	Status
Material	xxx	

Figure 4.3: A sample of Change list: Powerpoint- Approach C



Action List -Design freeze

#	Date recorded	Meeting	Priority	Change ID	Action	Details	Owner	Need date	Status	Date closed	Comment
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											

Figure 4.4: A sample of Action list: Excel- Approach C

4.2 Clustering of the change

During the observation and information gathering, it was seen that changes could be into broad categories based on the cause for the change. This type of categorizing helped in sorting the change request and was a significant parameter for the management when prioritizing the changes. The categories are as follows:

1. Cost-saving
2. Optimization
3. Quality improvement
4. Performance improvement
5. Customer request

6. Supply chain issue
7. New design and innovation

When closely observed these were in line with the ones cited in the literature [27]. In the literature, changes occurred because of a variety of reasons. The changes are broadly categorized into design innovation, new customer requirements, changes in customer requirements, and error rectification based on how they were induced.

4.3 Observation of current process

The team where the thesis was performed used the C approach. As mentioned, they used Microsoft Excel and PowerPoint. In the change meetings, actions relevant to a change were discussed and updated. The information was collected from discussions with the stakeholders, participation in the weekly change meetings and change management activities. The details of how the changes were taken in and processed are described in detail. The flowchart in figure 4.5 was created based on the data collection methods mentioned in the chapter 3.

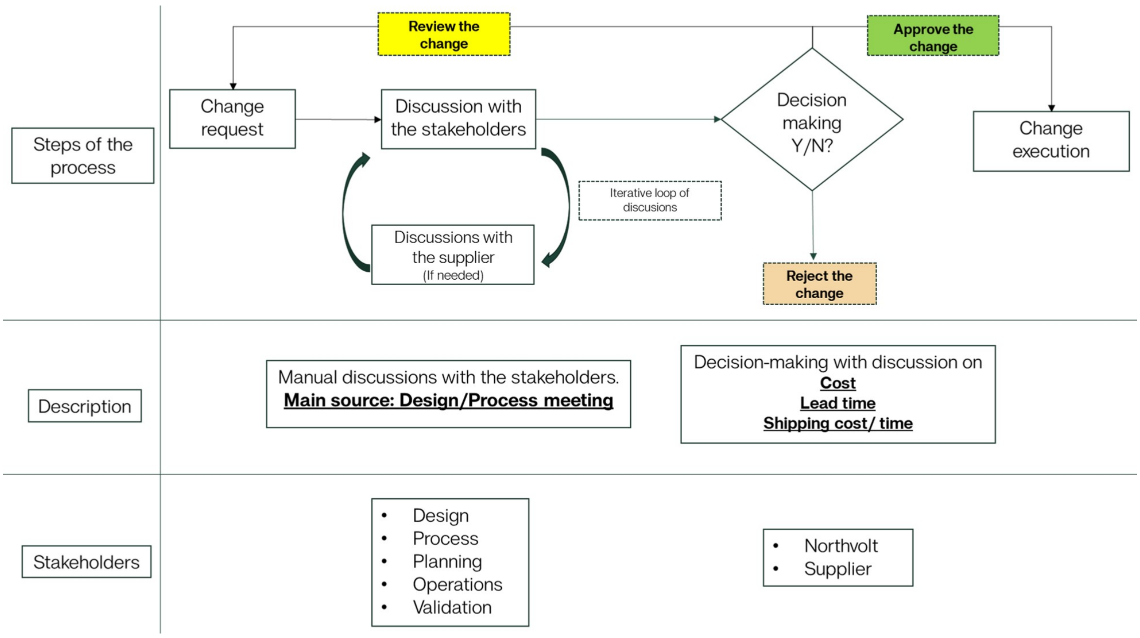


Figure 4.5: Process study- Current workflow

The details of how the changes were taken in and processed are described in detail.

- Gets a request for action in weekly change meetings or through an individual.
- After agreeing with the stakeholders in the meeting, the change list (PowerPoint) and the action list (excel) are updated.
- Right action owner is assigned.
- Makes an entry of all the relevant details for the change and action.
- Until the action owner confirms, the action is not closed.
- Discussions are between the change owner and the corresponding stakeholder only.
- After discussions and conclusion- action is closed.

- Updated in the documents and information is shared with the stakeholders in the change meeting.

In the design meeting, the changes and the actions were recorded as they come. Then the owner for each action was allotted based on discussions. Then it's the owner's commitment to assess the change with other stakeholders that they think were required. This sequence takes place as an iterative process until a decision was made and the action could be closed. If the change involved an impact on the process, then it was taken to the manufacturability meeting for a detailed discussion. Usually, the discussions were about the process, tool, and production line. So, in design change meetings, the changes that impact the product level- chemical design, product, supplier, and mechanical design was dealt with in detail.

When deep-dived into the manufacturability meeting the structure is as shown in figure 4.6. Manufacturability meeting details the tooling problems, cycle time impact, and the process. Though not all changes were taken into the manufacturability meeting, all changes that involve process engineering usually got into the manufacturability meeting. That added more depth to the production line setup and planning. Broadly the manufacturability meeting could be categorized into two types, based on the change and the steps in decision making. They were supplier change and structural change. Supplier change involved a change of supplier and nothing else. The material and its specifications stay identical. Structural change involved change in the product and relevant steps were followed as shown in the figure 4.6.

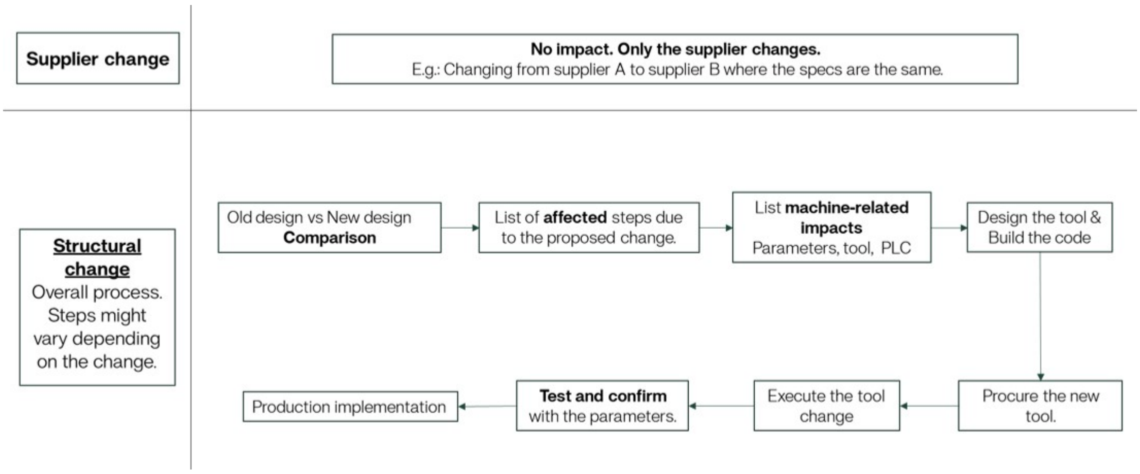


Figure 4.6: Process study- Manufacturability meeting

4.3.1 Gaps in the current system

This section was from the gap investigation between the literature and the working of the team. The team working style was observed during the data collection, interview with the stakeholders and observation from change meetings. There were some spots for advancement in processing capacity and efficiency. Overall, the reason for these gaps could be accounted for two main reasons. One was, the dynamic nature of the organisation. With a need for quick decisions, conclusions on a change request were done informally. Next was the diversity the company incorporates in it. Experts in their fields, from over 100 nationalities, get in line for a change [7]. This cultural diversity and dynamic working atmosphere could have been also a contributing factor.

- **Stakeholders' participation:** Regular and periodic participation of stakeholders' could improve the process. It was observed that there was attendance instability in change meetings. And in some cases, there were no definite roles assigned to individuals. These two factors resulted in ineffective discussions and delayed decision-making. Regularity in meetings and clarity in ownership/ roles will lead to an effective and in-depth discussion.
- **Impact analysis:** From the theory and data collection methods, it was observed that impact analysis is a crucial element in change management. Impact analysis for the changes was done in an unstructured way. There was no proper process or forms to carry on the process. One of the advantages of identifying a change earlier is it reduces the impact. So, with a proper impact analysis structure, the process will be defined and useful.
- **Resources:** There were no specific teams or resources that handled only changes. This was a point to focus on, especially when there were more demands to process immediate change proposals. A small working group solely dedicated to this might improve the working procedure and lessen the processing time.
- **Process flow:** No defined workflow on paper, that described the steps to follow. Usually, the process was without any instructions. In such circumstances, effectiveness depends on the individual who runs the show. This in the long run was not an ideal solution. A proper process flow with steps would help in effective functioning. In fewer cases, decisions were made and then the documentation of the process was followed owing to time constraints. Devising a proper flow would avoid this.
- **Tool competency:** The tools that exist under the prowess of the company could have been used better. For example, the available Teamcenter setup could assist to some extent, but it's not used. The reason was that not everyone was adept at using it. Providing guidelines, conducting workshops, and facilitating online video tutorials would educate and motivate users. Using a tool was always beneficial as it minimises human errors, whichever tool it may be. This enables a reduction in errors and would give proper links.

4.4 Overview of Tools

The benefit of using the right tool was seen throughout the study works. The right process implemented through the right tool should be always encouraged. This section deals with the results of discussions for tools and lists the possible ones. There were many available in the market, and there was scope for creating your own. This was evident from the brainstorming, talking with experts and internet search. So, to set up a perimeter these tools were picked based on two factors. The tool had been used in change management operations as a standalone system, preferably in Northvolt. Next, the package needs a smaller investment. This means no separate buy decision for the organization. This is because the company had to buy a licence if they had to use them. Based on the above conditions, five different tool options popped up, which are the following:

- JIRA
- Microsoft Planner
- Microsoft Office
- Teamcenter
- Combination of tools

So, in total, five tools were identified for handling the EC. As mentioned in section 1.5, the intention of this analysis was only to explore for future scope.

4.4.1 Jira

One of the choices was to use the issue tracker- JIRA. This tool was used in approach B as seen above. A Kanban setup in JIRA looked suitable for constructing a process flow. A Kanban board is a visualisation tool that helps in optimising the workflow process. This is done through cards and lanes [43]. A sample Kanban board created is shown in figure 4.7. Using the board, different steps of the workflow were created with each change being ticketed. Details for each change were added with the built-in features. The advantage was the page was customizable. The workflow could be customized, so changes flow in the process and not bypass steps. And fields in a change page could be added/ edited.

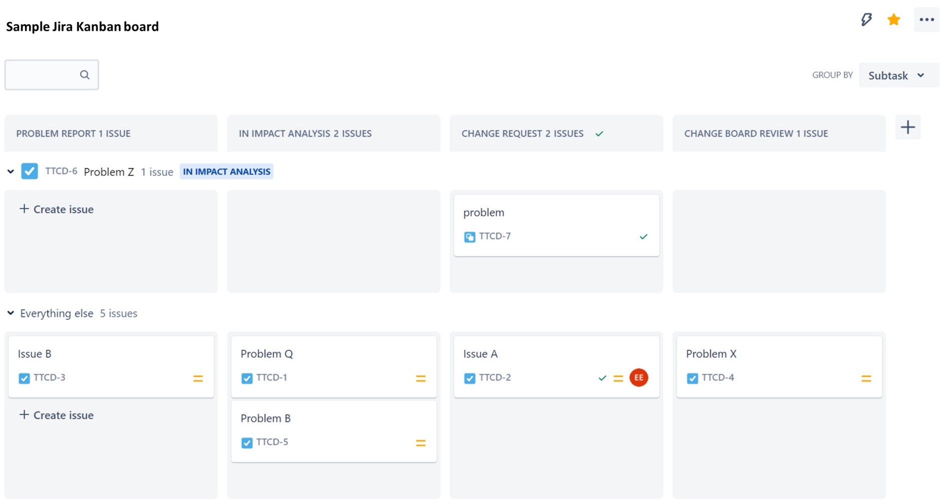


Figure 4.7: Sample Kanban board created

A sample pop-up from the board is shown in figure 4.9 and the customisation page that the software offered is shown in figure 4.8.

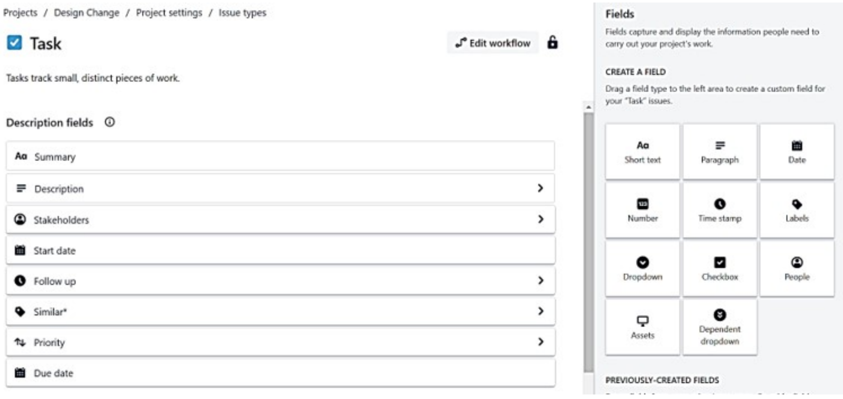


Figure 4.8: JIRA customisation interface

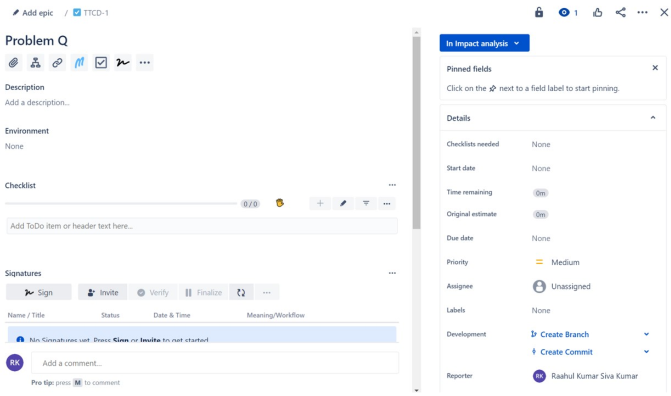


Figure 4.9: JIRA pop up for each change

4.4.2 Microsoft Planner

An alternative to that of the JIRA Kanban board was the Microsoft Planner. Created by Microsoft, this tool had a similar Kanban setup for devising the process and navigating the changes. A sample dashboard created is shown in figure 4.10. In this setup, buckets were created representing each stage of the change process. The issues/ problems details were filled in and toggled between the buckets.

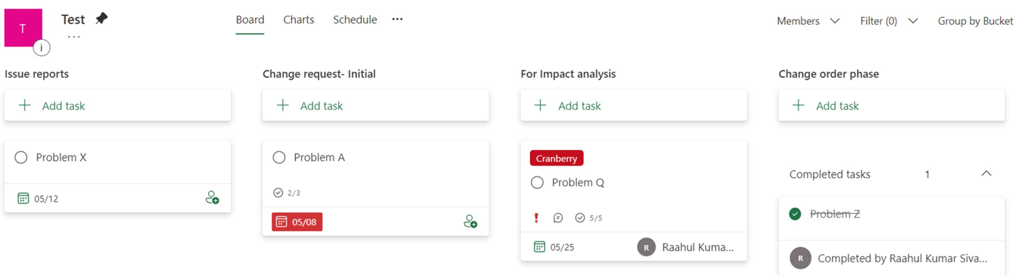


Figure 4.10: A sample dashboard in Microsoft Planner

Details for each change were defined with the in-built feature that pops out, as shown in figure 4.11. The available features include provisions for attachments and checklists, priority level, an option to tag people, setting up deadlines, and adding notes. This is like JIRA, the primary difference being the service provider. An additional feature was the software integration with the Microsoft teams network.

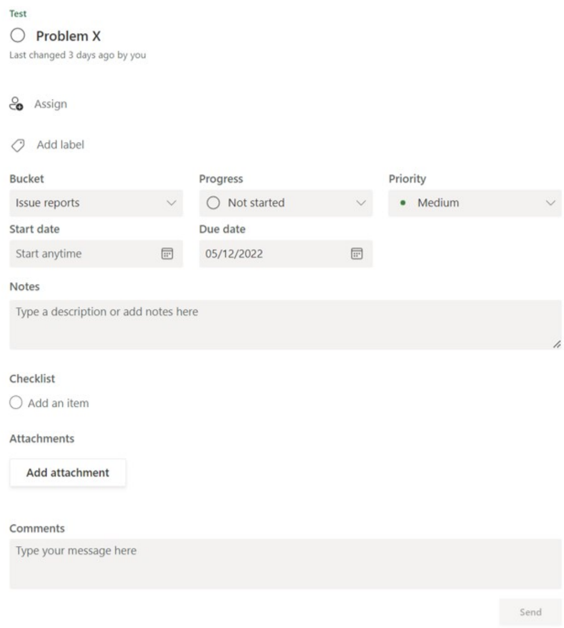


Figure 4.11: A pop-up for a task in Microsoft Planner

4.4.3 Microsoft Office

This involves using the packages provided by MS office- excel and PowerPoint in particular. The motivation was from approach C, where Excel and PowerPoint were used effectively. Though these packages have basic features, they could be used effectively in some capacity. This was evident from approach C and from the practical observations.

4.4.4 Teamcenter

This choice involved Teamcenter usage completely as a standalone. All activities starting with the problem report creation to the release of the Change order and notice could be done. The benefit of this system was that the options and the layout could be adjusted as per the requirements. Another being a complete PLM, Teamcenter satisfied the core requirement of traceability and integration in one system. With provision for linking CAD management, drawing and specifications available, Teamcenter served as a complete package. A sample workflow is shown in figure 4.12.

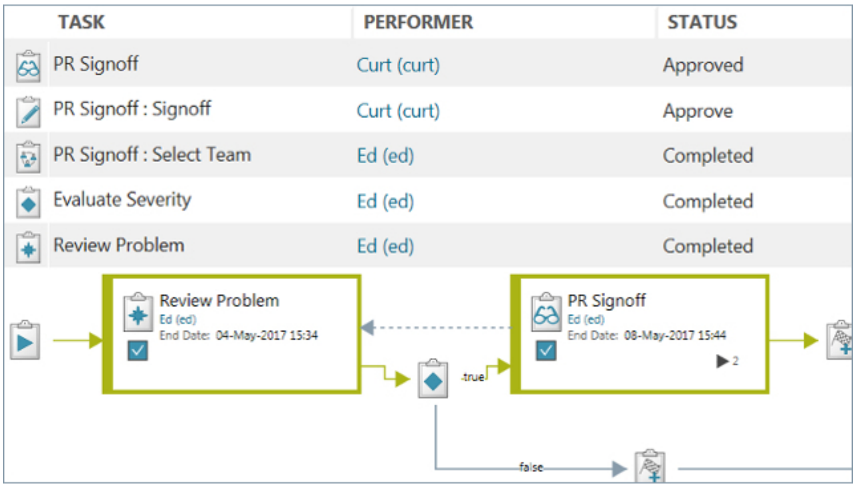


Figure 4.12: Sample Workflow in Teamcenter [16]

Teamcenter, as a tool, looked good, as it had a built-in package, and without much customization could be used. If the need arises, customization could be done. But it was decided to keep them as minimal as possible as it was expected that changing the layout involved cost. Another concern was tool competency as mentioned in the previous section. But the advantage the setup provided in terms of integration, linking, and efficiency were all desired once for an ideal change process. The core idea of the change process that could be set up in Teamcenter is as per the following figure 4.13.

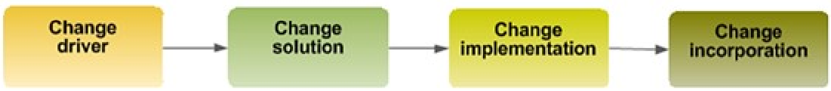


Figure 4.13: Sample process from Teamcenter [44]

4.4.5 Combination of tools

Improvised from approach B, this seems to be a likely option with the best available could be used. A tool good for a specific feature can be picked and linked with another one. And by this combining effect, the best of the lot could be derived. A potential drawback, in this case, was the integration part, where the transition should be smooth. If not, the system might collapse the system. For example, the use of Teamcenter and planner as combined tools. Though Teamcenter has good integration, the visualization was not that great when compared to the Planner. So, a summarized model could be maintained in the Planner and details linked to Teamcenter. In this way, the need for everyone to use Teamcenter could be avoided, better communication could be established.

From this current process study, it was observed how the process was taking place in the team, different approaches existing in the organization, possible tools that could be used, and gap analysis. With all this information, a new process flow creation was initiated whose details are in the upcoming chapters.

5

Preparation of New framework

This chapter deals with the preparation work for the new process flow. This includes the creation of a stakeholder's need list, an assessment of the systems with the requirements, and observations from the analysis.

5.1 List of Stakeholders

To fix the boundaries, a list of stakeholders involved was required. From the current process study and observation, it was seen that the following were the major stakeholders.

1. Design
2. Material
3. Operation
4. Process engineering
5. Validation
6. Quality
7. Customer
8. Finance

5.2 Stakeholders need list

Before initiating a new system, the requirements the system had to satisfy were required. This section deals with how these needs were carried out. From the discussions with stakeholders, brainstorming, and observation of the current system, a set of needs from the stakeholders was formed. These were for two purposes.

- Compare the existing tools and study their pros and cons.
- Provide a guideline for the new process flow.

Table 5.1 gives in detail the needs list and its description. As the data collection was qualitative, each criterion was equipped with basic questions rather than a quantifiable value to evaluate. For instance, each requirement when compared with the systems, it was seen to what extent it fulfils the questions asked to the one that is being compared. So, the formed requirements were basic with descriptions subjective. Decisions on these were made based on discussion, which for the moment served the purpose.

Table 5.1: Stakeholders need list

#	Requirement	Description	Questions to be answered
1	Traceability	The ability of the system to trace the information	With a change ID (part number) can all the affected items be traced? Will the system be able to trace the active changes to a selected part?
2	Efficiency	The speed with which the system can process information. Wish is minimal lag while navigating.	Linking the data, pages, and the auto-retrieval of relevant details by the system
3	Nonrecurring Cost	This involves the one-time implementation cost	The cost includes buying the software and setting it up. It includes the miscellaneous cost like buying hardware and supporting software for initial setup.
4	Recurring cost (maintenance cost)	This involves periodic costs like maintenance, software, and hardware update.	Periodic costs like the cost of an update and cost for maintenance.
5	Setup time	Setup plan and its relevant details	Can it be immediate, or any new software/ hardware is needed? Measured in terms of the number of man-hours that can be equated to money.
6	Time to roll out process	Focus on the roll-out time after implementation	Aspects such as training for the user, man-hours for it, preparation of the training material are focused.

7	User-friendliness	User friendliness of the interface to the end user	The measure of how friendly the system and the interface is with the end user. This measure could be a qualitative or a quantitative measure.
8	Flexibility	Flexibility of the system under different conditions.	Estimating the systems flexibility, different routes under different conditions, for different units, the possibility to skip steps under mutual agreements. Scalability of the system in the organization.
9	Capacity	The potential of the system in dealing the personals.	Measuring the system's capacity like the number of changes handled per month, users at a time.
10	Data management	The capacity of the system to handle and manage the data.	Locate the ways how the data is handled and avoid data corruption, and redundancy.
11	Data security	The safety of the data stored and handled.	Concerns on the security of the data stored, confidentiality of the company information and other IT security setup of the system.
12	Integration	Systems ability to integrate information from many possible platforms.	The capacity of the system to fetch and integrate all possible information relate to a change in one single platform is tested by this criterion. Helps in maintaining history and gives a holistic picture of the change.

13	Reliability	The reliability of the outcomes from the system.	The assessment of the results and their credibility. Subjective and can be concluded based on the field tests.

6

New framework

This chapter details the result of the work, which is the new process flow, steps in the flow, detailing the steps as per the requirement. Adding to it, are tests that were done and the plans for implementation.

6.1 Top level abstraction

As cited throughout the work, the process when seen from a higher level follows the same order. The issue gets reported into a problem report. From the problem report, a change request is created and analyzed, and a decision is made. Based on the conclusion further steps are taken. If approved, then execution-related activities are carried out, if rejected then it's sent to the rejection handling system. And there are instances where more information was required for deciding, and hence they were iterated. This aligns with the generic engineering change process mentioned in literature [15]. With scope for customization and this higher-level process in mind, a new framework was created as shown in figure 6.1

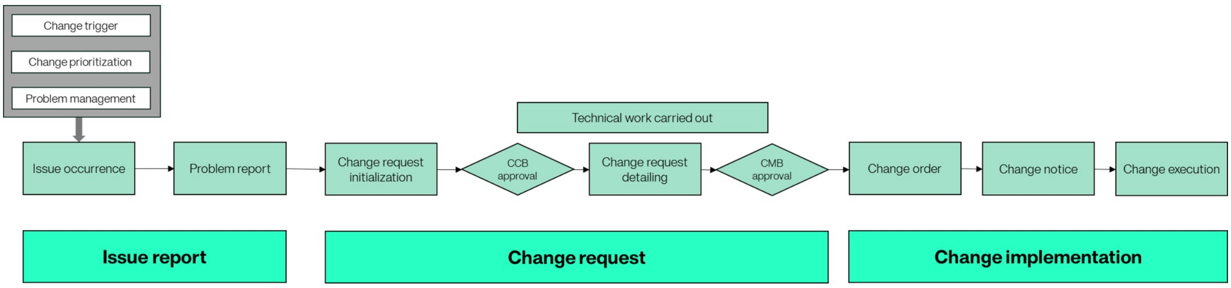


Figure 6.1: Top level abstraction of the Change process

The entire process is handled by an expert, called here a 'Change Analyst'. The CA moderates the process drives the meeting and manages the time plan. Next, there are decision-making groups called CCB and CMB. These are authoritative groups that make judgments. The composition, working and role of these will be detailed in corresponding sections. The process starts with issue occurrence where the problem occurred gets reported, by anyone in the company. A corresponding problem report is filled by the stakeholder or the team for the occurred issue. The change request follows up as the next process. To make the process more efficient, the change request phase was split into two- Change Request Initialization and Change Request Detailing. These are moderated with a CCB approval in between them.

The scope of the framework starts with a problem report created by the stakeholders in the organization. The trigger for the problem was not considered which is highlighted as grey in the figure. This was because how each team comes up with a problem report and a proposed solution is team dependent and that could not be generalized. But it's good to know how deep the process can go if needed. This was the reason for getting mentioned, not detailed. The step in the flow work is a multi-step process that involves collective decision-making. The entire process can be broadly categorized under three types:

- Issue Report
- Change Request
- Change Implementation

The steps involved are discussed in detail in the upcoming section.

6.2 Issue Report

In the Issue Report, two major activities exist. They are issue occurrence and problem reports. Issue Occurrence acts as a preface to the change process. Once a problem or a concern rises, an individual or the team comes up with a problem description. The issue occurred along with details and possible solutions were taken into the next step. This step has to do with the submitter and the change analysts do not have any roles. The possible solution mentioned, is not the final solution as the final solution proposal will be decided by CCB. The conversion of the issue to a problem is carried out in this step. In the Problem report phase, documentation of the issue is done. The submitter fills in a basic template built with probing questions on the problem details. Once a Problem Report is filled, it advances from the submitter to the change analysts. The Problem Report demands details such as problem description, affected part and process numbers, proposed solution, and relevant attachments, if any.

6.3 Change request

The Change Request phase is divided into four: Change Request Initialization, CCB approval, Change Request Detailing and CMB approval. Of these CCB and CMB are decision-making steps. The main motive for these approvals was filtering and efficient working. If a change is considered critical during the initialization phase, it is taken into the detailing phase. For example, if a change was termed 'not that important', then more time and resources could be diverted to 'important change'. The 'important' and 'not that important' are subjective and not defined in this work. Similarly, only when the CMB is convinced that execution is worth spending, change execution is considered. Each sub-process is briefed in the following sections.

6.3.1 Change Request Initialization

Change Request Initialisation is the initial step where the conversion of the problem reports to change requests occurs. A template created is shown in figure 6.2. In this, CR is detailed with the trigger and reasons for the change, main stakeholders for the solution, CCB, technical recommendations etc. The change analyst fills in the details with information taken from the problem report, periodic change meetings and discussions with the change requestor. This information collection continues until there is enough for CCB to take a call. The trigger for the change, based on the observation and literature were broadly classified as problem reports, customer requests and new design in accordance with the literature. The reason for the changes is brought under the following reasons- cost, quality, supply chain, performance, and manufacturability.

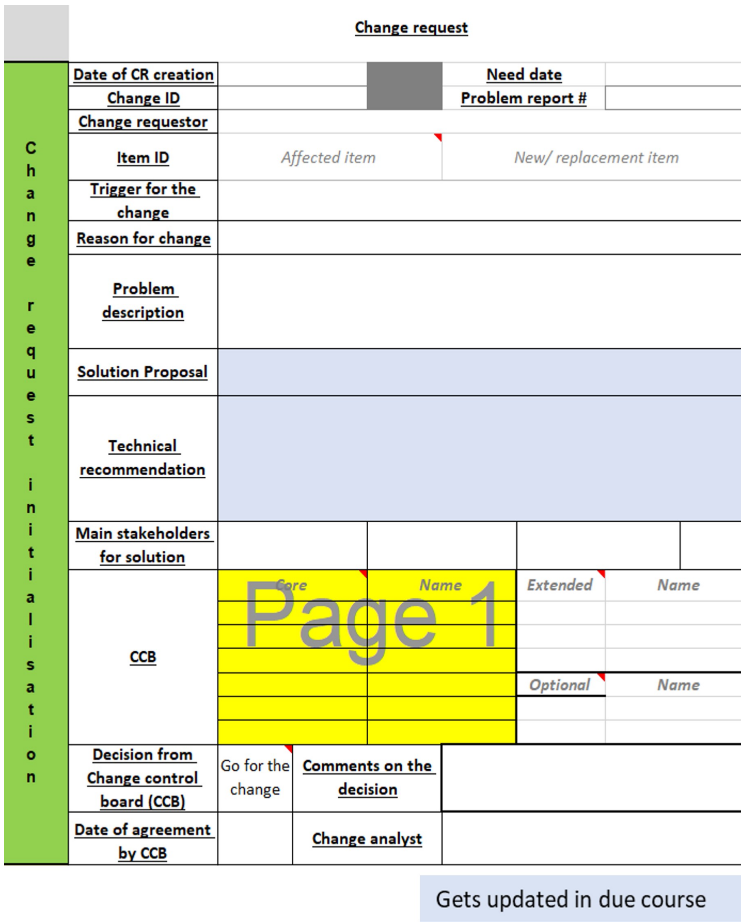


Figure 6.2: Change Request Initialisation sample template

6.3.2 Change Control Board

During the Change Request Initialization, the main stakeholders and the CCB are decided. 'Main stakeholders' are responsible for solution suggestions and validation. The role of CCB was to discuss the problem reported, review and pick a solution or a sequential approach for the problem and decide on the CR. Three possible decisions are expected at the end of this stage. They are

- Go for the change proposal
- Reject the change proposal
- More information is required

Based on the requirement, the pace of execution is decided at this stage. They are normal, fast track and urgent. Normal pace follows the steps, whereas urgent leaps to the execution portion. The triggers for these urgent might be customer requests or serious quality issues. In fast track, decisions are taken at a quicker pace with minimal detailing process. Urgent and fast track is just touched upon and is not described in detail in this work. The layout of CCB was framed as shown in figure 6.3 with the change and the change analysts at its nucleus.

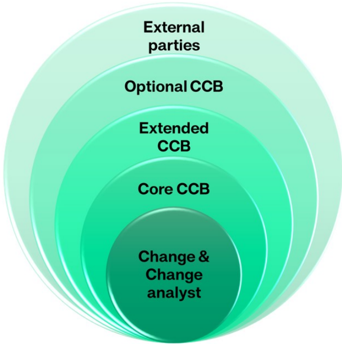


Figure 6.3: Formation of Change Control Board (CCB)

- **Core CCB** This involves the primary stakeholders whose presence and views are mandatory for picking the solution and deciding in the CR. These are the core group whose contributions are vital in impact analysis, solution picking, determining the change propagation and related activities. The contribution of this group is mandatory for every detail further down the process. Some of the stakeholders in core CCB are- manufacturing, design, testing, project management, product development etc.
- **Extended CCB:** This group includes stakeholders, whose presence is needed for the change but not mandatory for every detail. It is sufficient if this group is communicated periodically. Some units that fall under this group are- operations, packaging, etc.
- **Optional CCB:** This group includes stakeholders in the organization who might be used fewer times for opinions or consultation. Stakeholders like intellectual property experts or construction experts' consultations are needed once or twice.
- **External parties:** These include the relevant stakeholders outside the organization such as the supplier, external experts, and government agencies. Though they are external entities, they will have a point of contact with the CCB. For example, interaction with the customer would take place using the project management/sales team.

Once the change gets sanctioned by CCB, it is taken to the detailing phase for in-depth analysis with the relevant stakeholders. If more information is needed, then it is sent back into the system for acquiring more particulars. If the change is rejected, then it's sent to the rejection handling system.

6.3.3 Change Request Detailing

In the Change Request Detailing phase, requests approved by CCB are taken in. In this, more details for the change request are appended. These include a description of the agreed solution, impact analysis to be performed, BOM comparison, the scope of the change etc. To complete the Change Request Detailing phase, the following activities are to be done.

6.3.3.1 Adding technical details

In Change Request Initialization, only an overall summary of the change and solution proposal is put forth. Once approved, adding technical details to the solution is done during this phase. For example, a change of design was agreed upon in Change Request Initialization, and suitable material, tests for checking, and other details are added in this step.

6.3.3.2 BOM visualisation

An important aspect of the product release is its latest BOM. During a change, the impact of the change in the BOM is hence vital. At this stage, visualization of the new BOM after the change is executed is done. This pictorial visualization called '△ BOM' helps in realizing the impact of the changed item at its assembled levels and levels over it. A sample image of delta BOM is shown in figure 6.4.

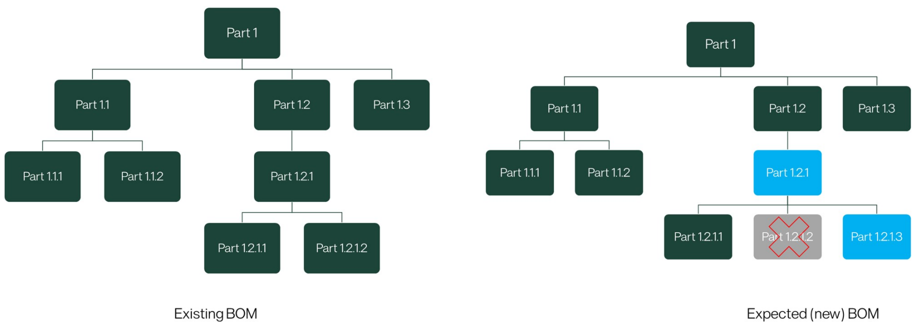


Figure 6.4: An overview of BOM and △BOM

6.3.3.3 Change Propagation Management

In Change Propagation Management, the propagation of the impact due to the affected item is determined. Every changed item in the BOM has an impact on the linked items. These are called affected items. To determine all possible affected items, the level of propagation is needed. Many scientific methods have been employed in various studies. For a basic version, the propagation levels are planned by the change analyst based on the discussions with stakeholders. In the figure 6.4, it is seen that due to the change of parts in the fourth level, the element in the immediate top gets affected (shown in blue). In some cases, the effect extends up to the top assembly.

6.3.3.4 Impact analysis

This is the key step in the detailing phase. Each stakeholder is probed with questions that try to assess the impact of the expected change. The questions are built in a basic template and are planned to share with the corresponding stakeholder. These questions try to cover or remind aspects that stakeholders must consider while assessing the overall impact of the change. Sample templates are attached in appendix D. Though there could be many, for scoping reasons only five units were selected: Design, Validation, Manufacturing, Quality, and Operations. Based on the observation and discussions, it was decided that these were the major areas that contribute to the changes occurring in the team at the moment. A sample template created in excel is shown in figure 6.5.

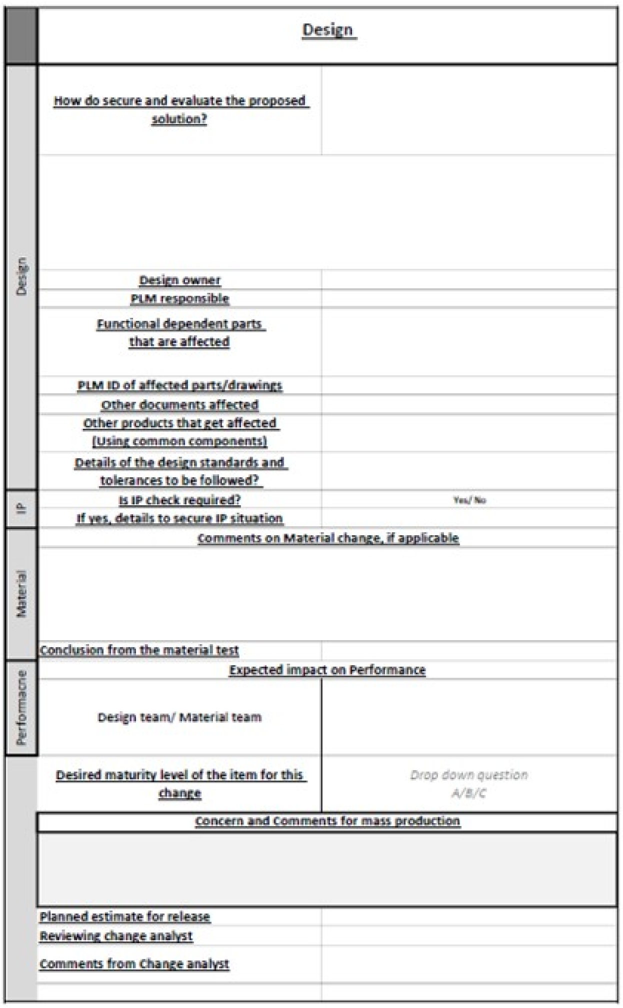


Figure 6.5: A sample Impact analysis template for Design

6.3.3.5 Financial Summary

The results from impact analysis and discussions are turned into monetary terms in this section. A sample template is shown in figure 6.6. The cost of the expected purchase, labour cost, and recurring costs involved are all listed. This was to give a basic understanding of the cost of the change and for decision-making for the management board.

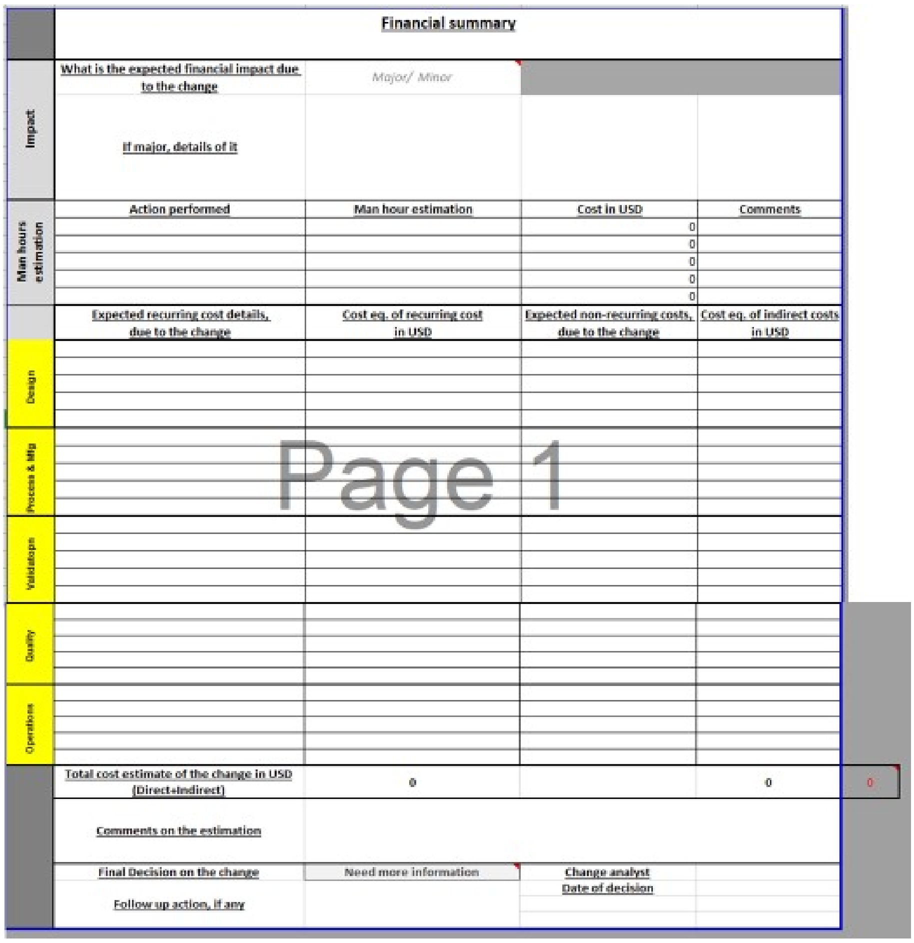


Figure 6.6: A sample financial summary report

6.3.3.6 Technical activities carried out

This is a parallel step that spans the detailing phase. All possible options and candidates mentioned in the proposed solution are tested and validated for obtaining a conclusion. Planned steps to be carried out are:

- Define the requirements and the relevant documents needed.
- Explore the right material/ composition.
- Filter the right supplier and finalise the samples.
- Test and validate the sample- component sub-assembly level, and eventually live cell.
- Conclude based on analysing the test report.
- Decide on the technical solution: Approve/ Reject/ Iterate.
- Introduce as the new reference for production.

6.3.4 Change Management Board

Based on the impact analysis, technical activities carried out, change propagation study and the financial summary, a final decision on the change is taken at this step. The stakeholders at the management level comprise the CMB, which decides and has a final say on the change. Three possible decisions are possible: Go for the change, Reject the change and more information is required.

6.4 Change Implementation

This section includes the steps that involve the implementation plan once a decision for change execution is done. These include Change Order, Change Notice and Change Execution. Due to the scope of the thesis, an in-depth analysis of these steps was not done. An overview of these is dealt in below section.

6.4.1 Change Order

Once a change is accepted, a Change Order is created. In change order, a conclusion of the agreed solution is made, and initiation for the implementation activities takes place. It starts with the documentation level where the changes are executed on paper. The execution plan, release packages, Clustering of multiple CR into one CO and execution plan are some of the major activities.

6.4.2 Change Notice

In the Change Notice stage, the action plan, release package schedules, and new reference documents for the change are all shared with all relevant stakeholders. This is to make sure all the stakeholders are aware of the details and are on the same page. These steps could be collectively grouped under change implementation, as shown in figure 6.7

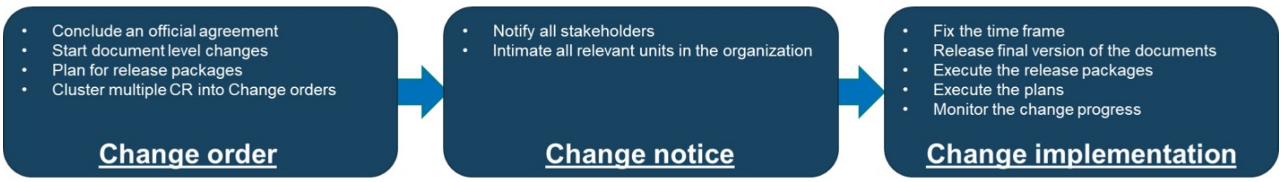


Figure 6.7: Steps for Change Implementation

6.4.3 Change Execution

This step focuses on the execution, where the time frame for change closure is planned, release of latest versions, execution of release packages and monitoring of the change until its effectivity is achieved. A summary overview of the entire process is shown in figure 6.8.

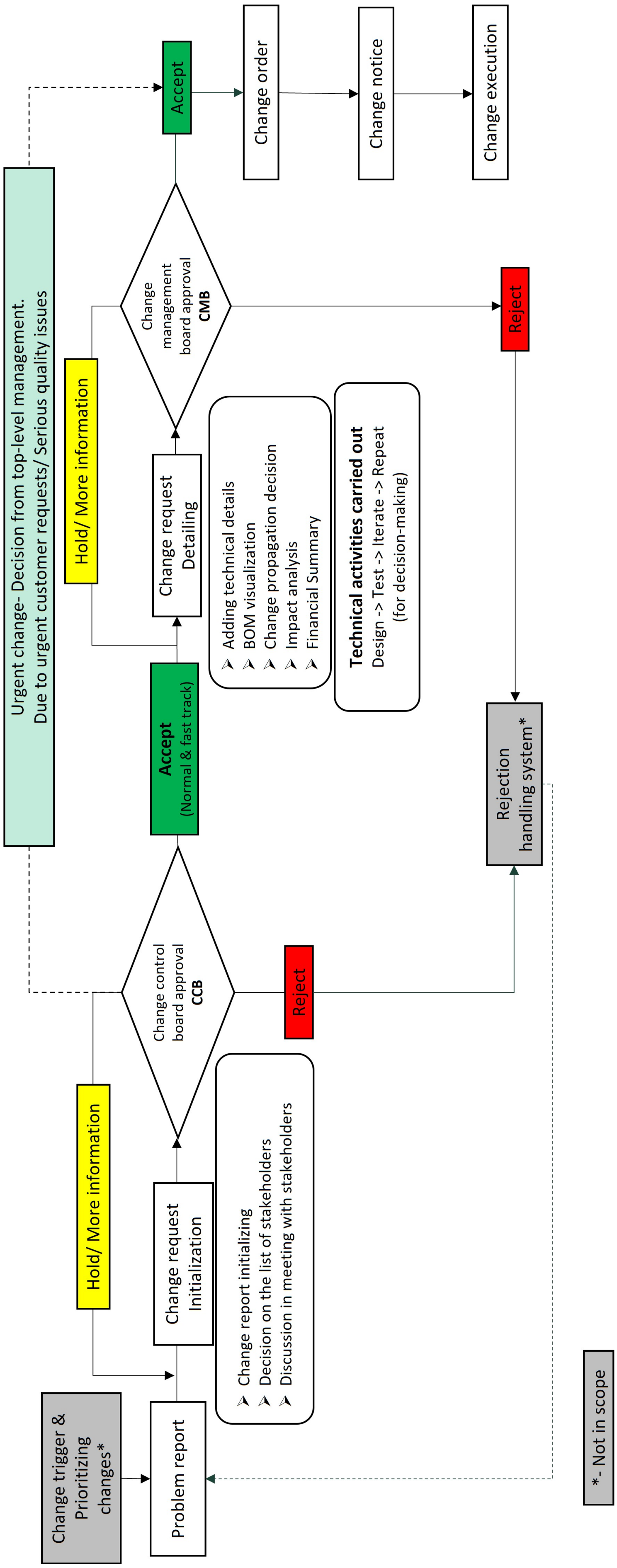


Figure 6.8: Detailed overview of the framed process

6.5 Testing of the impact analysis

Once the framework was formed, it was planned to test to understand the practicality of the system. Table 6.1 describes the test plan and the observations from it. In this, six different changes were taken, from A to F.

Table 6.1: Test plan

Part	**Problem faced during change execution**	**Questions that could spot the issue if the impact template was used**	**Comments**
Part A	Raw material thickness varies	Questions on process line,changeover, and machine setup	Additionally, explicit question added for material loading.
Part B	Coloured items are not detected by camera	Expected impact on the process line systems	Covered through the answer pop up: PLC, MES, Robotic arm, AGV etc
Part C	Parts are not in specs (dimension)	Should be covered in QC control plan	Quality control plan should ensure this.
Part D	The incoming material quality	Incoming quality checks required	Supplier quality question exists.
Part E	Air bubbles due to wrong process parameters.	No question on process parameters	Question on the parameters added.
Part F	Quality and auditing of internally produced material.	No supplier quality section/ question for internally produced items	Question added in supplier quality section

As mentioned, the impact analysis was focused on detailing, testing it was the primary objective. Adding to it, was the content of the questions. Based on the interactions, it was assessed whether the questions convey the exact intention it was meant. These were the criteria set. And for testing, an approach like the case scenario was picked[45]. Few past occurred changes were picked and were fed into the process flow & impact analysis. These are changes that when they were executed, had new issues that weren't known before. So, using this testing it was checked how far the process could spot these issues through its questions.

These were the changes that when executed gave way to a new problem that was not estimated. For example, during Part B change execution, different coloured material was considered. But due to colour, the robotic arm in one of the processes was not able to spot the material. This aspect was not considered. Had there been a deeper analysis, these details could have been spotted well before the execution. The purpose of this testing was to check whether the template captures these details. Five other such changes were fed and observed. It was seen that out of 6, 3 issues were captured by the template. They were for parts B, C, and D. For part A, though there were questions that covered the essence, no specific questions were there. So specific questions were added for it as it was thought important areas. Looked for aspects for Part E and F that were not present. Questions to address there were added, which are mentioned in the table. Besides these, some general feedback and observation from the stakeholders were recorded, which are:

- Material changes over, loading different thickness materials were not properly addressed.
- Audit for internally produced products was not addressed.
- Automation in equipment and its related aspects were not addressed.
- Pop-ups in the template did not guide the answers to what is expected.
- Combining a few sections to form a broad template.

Based on these observations and feedback, the template was revisited, and necessary modifications were done.

7
Discussions

In this chapter, the findings from the literature study, the results, and an overall assessment of the research questions are briefed. In chapter 1, research questions and specifications were laid out. The purpose was to serve as a guide for regulating and evaluating the process. So, the research questions are revisited and are fairly evaluated and discussed.

7.1 Findings

From the literature study, an overall picture of ECM was inferred. This includes the definition of ECM, the steps involved in the process and its details, and how different industries had adopted and customized it in its way. It was seen that large manufacturing companies which involved suppliers around the globe need better communication channels. Another key takeaway was knowledge management. Proper knowledge management helps in dealing with EC effectively. And another option to improve efficiency was the tool. Using a tool that allows the organization to customize the workflow adds an advantage to the company. It was seen that the steps at an abstract level could yield efficient results and could be implemented by all tools available. But equipping details to the steps as per the organization is vital. Adding to the tool, BOM, BOP, the importance of the controlling committee, the procedure followed and the way they manage the engineering change were also determining factors. The practised methods must provide a check and balance approach for effective analysis. This was where the impact of packages and tools was seen. The next interesting observation was the way Change propagation Management was dealt with. Many scientific methods were proposed for tracing the link and the affected chains. The use of artificial intelligence and graphical representation were seeming to be productive. The creation of its database, based on the BOM and BOP structure of the product was seen as a simple practical approach that could fit any organization that would start from scratch. And from the literature studies, it was inferred that no single method can be termed an all-purpose method. Several standard processes for ECM and implementation guidelines from CM were being proposed to enterprises for implementation. And in some circumstances, official and unofficial change process layouts were used in industries, depending on the time constraint. And while implementing, the tool was an essential aspect. The tool must help with managing the workflow and help engineers in decision-making. Another detail mentioned in these works was the role a design engineer plays in ECM. Stakeholders were expected to use their engineering judgement for better and more efficient results.

From the interaction with stakeholders, it was seen that the requirements were predominantly on the system interface. The requirements for the system like traceability, data security, user-friendliness, and reliability could be attributed to this. So, the users were more concerned about how the interface and the data management were than the actual process execution. This meant that the system with its basic version should be user-friendly for wider acceptance amongst its audience. Next stood the cost and time. The cost of buying/ creating the new system, it's testing and implementation and the corresponding time involved were also important aspects. From the interviews, it was observed that the core of the current process was accepted by everyone, with refinements in execution expected.

Next, the research questions are revisited and discussed. **RQ 1: What are the obstacles the company has while executing a new process flow?**
There was a lot of scope to stabilize and improve as the company is fast growing in the market. One such area was managing the engineering change management. There was no definite process for the organization to handle the change process, with each team having its own procedure. Another lacking aspect was the absence of an assigned expert group. There isn't any expert group, or an explicit team assigned that handles the matters of engineering change, though there are individuals who have vast technical experience on the subject. This could be confirmed from the interviews. And even with the right people, without a standard procedure and a tool, it was next to impossible for the expert(s) to handle the process in an efficient way. This could be attributed to the nature of the change process itself, complex without proper amenities. So, it could be seen that the lack of sufficient resources was a major obstacle that the company must overcome to improve the process. The process followed by some teams was fragile because of the absence of impact analysis. In some cases, the decision for the change was agreed and then the impact analysis was carried out. With improper estimation, this might end up in rework, which involved cost and time. Another obstacle was that insufficient bench-marking details. There aren't many players producing batteries in Europe. Though there are battery manufacturers around the globe, the way the change process was handled by them is not available in the public forum. So, there wasn't a window for complete bench-marking or available standards that could help the company in laying out some ground rules.

RQ 2: How can the formed process flow address the issue that exists?
The formed process served as a guideline for the team. Though it is at its basic level, the foundation for a deeper process was laid out. As the team progresses, new features and steps could be added to get a more in-depth change process. Along with it, the impact analysis templates help the stakeholders to expect and predict all possible issues when the change was executed. Also, the financial summary with all change details in the cost aspect will be an engaging facet for the management to consider. And with the new process, a change team should be formed which will answer the lack of resources issue. The process had a provision to add or delete

features. For instance, the scope for an urgent request was added after feedback from stakeholders. The same goes good for the impact analysis templates as well. Questions and sections could be easily updated which confirmed the process is customizable and user-friendly.
Apart from these, there were a few other aspects that were also noticed. The formed process flow was very abstract. This meant that it could be implemented for a product change, process change, design change and even organizational change. By customizing the details, the necessary process flow could be achieved. With the framework slowly evolving, there involved a lot of manual work during its initial phase. This was the reason for not picking a tool right away. The focus was to lay the process solid on paper and then find the right tool for it. With the options available in the market, the company can build its own database with all customizable features satisfying the team's needs. For now, only five stakeholders were identified along with finance. But there was scope for more stakeholders and impact analysis templates. For instance, operations could be split into logistics, warehouse, supply chain, planning, and purchasing. In that case, separate templates were to be created for individual stakeholders. These were some simple observations, which were worth mentioning.

7.2 Challenges

There were some challenges faced while performing and running the test runs for this work. As mentioned in the methodology section, the entire research approach was a qualitative type which involved data based on words and images. And this was followed in this work too. The data collected, results and observations could not be quantified. Predominantly, they were descriptive and observation based. An overall view of the process was interpreted with data collected from the interview and the observations from the change meetings. This was experienced when framing the needs list of the stakeholders. Measuring the requirements for the system and comparing the tools was a challenge, as there was not a measure to quantify and compare. So, from discussions, some basic questions were set to judge and assess the criterion. The next challenge was finding the standards and bench-marking the available systems in the industry. As the battery industry in Europe is upcoming, nothing specific for battery manufacturers in Europe in the change management domain was available in open source. So, a general approach available in the literature and some other complex industries like automotive was picked as reference. While framing the process, issues like problem management and rejection handling popped up. These were systems that involved not just a team under consideration, but the entire organization. So, a process for these areas could not be defined easily. So, forming a set of rules, for now, was a challenge and so it was not added in scope. The Impact analysis process and templates created were a basic outline with fewer questions. Direct involvement from the stakeholders during the template creation was very less due to the time constraint. But for a deeper process, stakeholders had to take up the ownership of these templates with the change team only engaged in managing the process. But this was a challenge with the current responsibilities and the workload of the stakeholders.

8

Conclusion

With all the process steps and findings from it, some future scope areas were identified. Some suggestions were also mentioned for the smooth running of the process. These topics are discussed in this chapter.

8.1 Recommendation

Based on the findings and observations of the process flow, there were a few recommendations suggested for the team and company. These are improvement points that could be implemented in the process flow without much delay. And by implementing these, the process was expected to be more efficient and time-saving. The foremost recommendation was for the tool. A proper working tool had to be picked for the implementation. As time progresses, using templates from excel will be laborious and could lead to manual errors. So, either one from the above-mentioned section 4.4, or one available in the market can be looked at as an option. Of the tools compared, JIRA looks promising with its features. Next was 'more information needed in the decision-making stages. When a change request is withheld or sent back for more information, how it reaches the line was not dealt with in detail. Some practical rule of thumb was needed for homogeneity. And after adding information how it is prioritized is another thing that should be regulated. Next was the numbering of the CR and CO. A proper configuration setup had to be laid. This setup must contain information that links the CR and its related CO and CN. As previously mentioned, a single CR could lead to multiple CNs. So, a database on that is always recommended. And with some reference to the CM, the naming and numbering of these CR, CN and CO could be improved for better visibility and traceability. Next, an important contributor to this work was the change meetings. Therefore, how good the meetings are structured is vital. A periodic change meeting with the core CCB was deemed mandatory. Adding to it, a summary meeting once a fortnight could be arranged with all CCB members- Core, Extended and Optional for project continuity and better understanding. And if needed, the members of the extended and optional could be invited to the regular change meetings. And as a preparation for these regular change meetings, the change analysts could draft an agenda for the items that are to be discussed. Sending this in advance would allow the core stakeholders to prepare the required updates they have. Though these are obvious requirements for any meeting stricter adoption of these should be ensured by the change expert. These would enable deeper discussions in the change meetings, rather than being impromptu. If needed one-to-one discussions between stakeholders could be arranged by the change analysts when needed. A proper change management team had to be formed for handling the system better. The role of this team is to only manage change, predict change propagation management, deduce the △ BOM and run the change meetings. The team could create their road map, plan, and prioritize the change based on the product release schedule. So, getting a competent team with a better performing tool is expected to solve the major portion of the issues caused and would give promising results. Imbalances in these might lead to unwanted scenarios: a good tool with incompetent human resources or highly skilled resources with a bad tool. Both extremities are unproductive for any organization.

8.2 Future scope

In this section, the areas that the company should address in the future for the effective functioning of the system are mentioned. During the entire course of the work, there were areas which were just mentioned and termed out of scope. The motive was that these were the areas which were found important to ignore. Some among them are scope for own tool creation, more depth to post change approval, problem management, rejection handling system, and fast-tracking of the urgent changes. The post-change approval process- change order, notice and execution process has to be defined with more depth. Once a change is agreed for execution, the steps for the work packages planning, stakeholders needed, time for change effectivity, and execution plan had to be developed. A proper process had to be developed and this required some research work. Based on the change triggers, a portfolio base approach could be framed. By this, each trigger follows its corresponding approach, and the approaches could be customized based on the trigger. Though this is a long shot, something similar might help greatly in standardising the process and a faster approach for decision and execution. Another long-term benefiting suggestion is the creation of its tool. The company can look to develop its own tool to satisfy its needs. Many external vendors available in the market or the IT team could be considered for this. With its own tool, the company can achieve its expectation and could maintain data privacy. Next, an interesting section was the problem filtering system. There could be plenty of changes in the organization, ranging from a problem with the forklift to a halt in production. A proper filtering system that filters only relevant problems was needed. This helps in reducing the time for the change team filtering. Next is the rejection handling system. Once a change is rejected, a post-rejection analysis is needed. This is to make sure that no improvement points are left untouched and not analyzed. Also, with a proper system, a closed-loop communication system could be achieved. For urgent requests, a fast-track approach had to be built. The process in this should be prioritized and should be as fast as possible to execute. A possibility is that a decision could be taken based on a quick discussion with the stakeholders. Once a decision is made, change execution initiation and steps like impact analysis, and financial summary can be performed in parallel. This could help in validating the decision made by the stakeholders and completing the process. A QCD-based financial model had to be developed for a detailed business model. All impact analysis and change results in terms of quality-

Cost and delivery had to be framed. This gives more financial depth to the change. Next is prioritizing the CRs. The number of open CRs that the team could work on is to be decided. And this decision usually depends on capital, human resource, and available time. So, a collective decision or a method for prioritizing must be laid out for smoother execution of the change process. Along with the BOM, the scope for BOP was also noticed. So, a BOP must be included in the analysis while developing more into the production-related changes. This would include the scope of production making the change process a wholesome one.

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A

Gantt Schedule

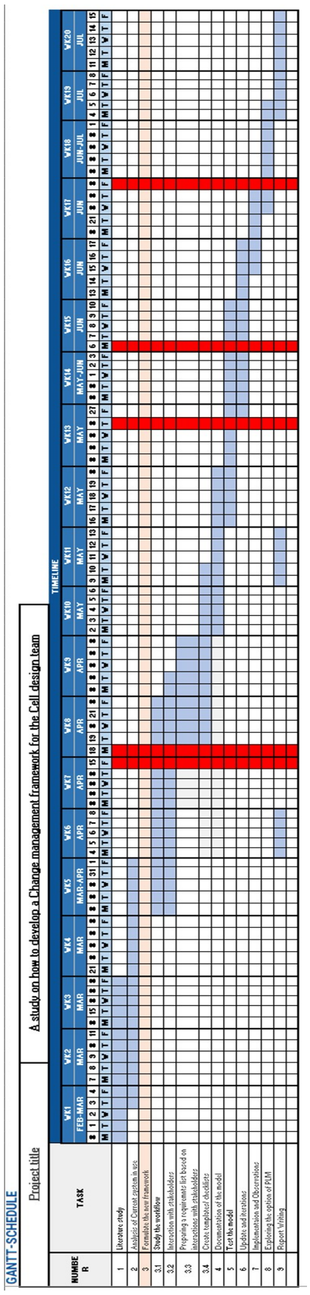

Figure A.1: Gantt schedule

B

Interview Transcript

Below is the summarised transcript of one-to-one interviews and informal discussions held with different stakeholders. These were to highlight the main context of the discussions only. For ethical reasons, the names of the interviewees, and any specific details mentioned during the discussions are not mentioned.

B.1 Change expert

The change expert was the main stakeholder responsible for running the meetings in the team where the analysis was carried out. The expert uses Microsoft office-excel and PowerPoint predominantly. Then a detailed explanation of the process flow was given by the expert that helped in mapping the current process flow with the details. The expert felt the need for a good process flow that could improve the traceability of the process. Though using Teamcenter was a better option in hand, the expert felt it will not be accepted by all the stakeholders. The major points of discussion were:

- How the design meetings usually run, the general agenda for these meetings and the details of it.
- The role of impact analysis in Engineering Change Management process flow.
- The importance of the stakeholder's participation
- The importance of documentation of the changes for future use, creating a knowledge base.
- How asking the right questions will lead the stakeholders to brainstorm all possible outcomes.
- The scope for problem management and change prioritisation. The expert believes that these were vital but on an organisational level.

B.2 Manufacturing meeting representative 1

Manufacturing representative 1 was the person responsible for running the manufacturing meetings. These meetings were held in parallel with the design change meetings. The expert first tried to explain the entire working procedure before, during and after the meetings. This helped in mapping the manufacturability meeting process flow, shown in the text earlier. Some points of the discussions are listed below.

- The changes were broadly classified into supplier change and structural change. In supplier only there was just the replacement of the supplier, no other change in any of the specification of the material, process, or product.
- When there was a change in the product, then the structural change approach was taken by the expert.
- In structural change, the first comparison was done with the existing product as the benchmark and the required new features.
- Then the possible affected items are enlisted. This is done by repeated meetings and brainstorming with the stakeholders. These discussions form the core of the manufacturability meetings that happen on a weekly basis. This includes material related, machine relates and sometimes procurement related too.
- There was a scope for a new path- for dimension change. These were changes where only the dimensions were only changed. These would involve documentation and drawings change, to summarise.

B.3 Manufacturing meeting representative 2

Manufacturing representative 2 was the person responsible for the impact change on the machines and contact with the machine suppliers. The representative explained the role of estimating the machine impact and conversations with the suppliers. The representative's main task was to negotiate with the supplier for the lead time and customisation of the products. The information sharing with the supplier was usually through mail communication- sending drawings and specifications and then getting updates for the same. The representative was more towards supplier relations, trying to negotiate with the supplier the feasibility of the change decision taken in design meetings. The channel helps in achieving the best performing product with the best possible tools/ raw material the supplier could provide with minimal time duration and optimal cost.

B.4 Approach A-representative

Approach A-representative was the person responsible for running the changes for customer-involved projects in the organisation. The interviewee explained how the process was executed and how the decision-making was done. The interviewee expressed the benefit of having a common setup across the entire organisation for change management. Though immediately not possible, this common platform was something they have been planning for. The interviewee expressed the importance of integrating the different units that get involved in a customer project. These units include quality, project management, and change team. The interviewee also detailed the need for keeping up the pace of these processes. How these processes had to be fast-paced as per the customer requirements. The usual practice was that data were gathered and then the decision on the change was taken. In critical cases, decisions were taken and then relevant data were gathered. And the decision-making was influenced by the customers and the execution was from Northvolt side. The risks attached to such steps were higher compared to the usual case, but the pace of decision-making was important. The interviewee also explained the flow of these processes. With the involvement of the customer, the decision-making was iterative. This was owed to the reason that every step involves customer consent as well.

B.5 Approach B-representatives

Approach B-representatives were the team responsible for running the changes that used the hybrid option mentioned in the text. This approach uses JIRA and Teamcenter. The representative team explained their working style which helped in understanding and mapping the process they follow. The problem reports were reported in the JIRA interface. Once the tickets were registered and assigned to the concerned teams, then the execution process starts. Once taken for execution, the issue was transferred to Teamcenter and then the process continues as shown in the text. The approach B team insisted the role of integration of different systems for the effective functioning of a change management system. Integrating change management systems, ERP would help in gauging the holistic approach to change and inventory planning. The team stressed the role of data management. As their style of working needs intact data flow between different systems, they realised the importance of a proper data management setup.

B.6 PLM architect

PLM architect explained the available features in Teamcenter that could be employed in the organisation. The architect first explained the available features in Teamcenter. There were some available aspects that teams use. The architect tried to explain how and why in this selective usage of the available features. The architect also explained the options of ECR and ECO creation in the Teamcenter setup and how the items were kinked in the created ones. Some important points from the meeting discussions were:

- Available options are extensive in Teamcenter are they are suitable for an in-depth change management process.
- Creation of a framework is possible in the Teamcenter network. Adding to that, customisation is always possible in Teamcenter.
- Traceability could be maintained till the end of production using the Teamcenter options.

C

Change request

Table C.1: Change request template

	Change request				
Change request initialisation	**Date of CR creation**			**Need date**	
	Change ID			**Problem report #**	
	Change requester				
	Item ID				
	Trigger for the change				
	Reason for change				
	Problem description				
	Solution proposal				
	Technical recomme -ndation				
	Main stakeholders for solution				

	CCB	**Core**	**Name**	**Extended**	**Name**
				Optional	**Name**
	Decision from Change control board (CCB)	Drop down box	**Comments on the decision**		
	Date of agreement by CCB		**Change analyst**		
Change request detailing	**Description of the agreed solution**				
	In scope				
	Out of scope				
	Related DOE and its details				
	Affected items from BOM (BOM visualization image)				
	Impact analysis agreed	**Impact template**	**Comments/ Updates**		

	CMB		**Final decision on the change**	
			Date of decision	
			Change owner	
	Comments			

D

Impact Analysis

D.1 Quality

Table D.1: Impact analysis Quality

Quality		
Internal Quality	Is a standard QC plan available?	*Yes/No*
	If no, will one be created? (Details of it)	
	Details of the checks/test planned (From QC control plan)	
	List and details of extra checks needed outside the control plan	
	Are the resources for the tests secured? Details of it	
	Are all quality checks handled internally?	*Yes/No*
	If not, then the details (Details of the external agency, cost, time to test)	
	Is the standard packaging instruction available?	*Yes/No*
	Details of the packaging instructions	
	Is the marking and packaging instruction secured?	
Quality equipment		
Equipment	Equipment details	
	Availability of equipment	
	Special actions/steps needed for confirming the checks	
Supplier Quality		
Supplier quality	Incoming quality checks required (for materials procured from the supplier)	
	Checks done by supplier, if any	
	The results and reports, if any (Attach the quality check report sent by the supplier)	

	Is the supplier audited and certified? (Details of it)	
	Incoming quality checks required (for materials procured in NV)	
Summary	Overall comments on the summary report	
	Stakeholder responsible for summary report	
	Reviewing change analyst	
	Comments from Change analyst	

D.2 Validation

Table D.2: Impact analysis- Validation

Validation		
Validation details	List of tests to confirm the proposed solution	
	Details of the tests, mentioned above	
	Estimated time plan for the test results (Critical path S&E and P&L)	
	List of special requirements	
	The cost impact of the test slots booked	
	Comments	
Equipments for testing		
Equipment	Availability of the test equipment? (Any constraints to consider)	
	Are all tests done internally?	*Yes/No type question*
	If not, details of it (Information of the test provider, cost, time plan)	
Results		
Results	Which exsisting results can/should be considered?	
	Are the test results stored? (If yes add their details or attach them)	
	Comments from validation team	
	Reviewing change analyst	
	Comments from Change analyst	

D.3 Operations

Table D.3: Impact analysis- Operations

Operations				
Logistics	Name the buy items (Expected to order)			
	Description	Name of the item	Item ID	Supplier
	Lead time estimations of logistics (From the supplier place to arrival of material in WH):	Expected ETA (first sample per item):		
		Country of origin:		
		Preferred mode of transport:		
Packaging information				
Packaging	What are the requirements for the packaging? Detail/attach packaging instructions if available.			
	How to distinguish current vs new material on the line			
Material safety				
Safety	Are the materials 'dangerous goods' if yes, specify the category			
	Are there any prerequisites for handling the material in WH? (Equipment, safety, training etc)			
	Are there any prerequisites for handling the material in the production line? (Equipment, safety, training etc)			

	Can the prerequisites be secured or are follow-up activities required? (Follow up of previous questions)			
	Attach the relevant safety documents, if available (MSDS, Specs sheets, handling instructions etc)			
Material handling				
Material handling	Define the NV shipping location			
	Do special storage conditions apply?			
	Can the special storage conditions are secured or are follow-up activities required?			
	Outline the expected material flow (for internal transportation within the facility)	*From the dock to WH storage:*	*From WH to production line:*	*Feed into the machine:*
	Expected shelf life of the material (in months)			
Purchasing				
Purchasing	Is the supply of the new item(s) secured? (Is the supplier capable of meeting the demand for the next 6+ months?)	*Supplier 1*	*Supplier 2*	*Supplier 3*
	Do new packaging instructions need to be shared with the supplier?	*Supplier 1*	*Supplier 2*	*Supplier 3*
	What is the cost difference, with the new material?	*Supplier 1*	*Supplier 2*	*Supplier 3*
	What is the cost difference, with logistics and packaging?	*Supplier 1*	*Supplier 2*	*Supplier 3*

	Is an investment required on the supplier side? (If yes, details of cost and the lead time)	*Supplier 1*	*Supplier 2*	*Supplier 3*
	What is the expected impact of the change on the supplier? (New tool, new line, relocation)	*Supplier 1*	*Supplier 2*	*Supplier 3*
Summary				
Summary	**Reviewing change analyst**		**Stakeholder responsible for summarising**	
	Comments from the change analyst			

D.4 Manufacturing

Table D.4: Impact analysis- Manufacturing

Process & Manufacturing		
Details	Processes steps affected due to the proposed change (Preferably from BOP)	
	Does the change involve a hardware change? Details of it	*Yes/No*
	Does the change involve a software change? Details of it	*Yes/No*
Impact on output- Relative comparison with reference (Positives and negatives)		
Impact on the output	Expected impact on the overall cycle time	
	Expected yield change Ref should be the previous yield 100	
	Expected impact on the process line (Physical)	
	Type of change over and its details	
	Details of availability of the machine for other products	
	Expected impact on the process line systems	
	Does new equipment bought? If so detail	
	Predicted impact on tool life and tool maintenance	
	Expected change over time between products	
	How is material loading in the equipment handled? Impact and details of it	
	Predicted lead time for setting up the machine	
Set up of equipment		
Equipment	Can the exsisting factory space accommodate the equipment? If no, how to secure	*Yes/No*
	Comments on the utilities availability	

	Does the expected change demand new process parameters in the equipment?	
	Does the expected change impact the BOP? details of it?	
Operations		
Operations	Is work instruction updated?	
	If training needed, details of it	
	Estimated time for validating the process	
Mass production		
Summary	Concerns and comments for mass production	
	Reviewing change analyst	
	Comments from Change analyst	

D.5 Design

Table D.5: Impact analysis- Design

Design		
Design	How do secure and evaluate the proposed solution?	
	Design owner	
	PLM responsible	
	Functional dependent parts that are affected	
	PLM ID of affected parts/drawings	
	Other documents affected	
	Other products that gets affected (Using common components)	
	Details of the design standards & tolerances to be followed?	
IP	Is IP check required?	Yes/ No
	If yes, details to secure IP situation	
Material	Comments on Material change, if applicable	
	Conclusion from the material test	
Performacne	Expected impact on Performance	
	Design team comments	*Material team comments*
	Desired maturity level of the item for this change	Drop down question A/B/C
Conclusion	Concern and Comments for mass production	
	Planned estimate for release	
	Reviewing change analyst	
	Comments from Change analyst	

E

Financial summary

Table E.1: Financial Summary

Financial summary				
Impact	What is the expected financial impact due to the change	Major/ Minor		
	If major, details of it			
Man hours estimation	Action performed	Man hour estimation	Cost in USD	Comments
	Expected recurring cost details, due to the change	Cost eq. of recurring cost in USD	Expected non-recurring costs, due to the change	Cost eq. of indirect costs in USD
Design				
Process & Mfg				
Validation				
Quality				
Operations				

	Total cost estimate of the change in USD (Direct+Indirect)	0		0
	Comments on the estimation			
	Final Decision on the change	*Need more information*	**Change analyst**	
	Follow up action, if any		Date of decision	

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